Annual Report

July 1, 2022 – June 30, 2023

Viticulture and Enology programs for the Colorado Wine Industry

Principal Investigators

Horst Caspari[1], Claudie Bertin[2], Grace Gardner[2], Peter Goble[3], Russ Schumacher[3]

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 as well as seasonal temporary staff at WCRC.

Weather conditions in the Grand Valley were warmer than average from July to September, average in October, much below average in November, and then slightly above average in December. September 2022 was the warmest September since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964. Six daily high temperature records were set during an 11-day heat wave between 30 August to 9 September.

Initially, vine development was early in 2022, due to the above-average temperatures from June through to September. However, due to a much higher crop load in 2022, ripening was later than in 2021. Averaged across all cultivars harvest was 10 days later than in 2021, ranging from 8 days earlier for Albarino to 33 days later for Chambourcin. Vine recovery following the October 2020 extreme freeze event was very good with full crops on most cultivars. All grapes were harvested prior to a killing frost on 24 October 2022.

Very good recovery from cold damage in 2020 is also evident from results of the 2022 Colorado Grape Grower Survey. Survey data indicate that the state-wide average yield was 3.5 ton/acre, the third highest since 1991. Average yield in Mesa County was 3.66 ton/acre.

[1]Department of Horticulture and Landscape Architecture, Colorado State University Western Colorado Research Center, 3170 B ½ Rd, Grand Junction, CO 81503

[2]Agricultural Experiment Station, Colorado State University, Western Colorado Research Center, 3170 B ½ Rd, Grand Junction, CO 81503

[2]Department of Atmospheric Science

Colorado State University, Fort Collins, CO 80523

There have been no extreme low temperature events during the 2022/23 dormant season. No or only minimal bud cold damage has been observed on any of the cultivars we monitor.

The monthly mean temperature for January was 4.2 F above average. However, February, March and April were cooler than average. The monthly mean temperature for March of 39 F was 6.2 F below the long-term average, making it the second coldest March since record keeping began at WCRC-OM in 1964. Temperatures remained well below average for much of April as well. As a result, bud break in 2023 was very late with full bud break on many cultivars not until the second week of May. Warmer-than-average temperatures in May resulted in a quick development of the grape canopy. However, the first half of June was cooler than average again with many cloudy or partially sunny days. Bloom of late breaking cultivars did not complete until the second half of June, about 7-10 days later than in 2022. While there was a warming trend at the end of June the monthly mean temperature was 1.1 F lower than the long-term average.

The Colorado Climate Center 1. Installed two new CoAgMET-lite stations in southern Colorado; 2. Cataloged temperature patterns in Colorado during cold air outbreaks with potential to damage vines; and 3. Updated the Colorado Climate Center's Colorado Wine Grapes informational page at climate.colostate.edu/climate_wine.html using data from the most recent years.

Fall and winter 2022-2023 did not include any major low temperature injury events for areas of western Colorado's major grape growing areas. The Climate Center analyzed the largest cold anomaly events for western Colorado in fall, winter, and spring, putting results for Montezuma County in the context of previous statements of work. December 2022 included a major cold air outbreak for eastern Colorado that was also analyzed in detail. Western Colorado was shielded from the coldest air by the Rocky Mountains during this event.

Colorado Wine Industry "Exploration Opportunity" maps have been updated with downscaled Parameter-elevation Regressions on Independent Slopes Model (PRISM) data from 1981-2023. The updated figures and tables are available at climate.colostate.edu/climate_wine.html.

For further information please contact:

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

Phone: 970-434-3264 x2 horst.caspari@colostate.edu

Growing conditions, 2022 season

Timing of bud break in the Grand Valley was average towards the end of April. Monthly mean temperatures were average for May and October but warmer than average from June through to September. September's mean monthly temperature of 71.8 F was the highest ever recorded at the Western Colorado Research Center – Orchard Mesa. For the second year in a row, Growing Degree Day (GDD) accumulation was more than 400 degree days above average by the end of September. By the time of the killing frost on 24 October 4,059 GDD had accumulated, 382 GDD higher than average.

The first part of the growing season was very dry with only 1.0" of precipitation recorded at the Western Colorado Research Center – Orchard Mesa between 15 April and 15 August. However, the remainder of the growing season was very wet with 5.16" recorded between 16 August and 31 October. Another 2.0" were added in November and December. Annual precipitation was 9.19" compared to the long-term (1962-2006) average of 8.91".

Dormant season 2022-2023

A killing frost occurred at WCRC-OM on the morning of 24 October 2022. Monthly mean temperatures were sightly above average in December 2022 and January 2023 but below average in November 2022 and from February to April 2023. The lowest dormant season temperature of 0.1 F was recorded on 16 February 2023. No or only minimal bud cold damage has been observed throughout the dormant season on any of the cultivars we monitor.

Precipitation over the dormant season was well above average. Most of that precipitation occurred in the form of rain, with only three significant snow events in the Grand Valley (last week of December; first week of January; third week of February) resulting in multi-day snow cover of the soil.

Growing conditions, early part of 2023 season

Colder than average temperatures throughout February to April led to very late bud break. Most cultivars didn't complete bud break until the first or second week in May. Percentage bud break of primary buds was very high, indicating a high crop potential in 2023. Warmer than average temperatures in May resulted in quick canopy growth. However, bloom timing was still substantially later than average with some cultivars not completing bloom until the second half of June.

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 our cultivar trials were up substantially compared to 2021. Extremely low yields in 2021 due to the record low temperature event on 26 & 27 October 2020 were followed by good to very good yields in 2022. For example, the average yield of *Vitis vinifera* cultivars in 2022 at Orchard Mesa was 5.5 ton/acre, five times higher than in 2021. Yields of cold-hardy, interspecific cultivars were up 1.5 to 2.5-fold. The smaller increase compared to *Vitis vinifera* cultivars is due to the fact that cold-hardy cultivars produced a crop in 2021 whereas most *Vitis vinifera* cultivars did not.

- Multi-state evaluation of wine grape cultivars and clones (Caspari, Bertin, and Gardner)

  This long-term (2004-2027), USDA multi-state research project (originally NE-1020, then NE-1720, now NE-2220) tests the performance of clones of the major global cultivars and new or previously neglected wine grape cultivars in the different wine grape-growing regions within the U.S. and is a collaboration of more than 20 states. All participating states follow the same experimental protocol. In Colorado, 10 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'. Following the extreme low temperature event in late October 2020 another five cultivars were removed that had sustained near 100 % bud damage and had shown poor performance in the long term. In late April 2021, five new entries were planted (Agria, Arinto, Corvina Veronese, Sagrantino, Teroldego)

  At Rogers Mesa, only MN 1200 and Marquette produced a crop (Table 1). All other cultivars are still recovering from the October 2020 extreme cold event. No wines were produced.

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

Cultivar	Harvest date 2022	Yield (ton/acre)
Marquette	26 September	2.36
MN 1200	9 September	1.29

At Orchard Mesa, all mature cultivars produced a crop. Harvest started with Itasca on 1 August 2022 and ended with Barbera on 17 October 2022 (Table 2). Although growing degree accumulations were very similar for 2020, 2021, and 2022, the average harvest date in 2022 was five days later than in 2021 and 12 days later compared to 2020. This delay in crop ripening is most likely the result of the higher crop load in 2022 compared to the previous two years. Averaged across all cultivars, yields were up 268 % compared to the 2020 season. When comparing the limited set of cultivars that did produce a crop in both 2021 and 2022, the increase in 2022 was 188 %. A summary of fruit composition is presented in Table 3. Seven varietal wines plus one blend were produced using micro-vinification techniques.

Table 2: Harvest dates and yield information for 19 mature grape cultivars planted at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Harvest date 2022	Yield per vine (lb)	Yield (ton/acre)[1]
Albarino	12 September	9.78	5.10
Aromella[2]	15 August	2.31	0.79
Barbera	17 October	25.33	8.28
Cabernet Dorsa[3]	7 September	12.56	4.84
Cabernet Sauvignon	3 October	9.27	4.84
Chambourcin[3]	14 September	14.41	5.89
Cinsault	7 October	27.18	8.63
Durif	7 October	11.67	6.04
Itasca[4]	1 August	2.91	1.41
Malvasia bianca	15 September	18.37	7.51
Marquette[3]	15 August	12.44	4.80
Marsanne	22 September	12.67	4.14
Merlot	9 September	9.47	3.65
Mourvedre	7 October	16.48	8.07
Roussanne	9 September	12.20	3.60
Souzao	3 October	8.48	3.46
Touriga national	30 September	12.56	3.76
Verdelho	7 September	16.78	6.40
Zweigelt[2]	9 September	7.51	3.92

[1] Yield calculation based on number of vines initially planted. Vine survival (out of 18 or 24 vines per cultivar) ranges from 55 % for Touriga national to 100 % for Chambourcin and Marquette.

[2] Planted in 2017.

[3] Planted in 2011 and 2012.

[4] Planted in 2017, 2018, and 2019.

Table 3: Fruit composition at harvest in 2022 for 19 mature grape cultivars planted 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	26.7	3.34	6.11	6.55	1.46	165	110
Aromella[1]	20.2	3.02	10.73	8.55	4.58	139	76
Barbera	24.2	3.14	8.33	7.51	3.28	199	132
Cabernet Dorsa[2]	27.7	3.44	6.07	7.15	2.13	140	109
Cabernet Sauvig	24.7	3.37	6.08	6.39	1.56	125	114
Chambourcin[2]	25.9	3.04	7.72	7.26	2.01	188	108
Cinsault	22.0	3.42	5.58	5.71	1.64	163	136
Durif	24.6	3.31	6.22	6.47	1.42	124	85
Itasca[3]	22.2	3.28	10.22	7.83	7.31	123	56
Malvasia bianca	22.3	3.33	5.73	6.43	1.76	102	87
Marquette[2]	28.6	2.97	9.69	4.44	4.89	401	154

Table 3 continued:

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)
Marsanne	20.5	3.37	5.86	6.55	2.01	122	91
Merlot	25.8	3.36	5.69	7.19	0.58	100	106
Mourvedre	19.2	3.28	6.53	6.34	1.81	109	93
Roussanne	25.3	3.23	6.87	7.43	2.17	159	110
Souzao	25.2	3.44	5.65	6.64	1.94	97	79
Touriga national	23.9	3.39	6.03	6.66	1.94	99	88
Verdelho	27.5	3.18	7.04	6.55	2.15	171	142
Zweigelt[2]	25.2	3.15	6.88	9.07	0.61	133	128

[1] Planted in 2017.

[2] Planted in 2011 and 2012.

[3] Planted in 2017, 2018, and 2019

- Cultivar evaluation for Front Range locations, Fort Collins (Caspari, McNeill 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. Vines were again damaged by an extreme cold temperature event in late October 2020, once again resulting in many vines dying back to the ground and no crop in 2021. Vine growth was better in 2022 compared to previous years, however fruit was removed on most vines to encourage vegetative growth. No yield data was recorded as total crop across all cultivars was less than 100 lb. Vine vigor at this site continues to be too weak.
- Cold-hardy, resistant cultivars for the Grand Valley (Caspari, Bertin, Gardner, 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.

There was minimal to no bud damage from the extreme low temperature event in October 2020. However, many vines needed retraining from the ground during 2021 indicating that while bud damage was minimal the cold event caused substantial damage to the trunks. The percentage of vines needed retraining from ground ranged from zero for Brianna and Marquette to 80 % for Chambourcin. Vines recovered well in 2021 and produced good to very good crops in 2022 (Table 4). Year-over-year changes in yield ranged from -76 % for Brianna to +952 % for Arandell. The year-over-year reduction for Brianna was due to >90 % bird damage, despite netting. On average, yields were up 365 % compared to 2021 while harvest was later by 16 days. A summary of fruit composition is presented in Table 5. No wines were produced from this trial.

Table 4: Harvest dates in 2022 and yield information for 12 grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	Harvest date 2022	Yield (ton/acre)[1]
Arandell	6 October	4.57
Aromella	13 September	2.70
Brianna	17 August	0.55
Cayuga White	29 September	4.83
Chambourcin	18 October	3.02
Corot noir	6 October	5.72
La Crescent	6 September	3.01
Marquette	23 August	4.58
Noiret	23 September	5.96
St Vincent	18 October	2.28
Traminette	15 September	1.30
Vignoles	15 September	2.65

[1] Yield calculation based on number of vines initially planted. Vine survival is >90 % for all cultivars except Chambourcin (79 %), Traminette (42 %) and St Vincent (29 %).

One unexpected observation at this site is 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 eight growing seasons only 29 % of the vines are still alive. Another cultivar with low vine survival is Traminette with 50 % vine losses over the past three seasons. However, 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: Fruit composition at harvest in 2022 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	23.0	3.86	4.57	6.32	2.61	204	77
Aromella	25.4	3.20	8.20	6.23	3.58	295	119
Brianna	16.7	3.25	11.79	5.89	6.88	241	81
Cayuga White	22.9	3.52	5.43	6.31	1.23	203	94
Chambourcin	27.0	3.20	7.00	6.26	2.32	145	89
Corot noir	24.0	3.68	4.00	5.70	0.46	226	102
La Crescent	27.8	3.04	9.55	7.30	4.93	177	95
Marquette	25.2	3.12	11.02	5.53	6.17	497	187
Noiret	22.0	3.33	6.84	7.89	1.96	173	98
St Vincent	22.0	3.03	8.59	7.81	2.67	119	86
Traminette	24.9	3.13	7.24	8.02	1.93	162	110
Vignoles	29.9	3.00	9.65	6.13	6.05	209	100

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. 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 prior to the discovery of phylloxera. 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, Bertin, and Gardner)

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.

Average yield per cropping vine in 2022 was 18.9 lb, up 540 % on 2021. Yield per cropping vine was highest on 140 Ruggeri (26.5 lb) and lowest on 5BB (13.7 lb). However, vine survival is very low for several rootstocks, resulting in very low yields per acre (Table 6). Viognier grafted to Teleki 5C had the third highest yield per cropping vine (16.9 lb) but due to the highest survival rate and highest number of vines with crop of any rootstock included in this trial, it had the highest yield for grafted vines per acre. However, own-rooted vines have had the highest survival rate throughout this study to date, and had a 1.4 ton/acre higher yield than 5C in 2022. Own-rooted vines have had the highest yield in five out of the past eight years with 5C having had the highest yield in three years. Cumulatively, vines grafted to 5C have yielded 2.1 ton/acre more than own-rooted vines.

Table 6: Effect of rootstock on vine survival after 14 years and yield in 2022 of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield per vine (lb)	Yield (ton/acre)
110R	57	18.0	5.59
140Ru	18	26.5	2.58
1103P	50	22.5	6.13
5BB	64	13.7	4.53
5C	79	16.9	6.90
Own-rooted	96	15.8	8.30

Vines grafted to 110R produced fruit with the lowest concentration of soluble solids, lowest pH, highest titratable acidity, and highest concentration of tartaric acid (Table 7). Fruit from vines grafted to 5BB had the highest soluble solids concentration which was 3.7 Brix higher than with 110R. Titratable acidity and the concentration of malic acid was lowest with 5BB.

Table 7: Effect of rootstock on fruit composition at harvest in 2022 of Viognier growing 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)
110R	22.8	3.23	6.91	8.38	1.09	126	122
140Ru	24.1	3.36	6.79	7.50	1.78	195	144
1103P	25.2	3.35	6.30	7.70	1.16	138	118
5BB	26.5	3.31	6.28	7.56	0.91	140	121
5C	25.3	3.28	6.65	7.84	1.16	132	117
Own-rooted	24.4	3.30	6.68	7.83	1.21	167	135

- 2017 Rootstock trial with Cabernet Sauvignon (Caspari, Bertin, Gardner, 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. Hilling and uncovering was again repeated during the 2020/21 dormant season. Some missing vines were replaced in late June 2021. At the end of the 2021 growing season only three out of eleven rootstocks have no missing vines: 1616C, 3309C, and 101-14. The highest percentage of missing vines is 17 % with 140Ru.

There was no yield in 2021 due to 100 % bud damage from the October 2020 cold event. All vines needed retraining from the ground. Graft unions were protected by hilling up with a wood chip mulch in November 2021.

Suckers / canes were retrained and retied to the fruiting wire in spring 2022. Surplus suckers were removed. There are some missing vines but overall vine survival is much better than in the 2018 companion study (see below). No yield data is available for 2022 as the fruit in the research plot was mistakenly harvested by a picking crew.

Vines were long-pruned in March 2023. When it became clear that the cool March and April temperatures would lead to a very late bud break the decision was made to finish-prune the vines in mid-April so as not to further delay bud break. Shoots were thinned to a target of 6 shoots per linear foot of canopy in early June.

- 2018 Rootstock trial with Cabernet Sauvignon (Caspari, Bertin, Gardner, 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 70 vines had died bringing the number of missing vines to 81 (out of 264). Another extreme low temperature event in late October 2020 caused 100 % bud mortality and the loss of a further 24 vines. All surviving vines required retraining from the ground. Seventy replacement vines were planted in spring 2021. At the end of the 2021 growing season there are 47 missing vines. Graft unions were protected by hilling up soil in November 2021.

Overall, 21 % of vines were dead in summer 2022, ranging from 4 % with 1616C and SO4 to 58 % with Riparia Gloire. Due to labor shortages we were unable to harvest this trial in 2022 and the fruit was harvested by the grower cooperator.

Vines were finished-pruned in mid-April 2023 so as not delay bud break in a year with much later than normal bud break. Many vines again showed cane/trunk damage and will require retraining from the ground up during the 2023 growing season. Cropping vines were shoot thinned to a target of 6 shoots per linear foot of canopy in early June.

- 2019 Rootstock trial with Souzao in a challenging soil. (Caspari, Bertin, Gardner, 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 conditions. 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. Consequently, surviving vines needed retraining from the ground in 2021. Twelve vines failed to grow in 2021. Five replacement vines were planted in June 2021. At the end of the 2021 growing season there were 22 missing vines (out of a total of 164), with half the missing vines grafted to 1103P.

Four more vines were dead falling the 2021/22 dormant season. Overall vine survival is 85 %, ranging from 46 % with 1103P to 100 % with 101-14 (Table 8).

Table 8: Effect of rootstock on vine survival after 4 years and yield in 2022 of Souzao growing in a commercial vineyard on Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield per vine (lb)	Yield (ton/acre)	Pruning weight (kg/vine)
110R	88	3.7	2.22	0.20
1103P	46	3.5	0.81	0.25
1616C	83	4.2	2.18	0.23
101-14	100	3.5	2.03	0.20
3309	88	5.2	3.18	0.22
5C	92	4.3	2.66	0.22
SO4	96	3.2	1.89	0.17

Yield per cropping vine and yield per acre was highest with rootstock 3309 followed by 5C (Table 8). The lowest yield per cropping vine was with rootstock SO4 but the lowest yield per acre was with 1103P due to its low vine survival rate of only 46 %. All other rootstocks have survival above 80 % and hence total yields two to nearly four times of 1103P.

Rootstock effects on fruit composition at harvest were minor (Table 9). Of note are the rather high alpha amino nitrogen and ammonia concentrations which result in yeast assumable nitrogen (YAN) concentrations right at or above 300 ppm.

Table 9: Effect of rootstock on fruit composition of Souzao in 2022 growing in a commercial vineyard on 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)
110R	24.3	3.48	6.55	7.08	2.65	199	132
1103P	25.6	3.45	6.19	6.84	2.00	187	131
1616C	24.4	3.52	6.32	7.01	2.54	225	148
101-14	25.6	3.54	6.04	6.86	2.21	219	146
3309	24.4	3.47	6.62	6.90	2.64	239	147
5C	24.8	3.54	6.32	6.76	2.70	232	147
SO4	24.9	3.51	6.46	7.37	2.43	212	143

Vines were initially long-pruned in early April 2023. Pruning weight ranged from 0.17 kg per vine with rootstock SO4 to 0.25 kg per vine with 1103P (Table 8). Long spurs were shortened to two live buds in early May so as not to further delay bud break. Shoots were thinned to a target of 6 shoots per linear foot of canopy in late May. Three replacement vines on rootstock 5C were planted on 24 June 2023.

- Inter-planting of grafted vines (Caspari, Bertin, and Gardner)

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 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 had 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. Vine mortality of 10 % 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.

Combined yields of inter-planted and mature own-rooted vines in 2020 were again much below expectations at 1.16 ton/acre. Mature grafted vines produced 5.42 ton/acre. 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. Vines were pulled out in early December 2020. Nineteen missing inter-plants were replaced in spring 2021.

Inter-planted vines produced a small crop of 0.56 ton/acre in 2021. This is a very low yield for 5-year old vines. However, while missing vines and a slow establishment contribute towards the low yield the main cause was bud damage from the October 2020 cold event. The mature Chardonnay vines grafted to four different rootstocks growing in the same block produced only 0.49 ton/acre.

The 2022 season was the second growing season after the removal of the old own-rooted vines, and the sixth growing season overall for the inter-planted vines. Without bud cold damage the yield increased to 4.03 ton/acre. The 30-year old grafted vines growing in the same block produced 4.92 ton/acre. This difference is almost entirely due to the missing inter-plants that needed replacement in spring 2021 as the replacement vines had no or minimal yields in 2022.

The cumulative yield after six years from inter-planted and mature own-rooted vines (removed at the end of year four) was 7.5 ton/acre. In comparison, six-year old

Chardonnay vines used for a study on graft union management (see below) had a cumulative yield of 10.1 ton/acre. Cumulative yields were similar up until year four but vines growing without competition from mature vines produced higher yields in years five and six than inter-planted vines.

It should be noted, however, that the inter-plant study is located within our long-term cover crop study and during the first four years this area was 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 not after the fourth season as in this study. A crop of 1 to 2 ton per acre should be produced in year three on inter-planted vines after mature vines have been pulled out. The results indicate that vine development and yields will be depressed unless special attention is paid to the inter-planted vines.

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

In Colorado, where low temperatures can cause trunk injuries, the graft union needs to be protected during the coldest part of the year to avoid lethal damage to the cultivar. Common methods of graft union protection are hilling up soil around the graft union or covering the graft union with mulch materials. In spring, after the risk of cold temperature damage has passed, the graft union needs to be uncovered to avoid self-rooting from the scion. Due to the semi-arid climate of western Colorado, the top part of the soil is very dry and hot during the growing season. Dry and hot soil conditions are generally not conducive for root growth. Hence, a study was initiated in 2017 to evaluate if planting grafted vines with the graft union just below the soil surface would result in no or minimal root development from the scion.

A field study to test the effect of planting depths, in combination with irrigation method, on the propensity of self-rooting was established at WCRC-OM in early May 2017. Chardonnay (clone 99) grafted to SO4 rootstock was planted with the graft union 2” above ground (Control = standard practice), or with the graft union 2”, 4”, or 6” below the soil surface. Half the vines are irrigated by drip, the other half by micro-sprinkler. There are 10 single-vine replications per treatment. Drip emitters are positioned so that the trunks are not wetted during irrigation events, while micro-sprinklers wet 100 % of the vineyard floor area.

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

Root development from the scion and the rootstock was evaluated from 2018 to 2021 on five to ten vines per treatment. Soil was carefully removed down to the graft union and slightly beyond. While scion rooting in year two was minor significant root development out of the scion was observed in subsequent years. By the end of year 5 many strong roots originating from above the graft union were found on all the vines that were evaluated (see photos below). Such high level of scion rooting is undesirable as a) these roots are susceptible to phylloxera feeding and damage, and b) it carries the risk that over time the scion roots develop into the dominant part of the root system and that the rootstock roots diminish. In contrast, no scion roots were observed on Control vines where the graft unions located 2" above soil level were hilled up in fall and uncovered the following spring.

Photos show root development from the scion part (above the graft union) of the same vines at the end of the third (top row) and fifth (bottom row) growing season of drip-irrigated Chardonnay/SO4 vines when the graft union is permanently buried at 2", 4", or 6" (left to right) below the soil surface.

While initial results of this study were promising, the number and size of scion roots observed in years four and five indicate that planting vines with the graft union just below the ground surface and covering with soil is not a viable technique for the protection of the graft union. Growers should use the standard methods – planting vines with the graft union above ground, hilling up in fall, and uncovering in spring – until other methods to protect the graft union can be tested.

One such alternative method to annual hilling up and uncovering is currently being investigated using five out of ten of the Control vines. There are ten Control vines each with either drip or micro-sprinkler irrigation. The graft unions of half the vines (five with drip, five with micro-sprinkler) are annually covered up in fall and uncovered in spring. The other half of the vines had the graft union continuously covered since fall of 2019 (the CC treatment). 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). In late fall of 2020, the mulch was removed to determine if any scion rooting had occurred in the CC treatment. No roots were found above the graft union. Graft unions were immediately covered up again and remained covered throughout the 2021 season. In the fall of 2021 and fall of 2022, the CC vines were again checked for scion rooting, and the graft union covered up again right after the observations. Again, no scion roots were found.

So far, the results from this study are promising. No scion rooting has been observed after three years of continuous cover with a wood chip mulch. If no scion rooting can be confirmed in future years, then this practice could replace the annual hilling up in fall and uncovering in spring. 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 to 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.

- 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, Bertin, and Gardner).

Based on the promising results with wood chips to protect the graft union, 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.

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, leaving the graft union exposed. In fall of 2021 those holes were filled up to the soil surface. Half the holes in this treatment were filled with soil, the other half with wood chip mulch. Graft unions will remain covered throughout the experiment. Graft unions of half the Control vines were covered in fall 2021 with soil while graft unions of the other half of the Control vines were covered with wood chip mulch. In early May 2022, for each covering treatment of the Control (soil or wood chip mulch), half the graft unions were uncovered while the other half remained covered. Uncovered graft unions were covered up again in the fall of 2022. These annual covering / uncovering treatments will be applied to the same Control vines for the remainder of the experiment while the graft unions of the other half of the Control vines will remain covered. Graft unions placed 2” below ground will remain covered throughout the experiment.

We will collect data on scion root formation, vine survival, and fruit yield and quality for a minimum of five years.

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, Bertin, and Gardner)

There are substantial differences in cold hardiness of cultivars. Understanding the patterns of acclimation, maximum 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 maximum 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. Since the 2020/21 dormant season we are also testing Frontenac, Itasca, and Vidal blanc from grower cooperator vineyards. For the 2021/22 dormant season Carmenere was replaced with Verdelho, another entry in the NE-1720 study. 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 early November 2022. Tests with cultivars Chardonnay and Syrah were conducted on a weekly basis with other cultivars tested every other week. For further information and updates visit:

https://aes.colostate.edu/wcrc/stations/orchard-mesa/viticulture/cold-hardiness/

- Crop load study with Chambourcin (Caspari, Bertin, and Gardner).

A crop load study with Chambourcin was initiated in the spring of 2020 at WCRC-OM. Briefly, own-rooted Chambourcin vines planted in 2014 were thinned to one inflorescence per shoot at the end of bloom or one cluster per shoot at veraison, or not thinned (Control). Vine x row spacing is 5.7' x 9' with vines trained to a high cordon system. On average, thinning removed 44 % of inflorescences/clusters. Thinning at veraison reduced yield by 44 % while thinning at bloom reduced yield by only 18 %. This lower yield reduction of bloom compared to veraison thinning was due to a 25 % increase in cluster weight with bloom thinning. The higher cluster weight was the result of increased fruit set (+19 %) and slightly larger berry weight (+5 %). The 2020 growing season was very hot, resulting in an unusually early harvest. Thinning effects on fruit quality were minimal.

The thinning study was repeated in 2021 using the same vines as in 2020. However, there was one modification – half the vines in the bloom thinning treatment were thinned just prior to bloom and the other half at the end of bloom. The study was replicated in another Chambourcin planting with GDC training at WCRC-OM as well as in a planting at a commercial vineyard with high cordon training about 2 miles East of the research center.

As expected, thinning reduced yield per vine. However, the effect was not uniform for all thinning treatments with the highest yield reduction with thinning at veraison and the lowest reduction with pre-bloom thinning. Pre-bloom and bloom thinning resulted in a higher fruit set but no change in the average berry weight. As a result, the average cluster weight was higher with pre-bloom and bloom thinning compared to the Control and veraison thinning. The 2021 growing season was again very hot, resulting in an unusually early harvest. Thinning effects on fruit quality were minimal except a darker juice/must color compared to the Control. At all three sites, pruning weight was higher than the Control with per-bloom and bloom thinning but was inconsistent with veraison thinning.

Compared to 2022, yields of the Control in 2023 increased 2-fold in the high cordon system and 4-fold in the GDC system at WCRC-OM. However, at the commercial vineyard the Control yield was down 20 %. Maximum yield at WCRC-OM was 11.3 ton/acre with GDC. Consistent with the results from previous years, thinning at veraison led to the highest reduction in yield (42-48 %). Pre-bloom and bloom thinning reduced yield about 20 %. Again, cluster weight was higher with pre-bloom and bloom thinning due to an increased number of berries per cluster than in the Control and veraison thinning treatments. At one of the three sites there was also an increase in average berry size with pre-bloom and bloom thinning. Differences in fruit chemistry were more pronounced in 2022 than in any of the previous years. The biggest differences were seen with veraison thinning, the treatment with the lowest yield. Depending on site, soluble solids increased between 1.2 to 2.0 ^{o}Brix while juice pH increased 0.03 to 0.09 compared to Control. Pruning weights were highest with pre-bloom and bloom thinning while those of the Control and the veraison thinning treatments were very similar.

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

The Colorado Climate Center 1. Installed two new CoAgMET-lite stations in southern Colorado; 2. Cataloged temperature patterns in Colorado during cold air outbreaks with potential to damage vines; and 3. Updated the Colorado Climate Center's Colorado Wine Grapes informational page at climate.colostate.edu/climate_wine.html using data from the most recent years.

Task 1 - Installation of two new CoAgMET-lite stations: Temperature sensors were installed at two locations with viticultural potential: western Pueblo County, and Montezuma County northeast of Cortez. These sites have been integrated in the Colorado Agricultural Meteorological (CoAgMET) Network. Temperature data since installation are available online at coagmet.colostate.edu. These stations have been named Pueblo West 01 (PBW01), and Dolores 01 (DLR01). Fig 1 shows where these stations are located, and Fig. 2 shows a time series of temperature measurements from PBW01. The DLR01 station was initially slated for installation in western Montrose County around Nucla. We have since connected with landowners in the Nucla area. This installation will happen in the coming fiscal year.

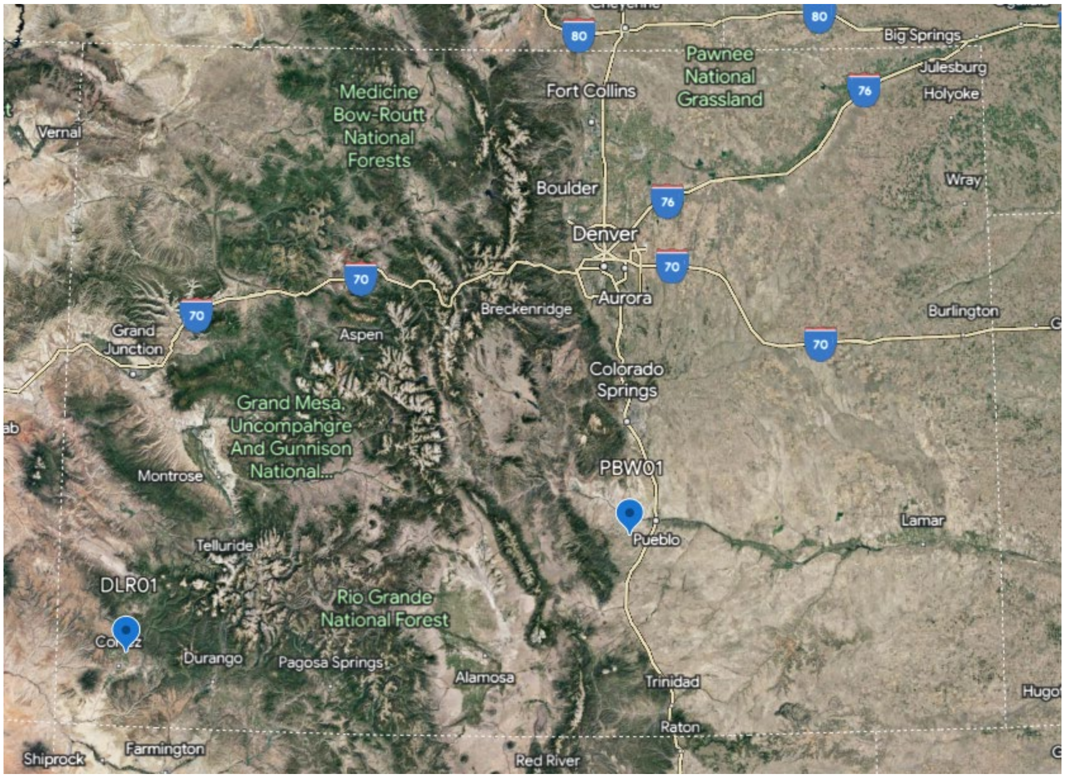

Fig. 1: Locations of two new installed CoAgMET-Lite stations (DLR01, PBW01) on Google Map overlay.

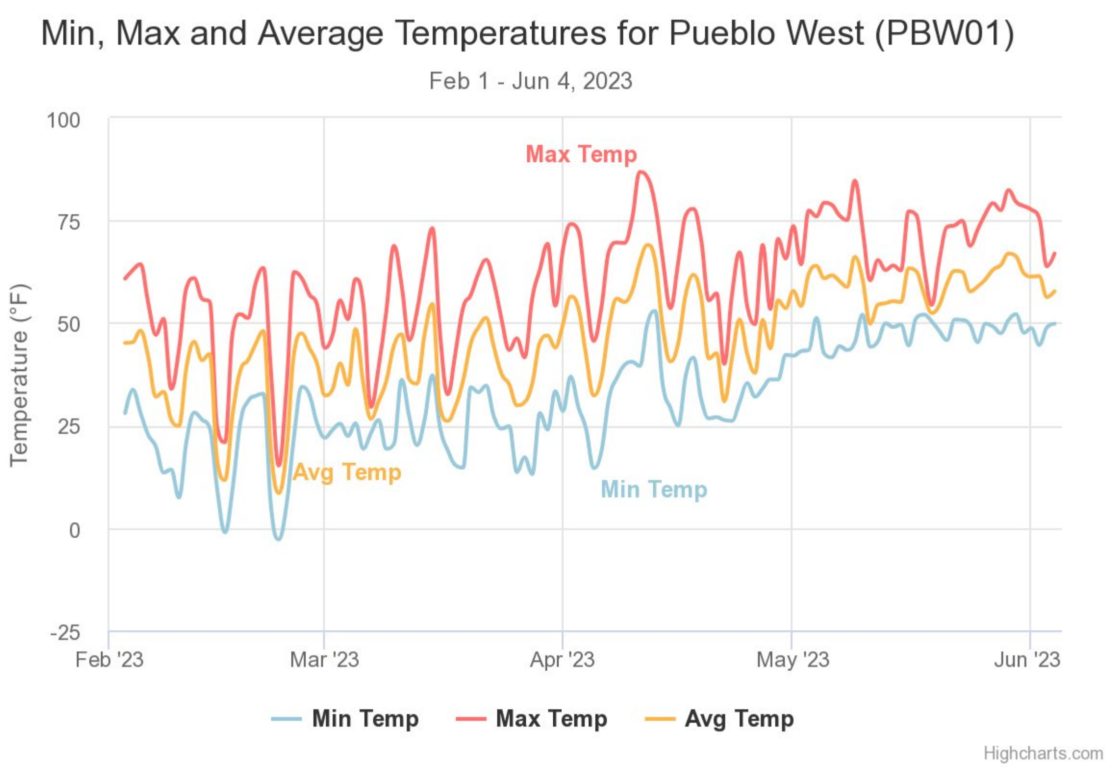

Fig. 2: Output from PBW01 from 1 Feb 2023 to 4 June 2023. Daily maximum temperatures (red), daily minimum temperatures (blue), daily average temperatures (yellow).

Task 2– Freeze Investigations: Tasks 2 and 3 address the frequency of potentially damaging freeze events for areas of grape production in Colorado. Similar to Goble et al. (2023), these freezes will be defined as "low temperature injury events," or LTIEs. The thresholds used for defining a LTIE in Colorado have been updated. Table 10 shows the LTIE thresholds used to approximate the success of European grape cultivars, moderately cold-hardy inter-specific cultivars, and super cold-hardy inter-specific cultivars.

Table 10: Thresholds of low temperature injury events (LTIE) for cold-tender *Vitis vinifera* cultivars, medium cold-hardy and super cold-hardy interspecific cultivars.

	European grapes (*Vitis vinifera,* unchanged from before)	Medium cold-hardy interspecific cultivars	Super cold-hardy interspecific cultivars
Type I	T_{min} <10 ºF prior to November 1 T_{min} <5 ºF prior to November 16 T_{min} <0 ºF prior to December 1	T_{min} <8 ºF prior to November 1 T_{min} <0 ºF prior to November 16 T_{min} <-8 ºF prior to December 1	T_{min} <3 ºF prior to November 1 T_{min} <-6 ºF prior to November 16 T_{min} <-15 ºF prior to December 1
Type II	Winter (DJF): T_{min} <-8 ºF	Winter (DJF): T_{min} <-13 ºF	Winter (DJF): T_{min} <-22 ºF
Type III	T_{min} <28 ºF after May 15, but before July 1	T_{min} <28 ºF after May 15, but before July 1	T_{min} <28 ºF after May 15, but before July 1
Type IV	Pre-harvest: T_{min} <28 ºF after July 1, but before October 1	Pre-harvest: T_{min} <28 ºF after July 1, but before October 1	Pre-harvest: T_{min} <28 ºF after July 1, but before October 1

Fall 2022 did not feature any dangerous killing freeze episodes in western Colorado, or portions of eastern Colorado where grapes are currently grown at scale (e.g. Cañon City). Winter 2022-2023 did include several cold spells strong enough to kill European grape cultivars. Figure 3 shows the portions of Colorado where grapes were expected to survive using the three different minimum temperature thresholds described in Table 10. Low-lying elevations of southwest Colorado including Palisade, Grand Junction, Delta, Montrose, and Cortez did not meet LTIE Type I or II thresholds for European grape cultivars (Table 10). The same is true of large portions of southeastern Colorado including most of Baca County and Huerfano County, much of Las Animas County, and portions of Pueblo and Fremont County around Pueblo and Cañon City. Most of northern Colorado, especially northeastern Colorado experienced temperatures too cold for all but super cold-hardy hybrid grapes. High elevations of Colorado do not typically get cold enough in winter to destroy cold hardy hybrids. This can be seen for winter 2023 in Fig. 3. However, these areas freeze throughout the year, and do not receive enough growing degree days for production. This is better represented by Figure 12 in task 3 (see below).

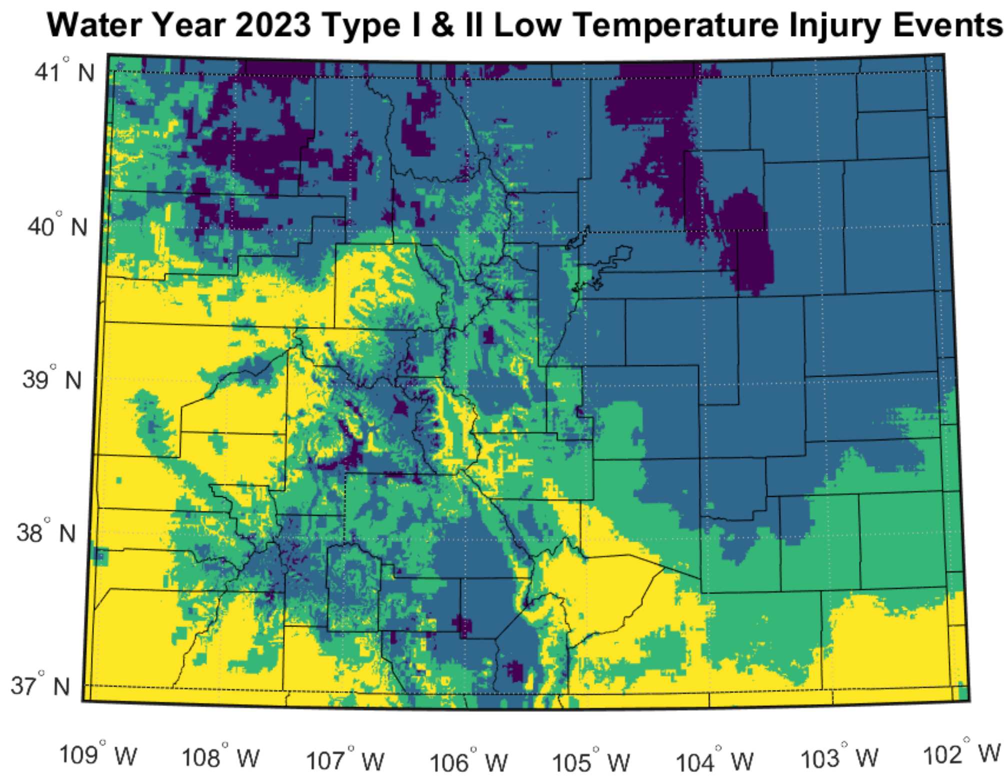

Fig. 3: Water year 2023 type I and II LTIEs using thresholds from Table 10. Yellow = no type I or II LTIEs for European grapes. Green = no type I or II LTIEs for medium cold-hardy hybrid grapes. Blue = no type I or II LTIEs for super cold-hardy hybrid grapes. Purple = type I or II LTIEs for all three types.

While no type I or II LTIES occurred for the areas in and around Cortez this growing season, we can analyze temperature patterns during cold snaps to further our understanding of spatial vulnerability on cold winter nights. Montezuma County saw low temperatures in the teens and single digits between 16 and 19 November 2022. While this does not meet the critea for a type I LTIE in most of the county, these temperatures are potentially dangerous depending on the level of cold acclimation in vines before the event. Figure 4 shows the lowest temperatures experienced over this four day period from PRISM and in the Cooperative Observer Network (COOP) and Colorado Agricultural Meteorological (CoAgMET) Networks. This was a strong inversion event. The top of Mesa Verde (7,800 ft) stayed 9 ºF warmer than the valley floor (6,000ft). Additionally, higher terrain to the north above the Canyon of the Ancients also stayed warmer. While this valley temperature inversion pattern is not atypical for Montezuma County it cannot be assumed for all cold air outbreaks. Goble et al. (2023) demonstrates that higher elevation terrain to the north and east of Cortez is sometimes as cold as the valley floor during potential LTIE events. PRISM may have overestimated temperatures in this area as PRISM shows values mostly above 20 ºF whereas observations ranged from 12-16 ºF.

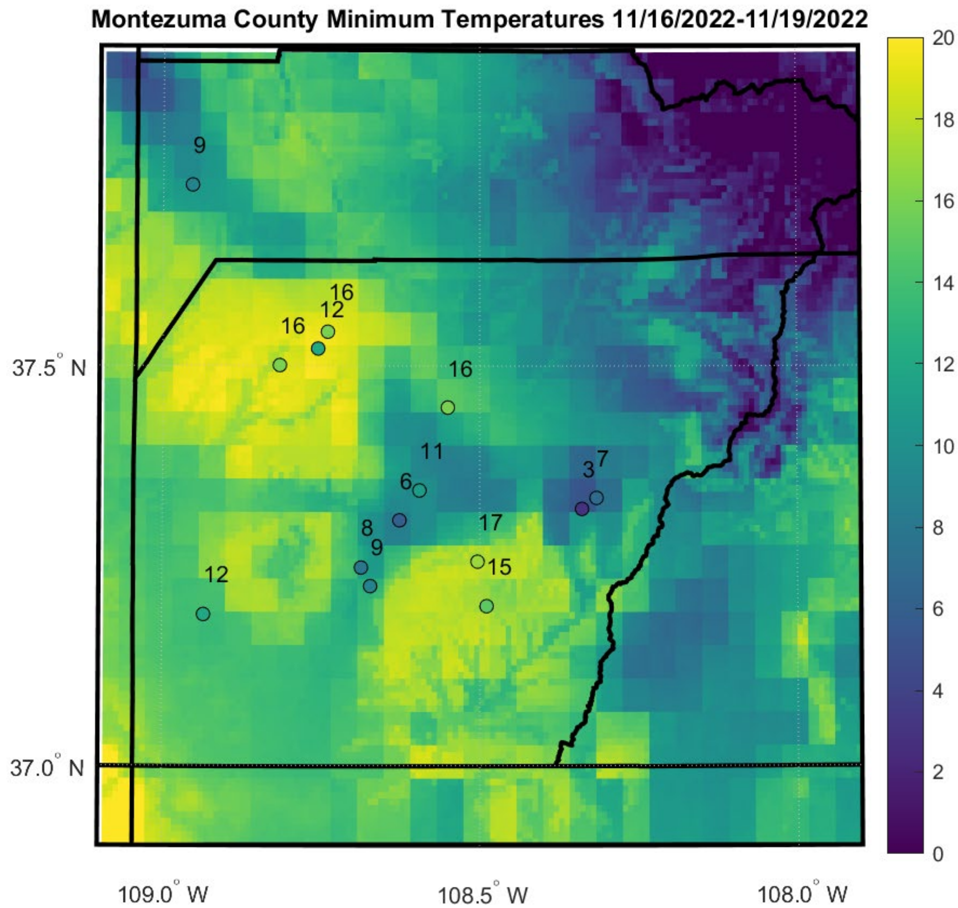

Fig. 4: Montezuma County minimum temperatures for 16 to 19 November 2022. Shaded grid shows minimum temperatures from downscaled PRISM model output. Filled circles show minimum temperatures from COOP and CoAgMET stations.

Figure 5 shows larger scale temperature and pressure patterns with wind speeds from 17 November 2022. This event featured a high pressure system to the north, centered over Montana, and lower pressure to the northeast (Minnesota), and southwest (Arizona). Colorado was mostly under clear skies and calm winds, though this large-scale pressure pattern should facilitate drainage flow from the northeast to southwest. Unlike many cold snaps, this event did not include snowcover at low elevations.

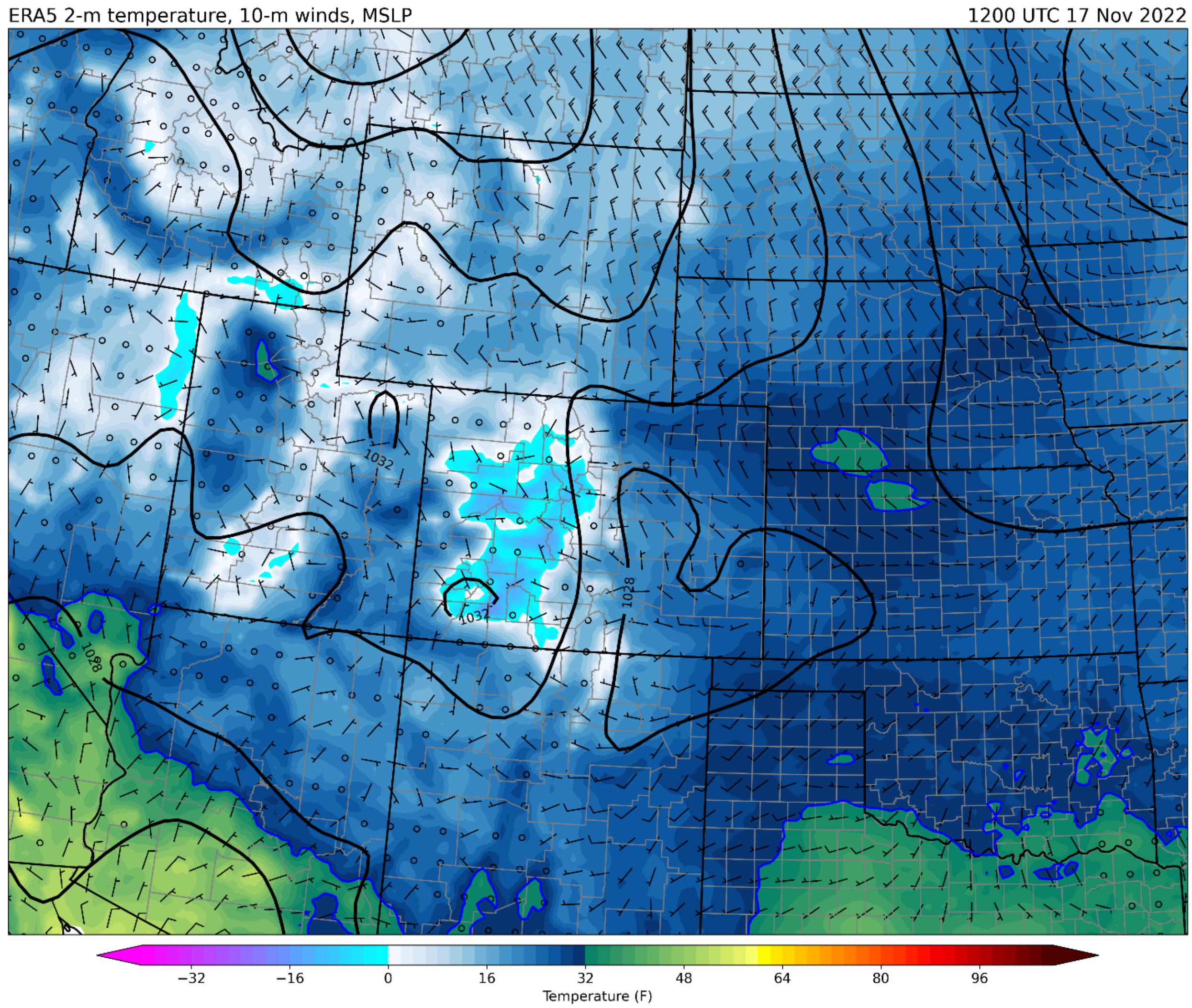

Fig. 5: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 5:00 AM MST (UTC) on 17 November 2022. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. ½ flag = 5 knots. Open circles indicate calm winds.

A strong cold front moved across much of the Contiguous United States including eastern Colorado from 21 to 24 December 2022. Growing areas on the Western Slope from Grand Junction down to Cortez remained well above 0 ºF during this cold snap as the coldest air did not cross the Continental Divide. Most of eastern Colorado saw temperatures below -10 ºF. The low temperature in Fort Collins, CO on 22 December 2022 of -17 ºF was the lowest recorded in over 20 years. Fig. 6 shows the temperature pattern across the state on the morning of 23 December 2022.

Figure 7 shows larger scale temperature and pressure patterns with wind speeds from 23 December 2022. Similar to the November event, this pattern features a strong high pressure airmass over the northern Great Plains with lower pressure to the southwest. The strong high pressure airmass to the north forced an arctic airmass southward across the central contiguous United States. The Rocky Mountains were absolutely critical in keeping the coldest air out of western and southwest Colorado as this large-scale pressure pattern would otherwise be bring the arctic air directly into western Colorado.

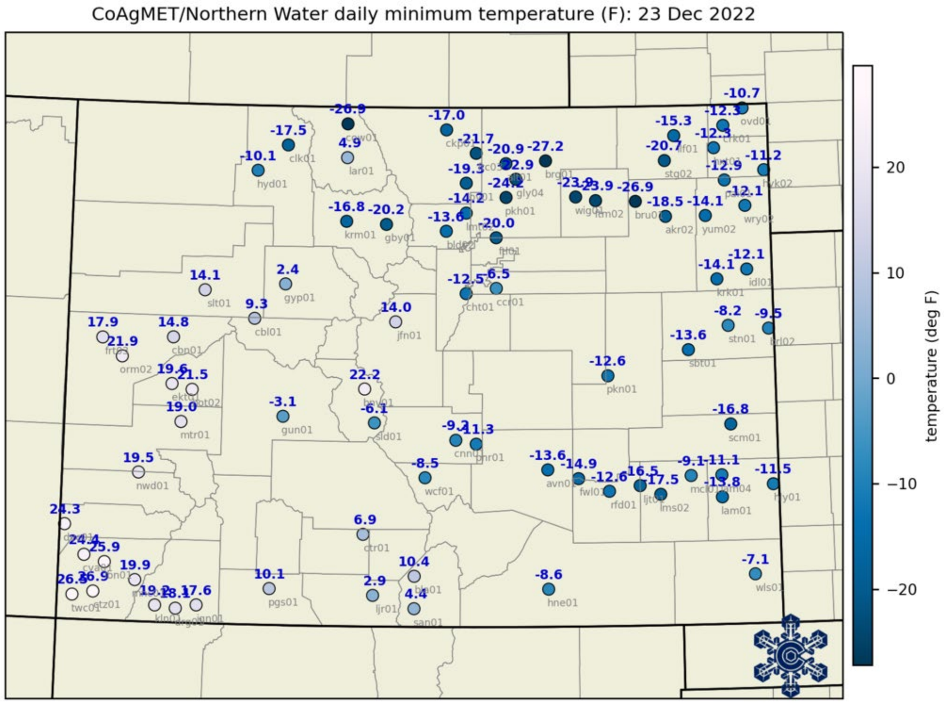

Fig. 6: CoAgMET minimum temperatures for 23 December 2022.

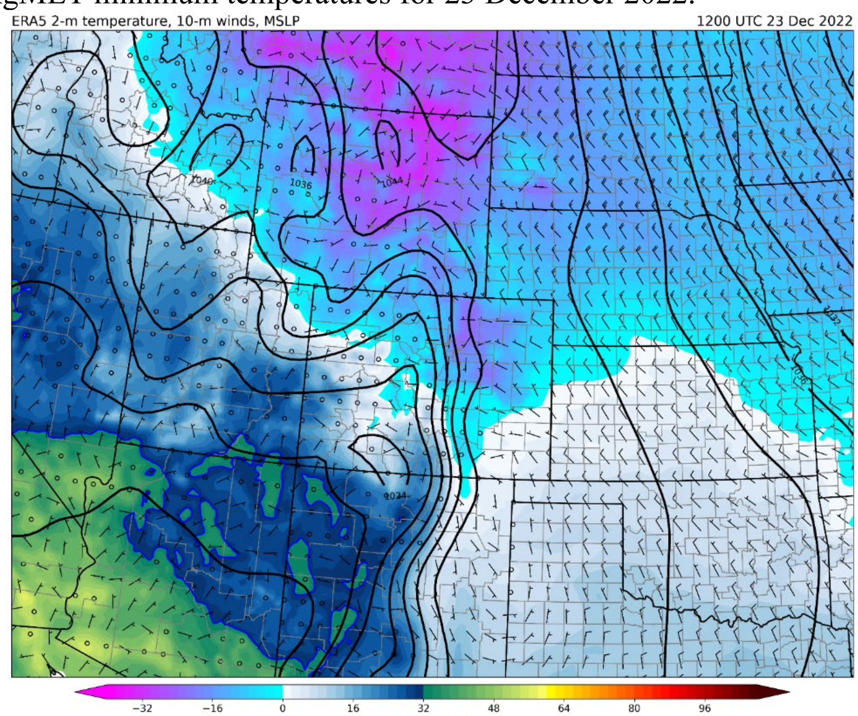

Fig. 7: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 1200 Universal Time Coordinate (UTC) on 23 December 2022. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. ½ flag = 5 knots. Open circles indicate calm winds. Local time is UTC -7 hours.

The strongest cold air outbreak for western and southwest Colorado in winter 2023 occurred from 15 to 17 February 2023. This event occurred immediately after a 4" snowfall event with additional snow cover from prior events. Figure 8 shows modeled and observed minimum temperatures across Montezuma County over this three-day timespan. This event did not feature a strong temperature inversion as from 16 to 19 November 2022. According to PRISM, the warmest areas were at low elevations in the southwestern portion of the county. Only three of the weather stations used in this analysis stayed above 0 ºF: The Towoac CoAgMET station at the Ute Mountain Farm and Ranch (8 ºF), the Canyon of the Ancients CoAgMET-lite station (3 ºF), and the Mesa Verde COOP station (1 ºF). Mancos was much colder than areas to the south and west, which is not atypical of potential LTIEs (Goble et al. 2023).

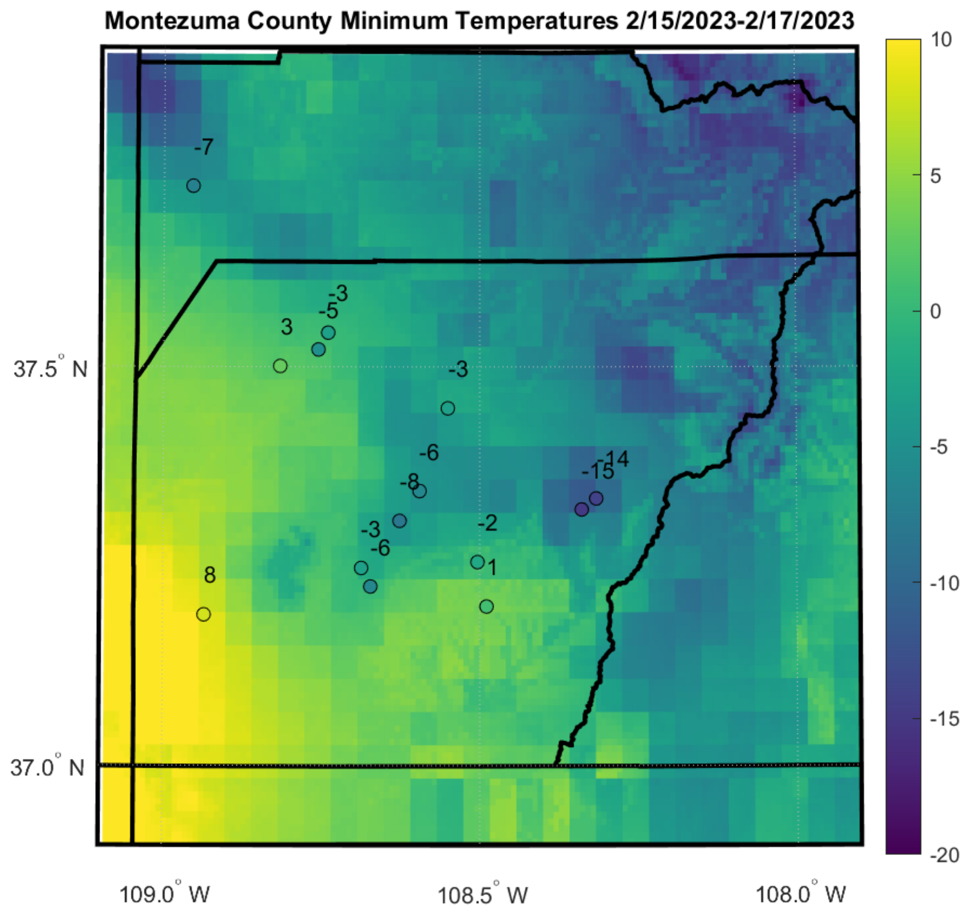

Fig. 8: Montezuma County minimum temperatures for 15 to 17 February 2023. Shaded grid shows minimum temperatures from downscaled PRISM model output. Filled circles show minimum temperatures from COOP and CoAgMET stations.

The larger-scale weather pattern associated with the 15 to 17 February 2023 cold air outbreak is shown in Figure 9. As is the case for many winter events, the morning of 16 February 2023 can be characterized by a high pressure airmass overhead with calm winds, clear skies, and snow on the ground.

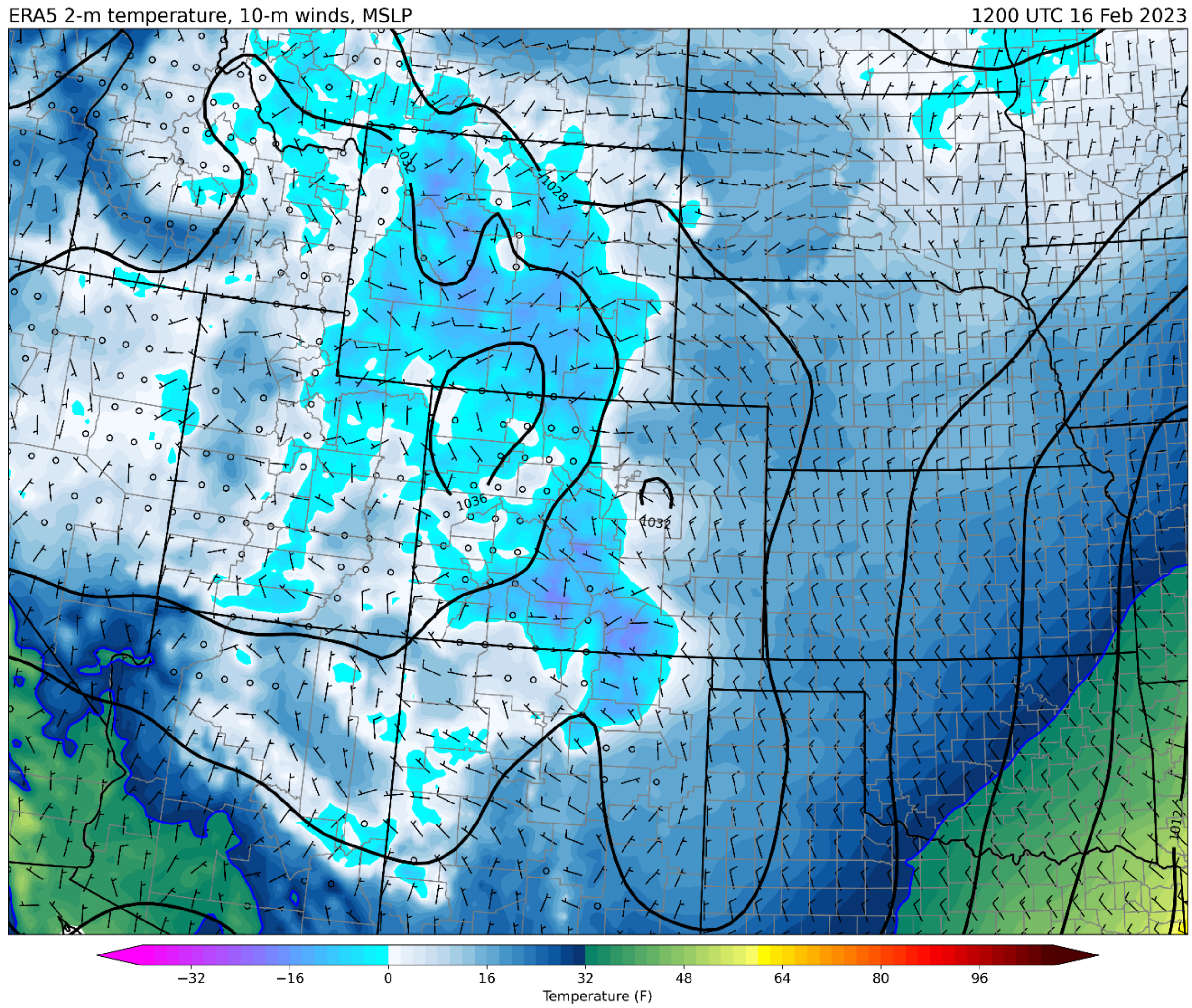

Fig. 9: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 1200 Universal Time Coordinate (UTC) on 16 February 2023. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. ½ flag = 5 knots. Open circles indicate calm winds. Local time is UTC -7 hours.

One of the coldest airmasses for western Colorado this spring occurred from 4 to 6 April 2023. Cold spring temperatures occurring before bud break can damage vines. This is not reflected in Table 10, or in Figure 12 from task 3 below. This cold air outbreak did include a temperature inversion, but not as strong an inversion as seen in the November cold air outbreak. Similar to the February event, the warmest part of the county was the southwestern portion at low elevation. Higher elevations on the Mesa Verde and near Yellow Jacket did remain warmer than Cortez or Mancos.

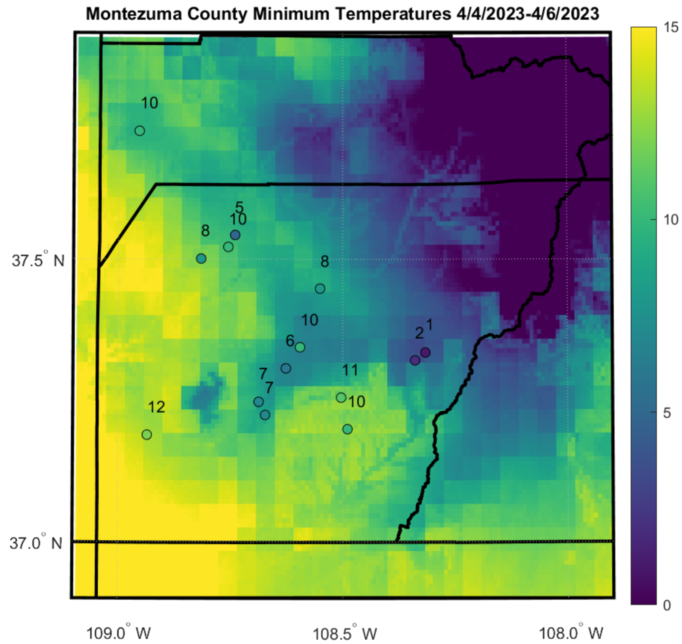

Fig. 10: Montezuma County minimum temperatures for 4 to 6 April 2023. Shaded grid shows minimum temperatures from downscaled PRISM model output. Filled circles show minimum temperatures from COOP and CoAgMET stations.

Fig. 11 shows the larger scale weather pattern on 5 April 2023. Like the February event, this event occurred with high pressure overhead following the passage of a cold front.

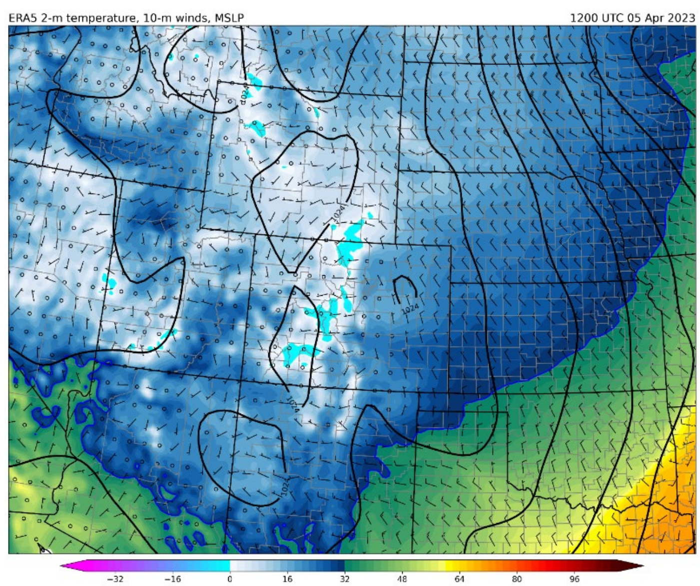

Fig. 11: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 1200 Universal Time Coordinate (UTC) on 5 April 2023. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. ½ flag = 5 knots. Open circles indicate calm winds. Local time is UTC -6 hours.

Task 3 – Exploration Opportunity Maps: Colorado Wine Industry "Exploration Opportunity" maps have been updated with downscaled Parameter-elevation Regressions on Independent Slopes Model (PRISM) data from 1981-2023. The updated figures and tables are available at climate.colostate.edu/climate_wine.html. These maps show a previous pattern to similar iterations: Western and southwest Colorado, unsurprisingly, show the highest success probabilities for European cultivars: particularly the Colorado, Gunnison, and San Miguel River Valleys, and Montezuma County to the south and west of Cortez.

Unlike previous versions of this map, much of southeastern Colorado, and even parts of northeastern Colorado including the Denver Metro area, are shown as exploration opportunity areas for hardy hybrids. This classification is derived from the thresholds in the "super cold-hardy" column of Table 1.

As always it should be noted that this map is based only on weather data, and should not be taken as a guarantee of success or failure. For example, the Cañon City area has successfully cultivated European gapes, but is only shown here as recommended for hardy hybrids.

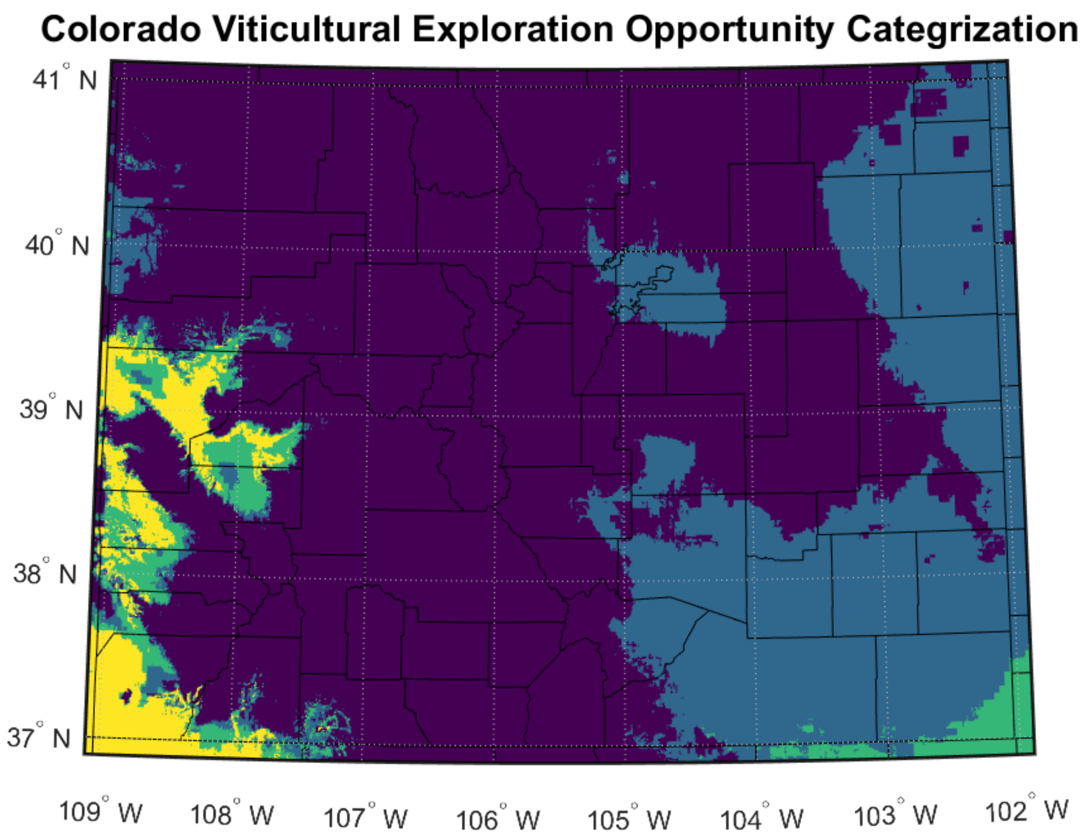

Fig. 12: Updated Colorado Viticultural Exploration Opportunity Categorization using downscaled PRISM data 1981-2023. Shading based on locations experiencing an estimated average of fewer than two Low Temperature Injury Event (LTIE) years/decade using Table 1. Yellow = best potential for European grapes, green = potential for medium cold-hardy grapes, blue = potential for super cold-hardy grapes, purple = not recommended.

The Colorado Climate Center and Colorado State University would like to thank the Wine Industry Development Board, and the Colorado Agricultural Experiment Station for providing the funding needed to publish a manuscript in the Journal of Applied and Service Climatologists (JoASC) that is based on our temperature investigations in Montezuma County for years 2017-2019. This publication is available online: https://doi.org/10.46275/JOASC.2023.04.001

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, Bertin, and Gardner)

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).

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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.

The results for 2015 to 2020 from this cover crop study have been reported in previous annual reports. Due to the cold injury from the October 2020 event and declining vine vigor due to phylloxera the decision was made to remove all own-rooted vines. Vines were pulled in December 2020. The guard rows for this trial were used for an inter-plant study, and inter-planted vines produced a small crop (see above). There were no inter-planted vines in the three rows used for the cover crop study. Thus, new vines (Chardonnay clone 37.1 on SO4 rootstock) were planted in spring 2021. There were no vine losses during the 2021 growing season. Graft unions were protected in early October 2021 using either soil or a wood chips mulch.

The 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 2022 season. No bud cold damage has been observed during the 2022/23 dormant season.

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, Bertin, and Gardner)

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. Turf density is continuing to increase and slowly suppressing native grasses and other, non-grass species.

III. Enology research

Enological research was limited to the small-scale wine lots produced from our cultivar trials as the position of the State Enologist has not been filled following the retirement of Dr Stephen Menke. Seven varietal wines plus one blend were produced from the NE-2220 cultivar trial at the Orchard Mesa site using micro-vinification techniques. An additional 12 wines were produced from the Chambourcin crop load trial that was replicated at three sites. White wines from the NE-2220 cultivar trial were bottled at the end of June 2023. All red wines are still in carboys and scheduled to be bottled during July 2023.

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. Since her hiring in June 2022, we have closely collaborated with Dr. Charlotte Oliver, Viticulture Extension Specialist, on outreach activities.

- Field demonstrations/workshops/tours

Together with Dr. Oliver we conducted a series of wine tastings of lesser-known cultivars. All the tasted wines came from our cultivar trials and were produced using micro-vinification techniques. At three events, participants did a vertical tasting of one white wine cultivar and one red wine cultivar. Generally, five to six vintages were served per cultivar. At the fourth workshop, participants tasted one white and two red wines but less vintages.

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 four 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.

- 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 2022 season, and the start of the 2023 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. Vineyards at the Western Colorado Research Center - Orchard Mesa are used in the first or early stages of testing of new methods and/or trials that carry a high risk of crop damage.

- Colorado Wine Grower Survey

Colorado State University has conducted this annual survey for over 20 years. Survey forms were sent out in early December 2022. All forms were sent electronically. A total of 39 responses were received (representing 91 vineyard sites) totaling 444 acres. The preliminary results of the survey are:

- Approximately 8 times higher production compared to 2021
- 1,400 ton production reported
- Estimated total production near 2,000 ton
- Minimal surplus grapes
- Average yield of 3.45 ton/acre; up 2.95 ton/acre from 2021
- Very good yield recovery from 2020 cold damage
- Average price of $1,851/ton; up about $220 on 2021
- Vineyard area planted / replanted equal to area removed (~30 acre), i.e. no change in total vineyard area

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