Annual Report

July 1, 2021 – June 30, 2022

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

This annual report covers the second half of the 2021 growing season, the 2021/22 dormant season, and the early part of the 2022 growing season.

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, dormant pruning, 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 2021, much below average in October, then again above average in November and December. June 2021 was the second-warmest and July 2021 was the third-warmest since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964.

Vine development and crop ripening was very early in 2021, due to the above-average temperatures from before bud break to late October. With few exceptions there was no crop on *Vitis vinifera* cultivars and a less-than-full crop on most interspecific cultivars. This low crop was due to an extreme low temperature event in late October 2020 that caused 100 % or near 100 % bud damage on *Vitis vinifera* cultivars, but minor damage to most interspecific cultivars. Only a small fraction of grapes was still hanging at the beginning of October.

The extreme low temperature event in late October 2020 resulted in significant bud damage on most cultivars growing at WCRC. Twenty out of 40 cultivars grown in the research vineyards produced no crop in 2021 and only 10 cultivars produced more than 2 ton per acre. Averaged across all cultivar trials the yield in 2021 was down 37 % compared to 2020. That is much less than the 90 % reduction evident from data from the 2021 Colorado Grape Grower Survey. This difference is explained by the fact that 40 % of the entries in the cultivar trials are cold-hardy interspecific cultivars compared to ~20 % of the

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area planted to those cultivars by commercial growers in Colorado. Survey data indicate that the average yield was <0.5 ton/acre, the lowest since 1991.

In contrast to the previous two seasons there were no extreme low temperature events during fall and early winter of 2021. The minimum dormant season temperature recorded at WCRC-OM was 5.1 F on 3 January 2022. At that time all the cultivars we monitored had cold hardiness values well below 0 F. No bud cold damage was observed at any time during the dormant season. However, a very late spring frost on 21 May did cause damage in some vineyards in the Grand Valley.

Mean temperatures in January and April 2022 were slightly above average, below average in February 2022, and near average in March and May 2022. The mean temperature in June was 2.5 F above average. Growing degree day (GDD) accumulation until the end of June was 100 GDD above the long-term average, but 69 GDD behind the very hot 2021 season.

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Growing conditions, 2021 season

Timing of bud break was average towards the end of April. May and August temperatures were warmer, June, July and September temperatures much warmer than average. October, in contrast, was much cooler than average. 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 11 November 4,072 GDD had accumulated, 372 GDD higher than average. Both November and December were much warmer than average.

The first half of the growing season was drier whereas the second half was wetter than average. Seasonal precipitation of 5.8” at WCRC-OM was near average.

The very warm growing conditions resulted in both a very early start and completion of harvest. Averaged across all cultivars harvest was 4 days later than in 2020, but about 8 days earlier than the long-term average. At WCRC-OM all fruit was harvested by 21 September, more than seven weeks before the killing frost on 11 November.

Growing conditions at the beginning of the 2022 season

Timing of bud break was average towards the end of April. Monthly mean temperature was near average for May and 2.5 F warmer than average in June. There was an unusually high number of windy to very windy days during spring in the Grand Valley as well as several extreme temperature fluctuations. Growing degree day (GDD) accumulation was more 100 degree days above average by the end of June. The first six months of 2022 have been very dry with only 1.40” of precipitation received at WCRC-OM which is less than 40 % of the long-term average of 4.04”.

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 most of our cultivar trials were down substantially compared to 2020 due to the extreme low temperature event on 26 & 27 October 2020. The majority of *Vitis vinifera* cultivars had no crop and many vines required retraining from the ground. Cold-hardy, interspecific cultivars had less cold damage and all produced a crop.

- Multi-state evaluation of wine grape cultivars and clones

  This long-term (2004-2022), USDA multi-state research project (originally NE-1020, now NE-1720) 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). There was no crop on Aromella, Auxerrois, Bianchette trevigiana, Blauer Portugieser, Chambourcin, Grüner Veltliner, NY 81.315.17, and Vidal. Data on fruit composition at harvest are presented in Table 2. 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 2021	Yield (ton/acre)
Marquette	16 September	1.03
MN 1200	9 September	0.43

Table 2: Fruit composition at harvest in 2021 for 2 (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})
Marquette	30.0	3.54	9.24	4.02	6.35	288	129
MN 1200	25.8	3.23	8.92	7.00	3.71	149	85

At Orchard Mesa, only 10 out of 21 mature cultivars produced a crop. Harvest started with Itasca on 2 August 2021 and ended with Barbera and Souzao on 21 September 2021 (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 about 40 % compared to the 2020 season. Eight varietal wines were produced using micro-vinification techniques.

Table 3: Harvest dates and yield information for 10 (out of 21) mature grape cultivars planted at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Harvest date 2021	Yield per vine (lb)	Yield (ton/acre)[1]
Albarino	20 September	7.09	3.70
Barbera	21 September	2.08	0.45
Cabernet Dorsa[2]	24 August	8.70	3.36

Table 3 continued

Cultivar	Harvest date 2020	Yield per vine (lb)	Yield (ton/acre)[1]
Chambourcin[2]	14 September	10.06	4.11
Itasca[3]	2 August	2.87	1.43
Marquette[2]	18 August	9.19	3.34
Roussanne	15 September	5.05	1.15
Souzao	21 September	2.36	0.77
Verdelho	31 August	9.20	3.51
Zweigelt[2]	7 September	6.79	3.54

[1] Yield calculation based on number of vines initially planted. Vine survival (out of 18 or 24 vines per cultivar) ranges from 54 % for Barbera to 100 % for Chambourcin, Itasca, and Marquette.

[2] Planted in 2011 and 2012.

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

Table 4: Fruit composition at harvest in 2021 for 10 (out of 21) 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	26.3	3.69	5.25	5.29	1.38	165	95
Barbera	27.1	3.53	7.49	6.06	3.72	218	175
Cabernet Dorsa[1]	25.6	3.50	6.69	6.48	2.01	218	130
Chambourcin[1]	26.0	3.22	8.98	7.62	3.11	169	106
Itasca[2]	26.0	3.45	7.86	8.19	4.34	171	78
Marquette[1]	31.5	3.48	7.33	3.33	3.91	408	167
Roussanne	27.6	3.48	6.47	6.52	1.53	184	121
Souzao	26.1	3.51	7.01	6.85	2.78	115	107
Verdelho	26.5	3.22	8.41	6.52	2.87	195	145
Zweigelt[1]	25.3	3.34	6.27	7.66	0.42	130	111

[1] Planted in 2011 and 2012.

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

Three recent new cultivar releases from the breeding programs at the University of Udine and Institute of Applied Genetics, Udine, Italy, were planted in late April 2022. The three new entries are interspecific cultivars having good to very high tolerance to powdery mildew. The cultivars are Cabernet Volos (Cabernet Sauvignon x Kozma 20-3) grafted to SO4, and Fleurtai (Friulano x Kozma 20-3) and Soreli (Friulano x Kozma 20-3), both grafted to 101-14. Although these cultivars were not planted within the same block where the NE-1720 trial is located, the same experimental protocols will be followed.

- Cultivar evaluation for Front Range locations, Fort Collins

  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 vigor at this site continues to be weak.

- Cold-hardy, resistant cultivars for the Grand Valley

  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). Year-over-year changes in yield ranged from -62 % for Arandell to +91 % for Brianna. Averaged across all cultivars, yields were up 10 % compared to 2020 while harvest was later by 2.5 days. A summary of fruit composition is presented in Table 6. Due to insufficient yields on five cultivars only seven varietal wines were produced using micro-vinification techniques.

  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 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.

  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 33 % 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 2021	Yield (ton/acre)[1]
Arandell	7 September	0.48
Aromella	30 August	3.20
Brianna	6 August	2.27
Cayuga White	13 September	1.63
Chambourcin	15 September	0.45
Corot noir	14 September	1.64
La Crescent	30 August	2.13
Marquette	13 August	2.11
Noiret	7 September	1.36
St Vincent	5 October	0.88
Traminette	7 September	0.55
Vignoles	2 September	0.37

[1] Yield calculation based on number of vines initially planted. Vine survival is >90 % for all cultivars except Chambourcin (75 %), Traminette (66 %) and St Vincent (33 %).

Table 6: Fruit composition at harvest in 2021 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	24.2	3.98	5.05	6.13	2.46	213	54
Aromella	24.4	3.24	7.85	7.67	2.11	184	119
Brianna	20.2	3.46	7.77	5.56	3.60	243	70
Cayuga White	22.7	3.37	6.33	7.74	0.67	169	88
Chambourcin	26.1	3.27	8.25	7.35	1.47	165	105
Corot noir	25.4	3.79	4.36	6.34	0.09	270	111
La Crescent	27.8	3.26	9.55	7.30	4.93	177	95
Marquette	30.2	3.27	9.47	4.04	5.04	476	171
Noiret	23.4	3.71	5.76	7.42	1.61	178	88
St Vincent	20.1	3.06	8.03	8.99	1.24	120	88
Traminette	25.2	3.48	6.84	6.37	2.10	144	73
Vignoles	30.0	3.15	7.86	6.41	2.21	164	94

2. Mitigating damage from grape phylloxera

Grape phylloxera (*Daktulospheira vitifoliae*) is an aphid-like insect that feeds on grape roots. Phylloxera is native to the northeastern United States and many American grape species are tolerant to phylloxera. However, the European grape (*Vitis vinifera*) has no tolerance and phylloxera feeding on roots will eventually kill the vines. The first recording of phylloxera in a commercial vineyard in Colorado occurred in August 2015. During a routine Grape Commodity Survey, personnel working for the

Cooperative Agricultural Pest Survey (CAPS) found phylloxera on leaves of hybrid vines in Larimer county. In November 2016, CSU personnel assisting a grower in Mesa County discovered phylloxera on the roots of young *Vitis vinifera* vines. In subsequent surveys by CSU, phylloxera was discovered in six further vineyards in Mesa County, and one vineyard in Delta County. Phylloxera was found in vineyards planted with hybrid as well as *Vitis vinifera* cultivars. More vineyards infested with phylloxera were found in further surveys in 2017, 2018, and 2019. Presently there are 18 positive vineyards in Mesa County, 3 in Delta County, 1 in Montrose County, and 2 on the Front Range. It is very likely that in some vineyards phylloxera has been present for more than 10 years.

Phylloxera represents a major threat to the Colorado grape and wine industry. Vineyards in Mesa and Delta County produce >90 % of Colorado's grape crop. About 80 % of these vineyards are planted with own-rooted vines of European cultivars, making them susceptible to phylloxera damage. Initially, feeding of phylloxera on roots of susceptible grape vines leads to reduced vine vigor and lower yields. However, phylloxera feeding, in combination with fungal and bacterial infections of the damaged root system, will eventually kill the vines. While phyto-sanitary practices and insecticide applications can slow the spread of phylloxera, the long-term solution is the removal of own-rooted vines of cultivars that are not phylloxera tolerant (all *Vitis vinifera* and some hybrid cultivars) and then replanting with susceptible cultivars grafted to tolerant rootstocks or with tolerant hybrid cultivars.

While there is a large body of research on the performance of rootstocks in many grape growing areas around the world, there is very limited information for Colorado. Only two replicated rootstock studies have been conducted in Colorado 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

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 2020 record low temperature event showed the highest fruitful (primary and secondary) bud kill of 81 % on own-rooted vines (Table 7). At 74 % own-rooted vines also had the highest bud mortality. On grafted vines fruitful bud death ranged from 34 % with 5BB to 72 % with 110 Richter. Bud mortality on grafted vines ranged from 19 % with 5BB to 62 % with 110 Richter.

Average yield per cropping vine in 2021 was 3.5 lb, down 10 % on 2020. Yield per cropping vine was highest on 1103 Paulsen (6.6 lb) and lowest on 140 Ruggeri (0.5 lb) and own-rooted vines (0.8 lb). 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 second highest yield per cropping vine (4.5 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 per acre.

Table 7: Effect of rootstock on vine survival after 13 years and yield in 2021 of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Fruitful bud damage in October 2020 (%)	Yield (ton/acre)
110R	57	72	0.34
140Ru	18	67	0.04
1103P	50	58	1.67
5BB	64	34	1.04
5C	79	54	1.75
Own-rooted	93	81	0.28

- 2017 Rootstock trial with Cabernet Sauvignon

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.

- 2018 Rootstock trial with Cabernet Sauvignon

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.

- 2019 Rootstock trial with Souzao in a challenging soil

A new rootstock trial with Souzao (clone 1) grafted to seven 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. Vegetative growth was strong during 2021 so that most vines could be retrained onto the cordon wire. Percentage bud break was high in spring 2022 but the very late freeze on 21 May did cause some shoot damage. We expect to harvest the first crop in the fall of 2022.

- Inter-planting of grafted vines

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 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. 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.

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. Twenty 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. Mature Chardonnay vines grafted to four different rootstocks growing in the same block produced only 0.49 ton/acre.

It should be noted, however, that the inter-plant study is located within our long-term cover crop study and during the first 4 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 – 2017 study

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 above-ground section of 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 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 was 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 were due to lower vine vigor with micro-sprinkler irrigation in the first 3 years. It took longer to establish canes and cordons and reach a full canopy with micro-sprinklers compared to drip. In 2019 and 2020, there was a trend for higher yields on Control vines in both irrigation treatments.

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. In other words, we evaluated roots on the same vines that were used in fall 2018. Aside from the obvious and expected increases in root diameter, a comparison of the images from 2018 and 2020 suggested minimal or no new root development above the graft union in two years. However, results looked very different when the five reps previously evaluated in 2019 were reevaluated in the fall of 2021 (see photos below). By the end of year 5 many strong roots originating from above the graft union were found on all the vines that were evaluated. 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.

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.

The trend of higher yields in the Control treatments was confirmed again in 2021 when drip-irrigated Control vines produced 2.4 ton/acre versus an average 1.7 ton/acre for the treatments with the graft union below ground. Control vines with micro-sprinkler irrigation produced 1.8 ton/acre versus an average 1.1 ton/acre for the treatments with the graft union below ground. Further, with both drip and micro-sprinkler irrigation there was a trend for lower yields the deeper the graft union was placed below ground.

While initial results of this study were promising, the number and size of scion roots observed in years 4 and 5 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 alternative to the annual hilling up and uncovering is currently being investigated using 5 out of ten of the Control vines. There are 10 Control vines each with either drip or micro-sprinkler irrigation. The graft unions of half the vines (5 with drip, 5 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 chips 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 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 wood chips study are promising. No scion rooting has been observed after 2 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.

One question that arises when using materials other than soil to protect graft unions is how well those alternatives thermally insulate the graft unions. In early December 2020, two temperature loggers (USB-501 Pro) were placed at the height of the graft union and covered inside the wood chip mulch. Two additional temperature loggers were attached to the cordon wire immediately above. Temperature data was recorded every five minutes from 8 December, 2020 to 23 April, 2021 (Fig. 1). The lowest temperature measured under the wood chips mulch at the height of the graft union was 21.5 F on 27 January, 2021 compared to 6.6 F at the cordon height on 2 January, 2021. During the coldest part of winter (December to mid-January) the temperature at the graft union was on average 13 F higher than at the cordon wire. The largest difference of 20 F was observed on 2 January, 2021, the day with the lowest temperature of the dormant season. The last day that a freezing temperature was measured at the height of the graft union was 31 March, 2021 whereas four more temperatures below 32 F were recorded at cordon height during April 2021. The temperatures at the graft union never dipped low enough to cause cold temperature injury indicating that a wood chips mulch provides sufficient thermal insulation and is an alternative to hilling up with soil.

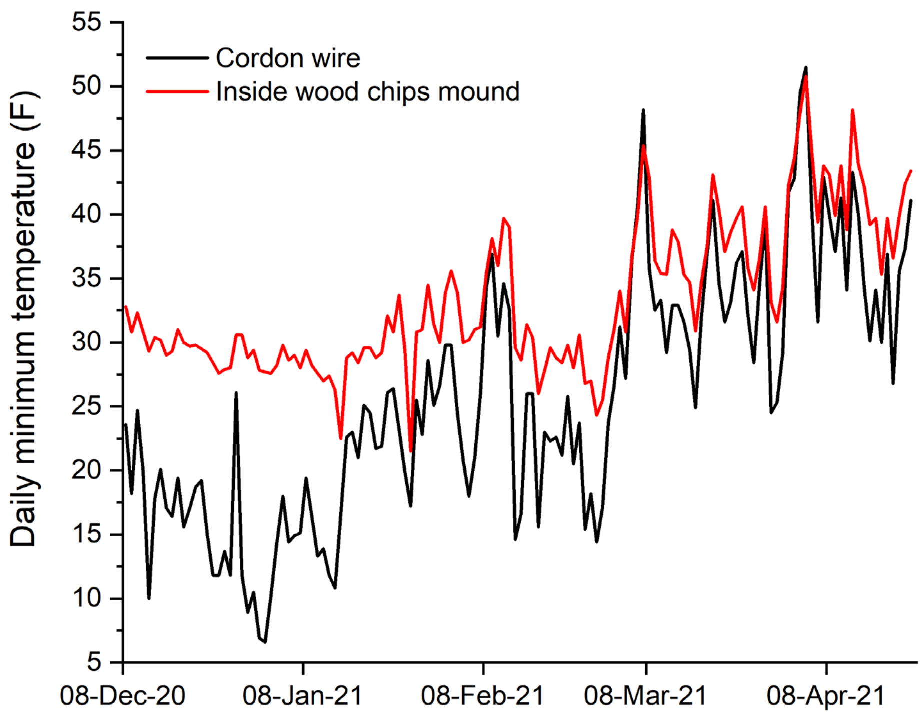

Fig. 1: Daily minimum temperatures at the height of the graft union covered with a wood chips mulch and at the height of the cordon wire (Western Colorado Research Center, Grand Junction, CO).

- 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.

  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. Temperature data loggers were placed at the height of the graft unions of eight vines: four Control vines (two with soil and two with mulch cover) and four vines with the graft unions 2” below the soil surface (two with soil and two with mulch cover). In addition, two temperature loggers were placed at cordon height. Temperatures were recorded from 6 October 2021 to 3 May 2022. The lowest temperature recorded at a covered graft union was 21.2 F, whereas the minimum temperature at cordon height was 3.5 F. Soil and wood chip mulch provided the same thermal protection of the graft union. Where the graft union was above ground (Control) the dormant season minimum temperatures were about 5 F colder than where the graft union was at 2” below ground. Note that the 2021/22 minimum temperatures measured at the graft union covered by soil or wood chips mulch were very similar to those measured the previous year (see above).

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 will be 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 at all times. 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. *Crop load effects on fruit and wine quality and bud cold hardiness.*

- Crop load study with Chambourcin

Chambourcin is a late ripening red interspecific cultivar with medium cold hardiness. Long-term evaluations of bud cold hardiness from three different cultivar trial sites show that the lethal temperature to cause a 50 % primary bud kill (LT_{50}) range from -14 F to -21 F, compared to a range of -8 F to -15 F for Chardonnay. The vineyard area in Colorado planted with Chambourcin has increased over the past ten years. Survey data from 2021 indicate that Chambourcin is now ranked #7 in acreage, but was #1 in production due to massive cold damage to the leading *Vitis vinifera* cultivars from the October 2020 event. Chambourcin is a very fruitful cultivar producing large clusters which can result in very high yields. However, similar to other late ripening cultivars, there is the risk that fruit may not ripen sufficiently if crop loads are high, especially in seasons with less heat accumulation or early fall frosts. For example, in 2019 most of the Chambourcin grown in the Grand Valley was harvested after an early killing frost on 11 October. Chambourcin fruit is high in acidity, and growers often delay harvesting in an attempt to reduce acidity. In this trial we aim to determine the optimal crop load for Chambourcin grown in the Grand Valley.

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'. 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 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 reduction in yield 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.

This study is continuing in 2022. Pre-bloom and bloom thinning treatments were applied in mid-May and early June, respectively. Shoot fruitfulness was much higher than in 2021 in the two blocks at WCRC but slightly down in the commercial vineyard.

4. 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

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 has been 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 late September 2021. 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/

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

This year's climate study had three objectives: installing more permanent weather monitoring equipment in Montezuma County that provide data in real time, extending USB-501-PRO data collection east of the Continental Divide to include parts of Pueblo and Huerfano Counties, and monitoring potentially damaging freeze events in water year 2022 (1 October 2021 to 30 September 2022).

Two more permanent stations have been installed in Montezuma County. The data are available at coagmet.colostate.edu under the station names "Canyon of the Ancients (CYA01)" and "Lebanon (LEB01)." They are both north of Cortez along hillsides where cold air may drain into canyon ravines (Fig. 2). CYA01 and LBN01 have consistently recorded higher daily minimum temperatures than the Cortez National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer (COOP) Network station in Cortez (Fig. 3).

Temperature data collection continued with strong local engagement in Fremont County, but success extending to Pueblo and Huerfano County was minimal with only six new USB-501-Pro stations. Thermometer locations can be seen below in figures 4-6.

Cold weather events were tracked across the state for water year 2022 using Parametrized Regression on Independent Slopes Model (PRISM) data and in-situ observations. Colorado grape growing areas were spared any lethal freeze events prior to full vines reaching full cold acclimation this year. February 3rd-4th temperatures were cold enough to damage less hardy cultivars in the Fremont, Huerfano, Pueblo County area in 2022. The February 3rd-4th event was unique because historic grape growing portions of Fremont County recorded cooler temperatures than most locations on the Front Range or Eastern Plains. Freezes also occurred after bud break (estimated as May 15th) in grape growing areas both west and east of the Continental Divide. For some, these were hard freezes. May 21-22nd temperature patterns for Fremont/Huerfano/Pueblo County, and the May 30-31st temperature pattern for Montezuma County are examined in detail below.

Task One – Installation of new CoAgMET-lite Stations in Montezuma County: Two automated temperature sensors have been installed on producers' properties in Montezuma County. Both stations are north of Cortez. Locations were chosen based on temperature readings in previous climate studies and/or potential for favorable drainage winds (both stations sit above a canyon). Station locations (named

“Lebanon” and “Canyon of the Ancients”) are shown in Fig. 2. Stations were installed in November, and added to the CoAgMET database in early February. So far, both CYA01 and LBN01 are warmer than the Cortez COOP at night by 3.3 F and 2 F respectively. Figure 3 shows a timeseries of nightly minimum temperatures from February 4th, 2022 through June 15th, 2022.

Fig. 2: Google Earth view of new station installations (yellow pins), and the Cortez Cooperative Observer Network Station (red pin).

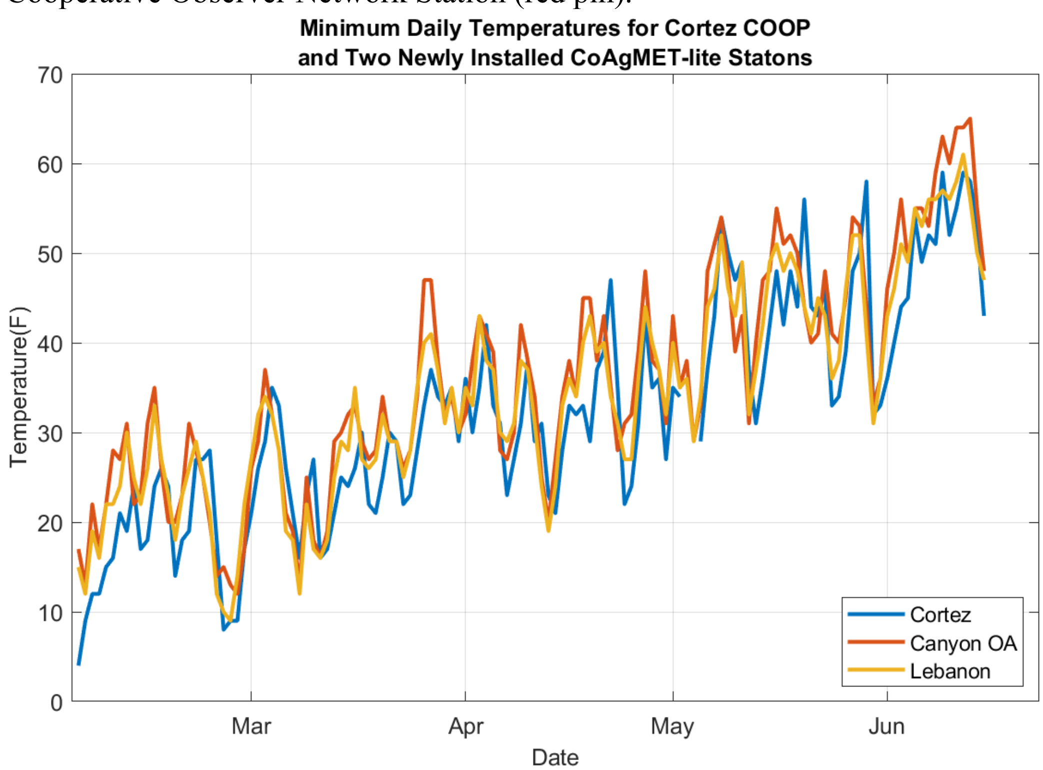

Fig. 3: Minimum daily temperatures from Cortez COOP Station (blue), Canyon of the Ancients CoAgMET (red), and Lebanon CoAgMET (yellow).

Task Two – Data Collection in Fremont, Pueblo, and Huerfano Counties: Six new USB-501 PRO sensors were added to the project in the Rye/Colorado City area in October. Two views of the new stations are shown in Fig. 4 and 5. We would have liked to set up at least twice as many stations with more sites at prospective vineyards. Engaging the community proved challenging, and primarily for this reason, we are not recommending further USB-501 PRO data collection in the area. Data collection continued in Fremont County. Community engagement there remained strong. Temperature data from the two areas are analyzed jointly in task three.

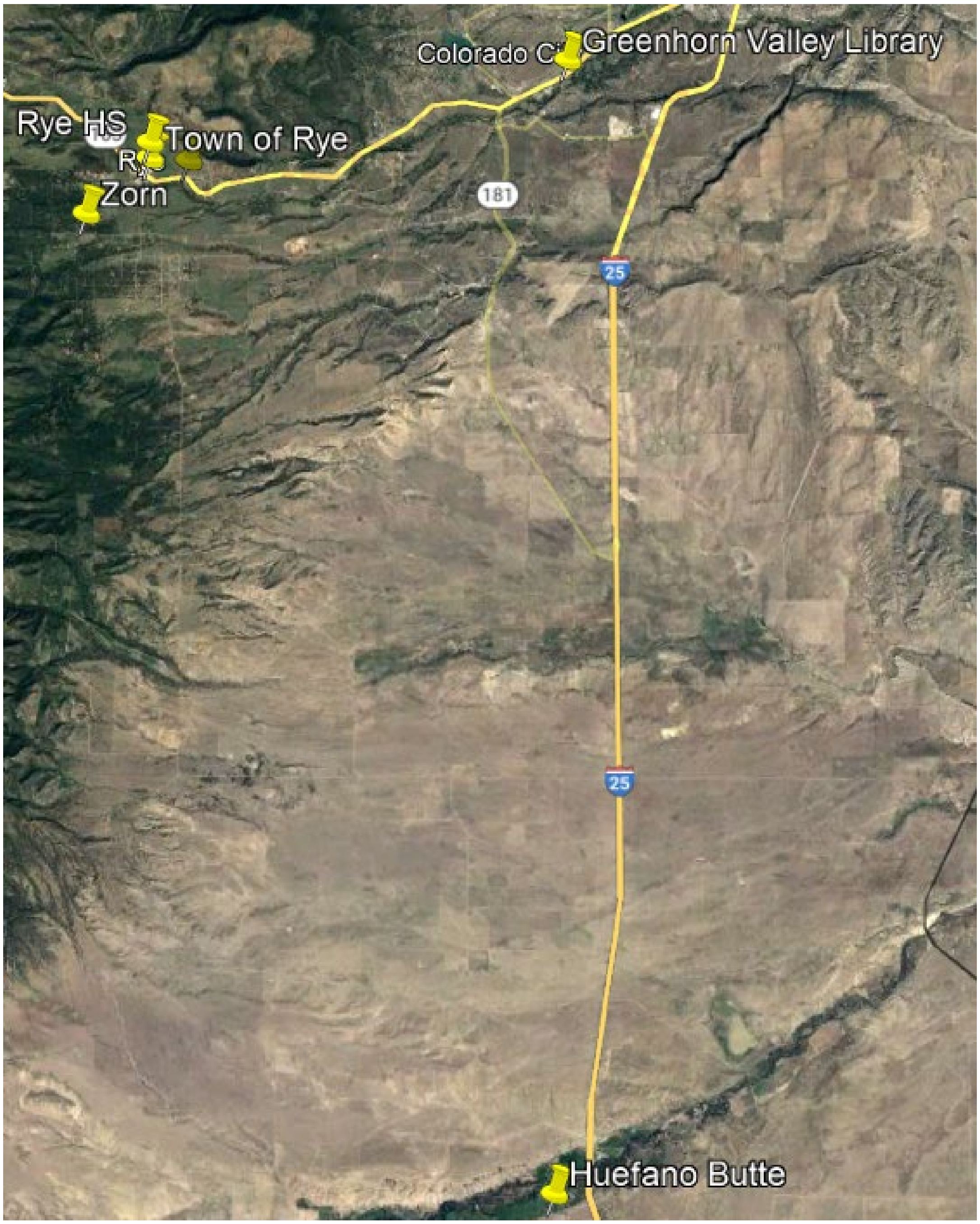

Fig. 4: Rye/Colorado City area stations (yellow pins).

Fig. 5: Rye/Colorado City zoomed in.

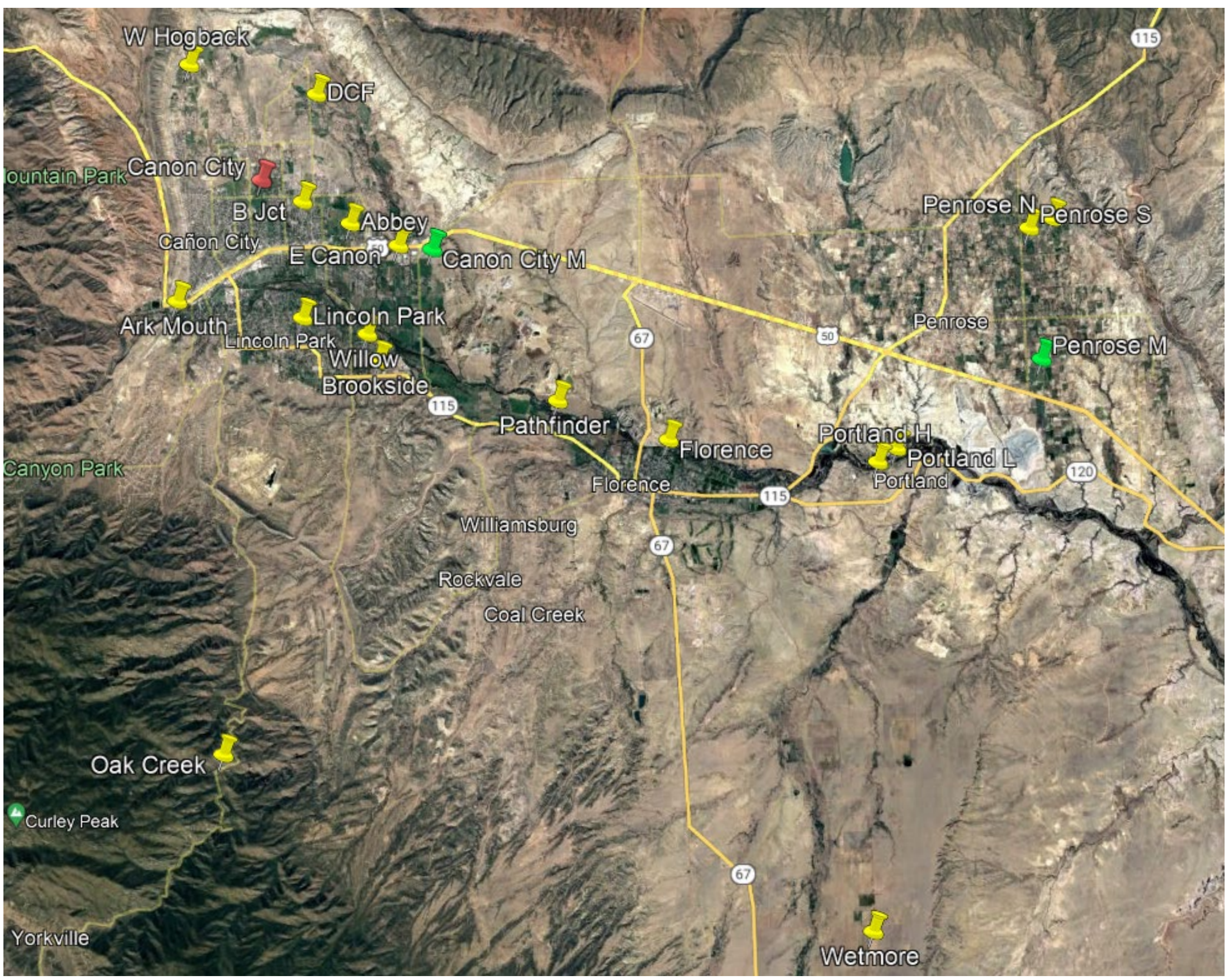

Fig. 6: Cañon City data collection locations. Yellow pin = project-specific thermometer. Red pin = COOP Station. Green pin = CoAgMET station.

Task Three – Freeze Investigations: Water year 2022 began with a mild autumn. Temperatures in Grand Junction did not fall below 20 F until after December 1st, a stark contrast from October 2019 and 2020, which both saw lethal conditions.

Several potentially damaging weather events occurred in water year 2022 (Fig. 7). Two events occurred during full dormancy, and one in late May after typical occurrence of bud break. Cold snaps on February 3rd and February 23rd brought Cañon City temperatures down to -17 and -13 F respectively. Both were record lows. Temperatures fell below freezing for parts of Fremont and Pueblo Counties on May 21st and 22nd, and in Montezuma County on May 30th and 31st.

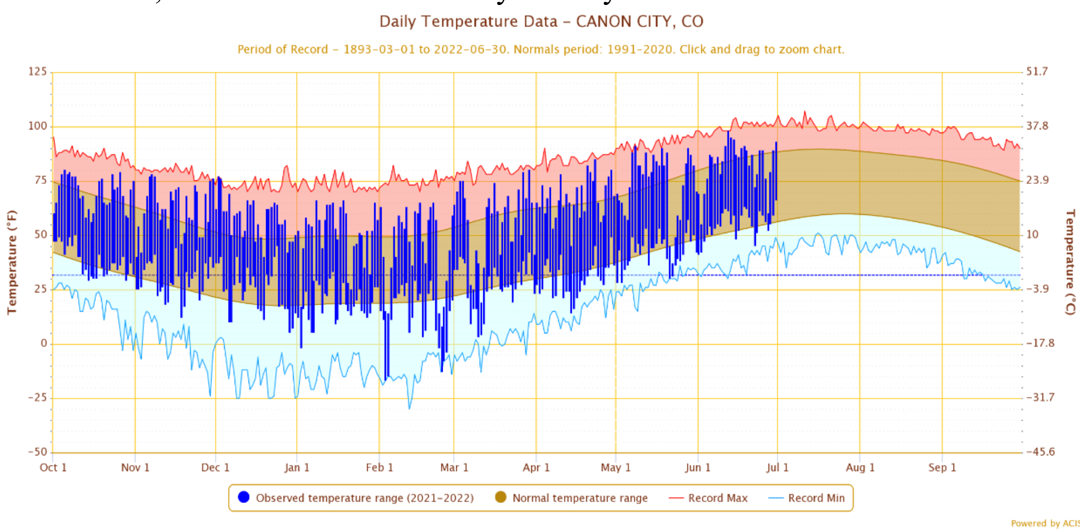

Fig. 7: Water year 2022 daily temperatures for Cañon City CO. Observed daily temperature range (blue bars), normal temperature range (brown shaded area), daily maximum temperature records (red), and daily minimum temperature records (light blue).

February 3-4: The February 3rd and 4th cold snap (Fig. 8) is an interesting case study over the Fremont, Huerfano, Pueblo County area for a few reasons: Firstly, temperatures were low enough to threaten even fully cold acclimated European cultivars (below -15 F). Temperatures below -15 F were observed at a number of stations including parts of Cañon City, Rye, Walsenburg, and Wetmore (Fig. 9). Most weather stations not exceeding this threshold recorded temperatures within a few degrees of it. Secondly, the temperature pattern was atypical. Cañon City often stays warmer than Pueblo and other areas to the east because it is shielded from arctic airmasses by mountains to the north. This creates an east-to-west temperature gradient in the Arkansas River Valley. During the February 3-4 cold snap, this temperature gradient was reversed. Cañon City recorded a low of -17 F, and the Pueblo Reservoir COOP recorded a low of only -2. Furthermore, this event generated greater discrepancies between PRISM and observed values than typical. Differences between PRISM and observations are within 5 F in most cases. PRISM did not indicate any temperatures below -15 F from Cañon City to Walsenburg, missing the observed low near Wetmore by 14 degrees.

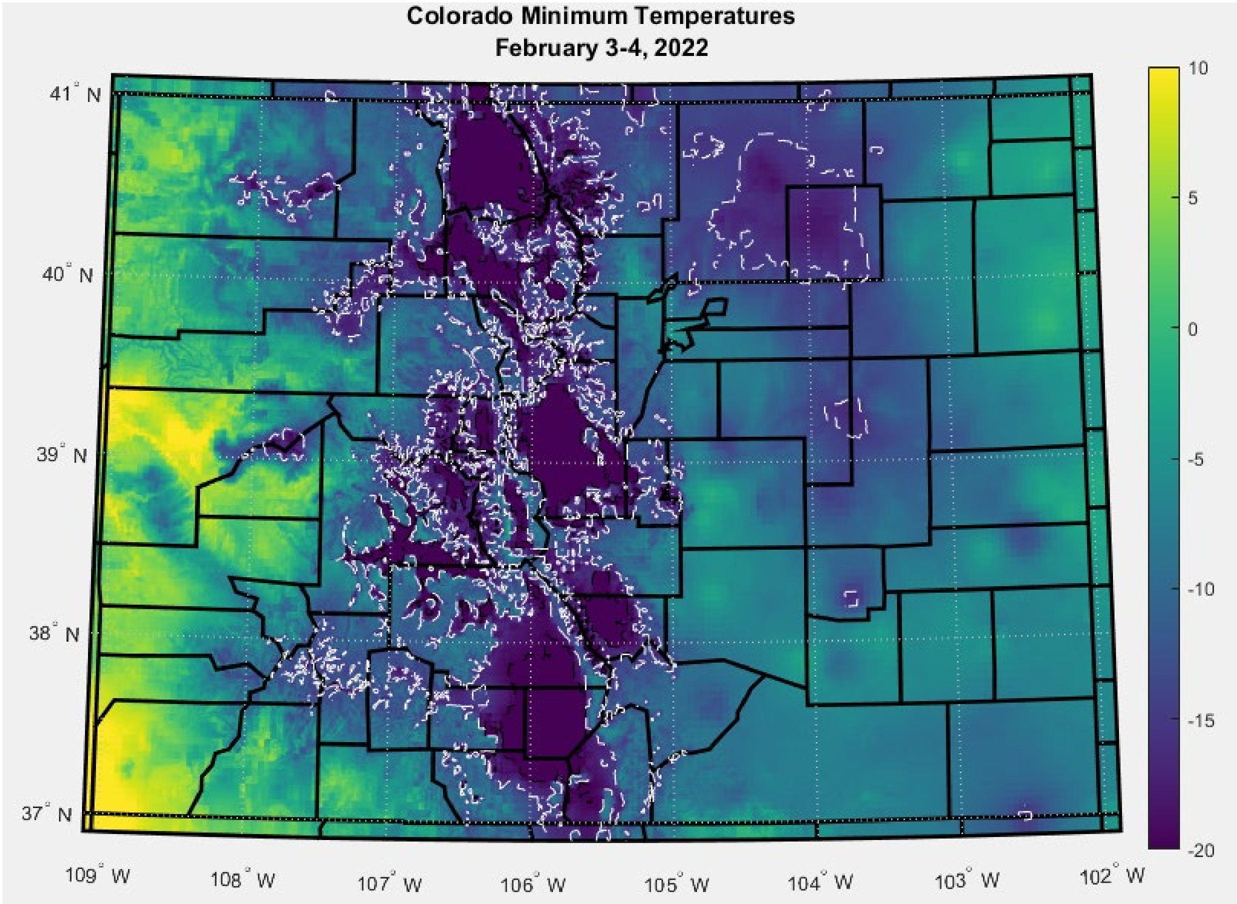

Fig. 8: Colorado PRISM minimum temperatures for February 3-4th (Fahrenheit). Black, dashed line = -20 F contour. White, dashed line = -15 F contour. -20 and -15 F thresholds were used in previous reports as mid-winter hardiness thresholds for cold-hardy hybrids and European grapes respectively.

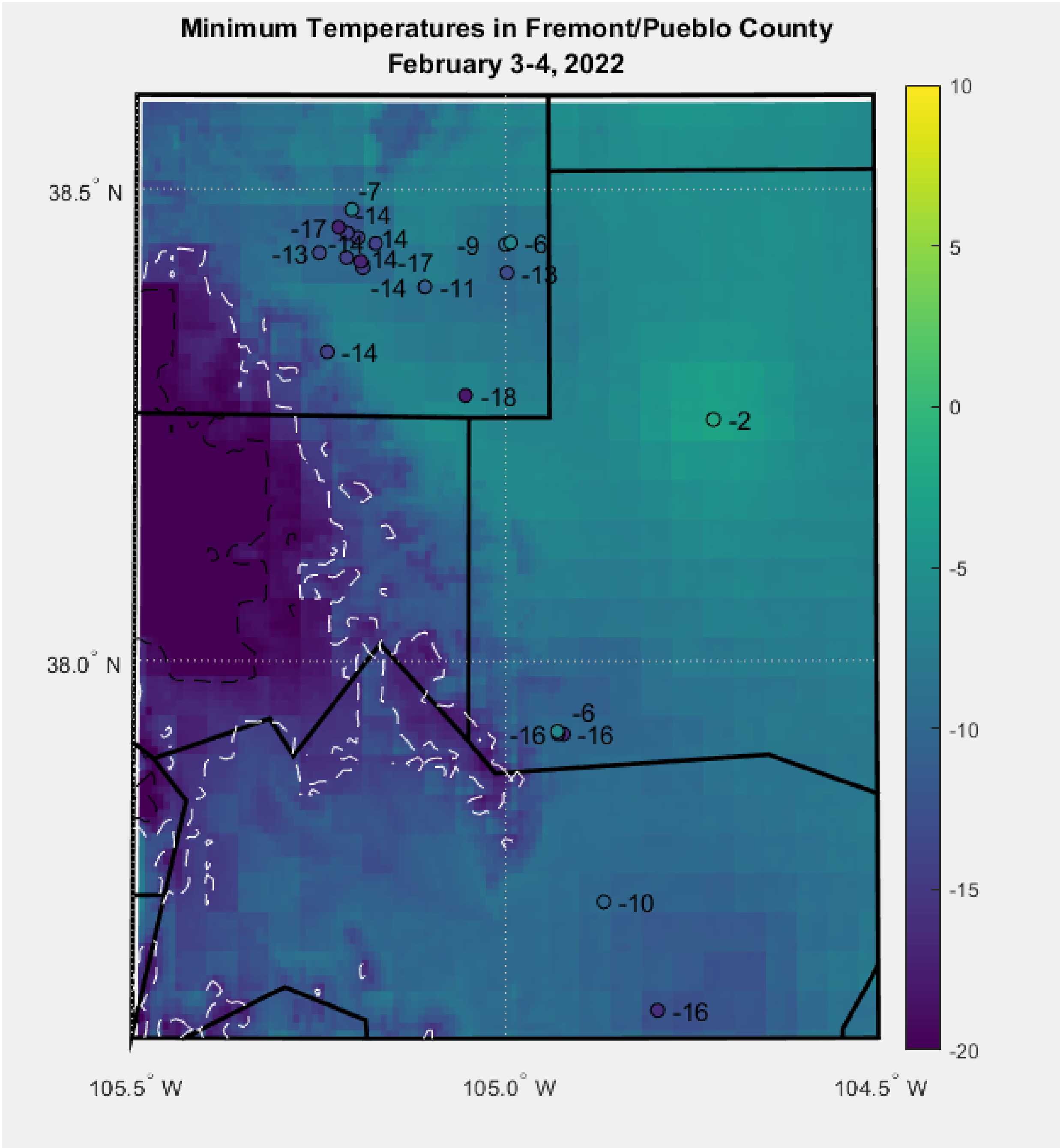

Fig. 9: Fremont, Huerfano, and Pueblo County minimum temperatures for February 3-4th (Fahrenheit). Gridded data from PRISM. Labeled circles represent observations from COOP stations, CoAgMET stations, and project-specific sites. Black, dashed line = -20 F contour. White, dashed line = -15 F contour. -20 and -15 F thresholds were used in previous reports as mid-winter hardiness thresholds for cold-hardy hybrids and European grapes respectively.

May 21-22: A strong cold front tracked down from Canada over the leeward side of the Colorado Rockies on Friday, May 20th (Fig. 10). This storm system brought unseasonably late snow to low elevations of eastern Colorado. The storm brought 9.5” of snowfall to Cañon City and was the latest snowfall on record for the area. Impacts from this system were primarily experienced east of the Continental Divide, though Grand Junction Walker Field recorded a low temperature of 29 F on May 21st, and frost damage was observed in several vineyards in the Grand Valley.

Every station in the Fremont, Huerfano, Pueblo County area recorded a freeze during this late snow event with hard freezes occurring in Rye and Oak Creek Grade (south of Cañon City). Similar to the February 3rd-4th event, PRISM suggests that the warmest spots during this event were east of the area of Cañon City (Fig. 11). Unlike February 3rd-4th, this gradient is not clear in observations locally.

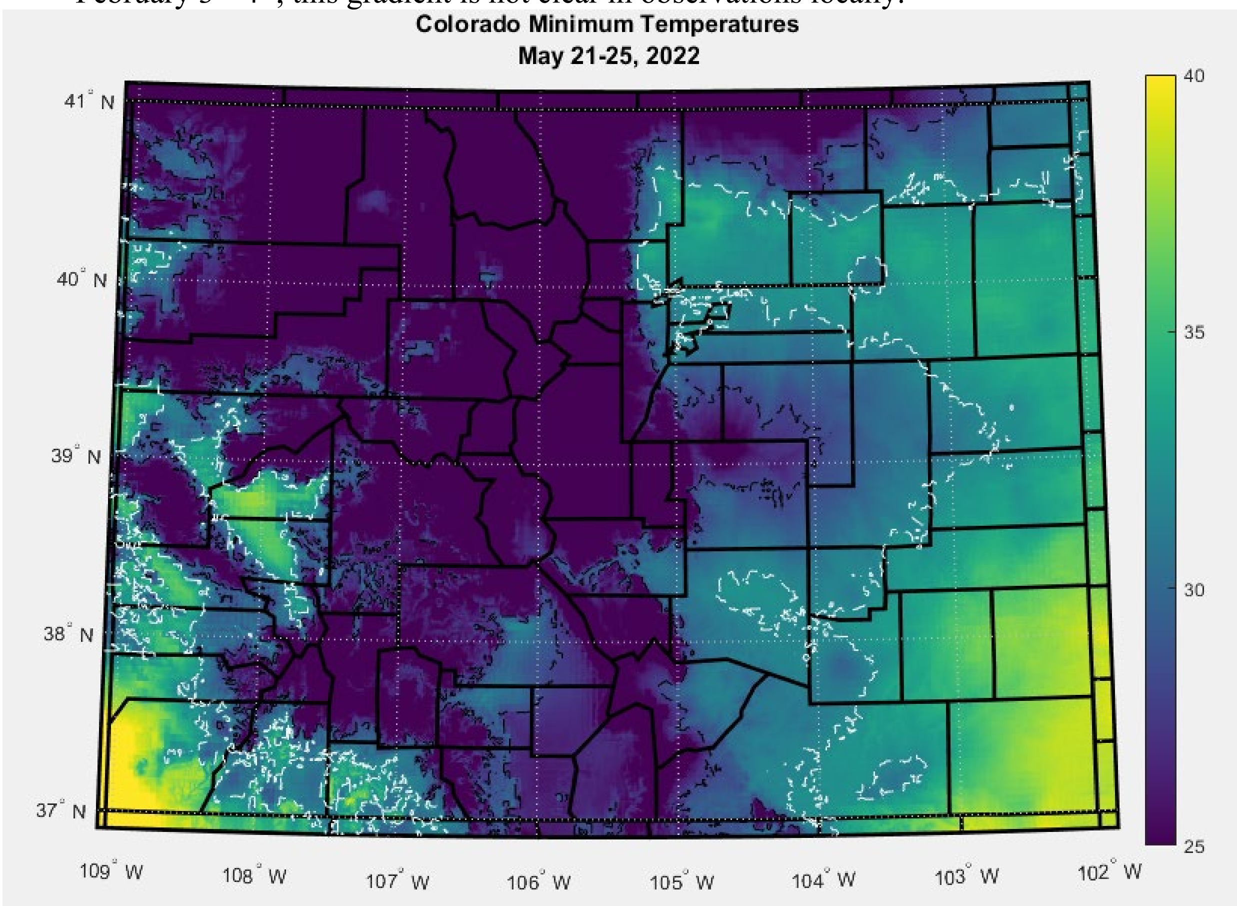

Fig. 10: Colorado PRISM minimum temperatures for May 21-25th (Fahrenheit). Black, dashed line = 28 F contour (hard freeze). White, dashed line = 32 F contour (freeze).

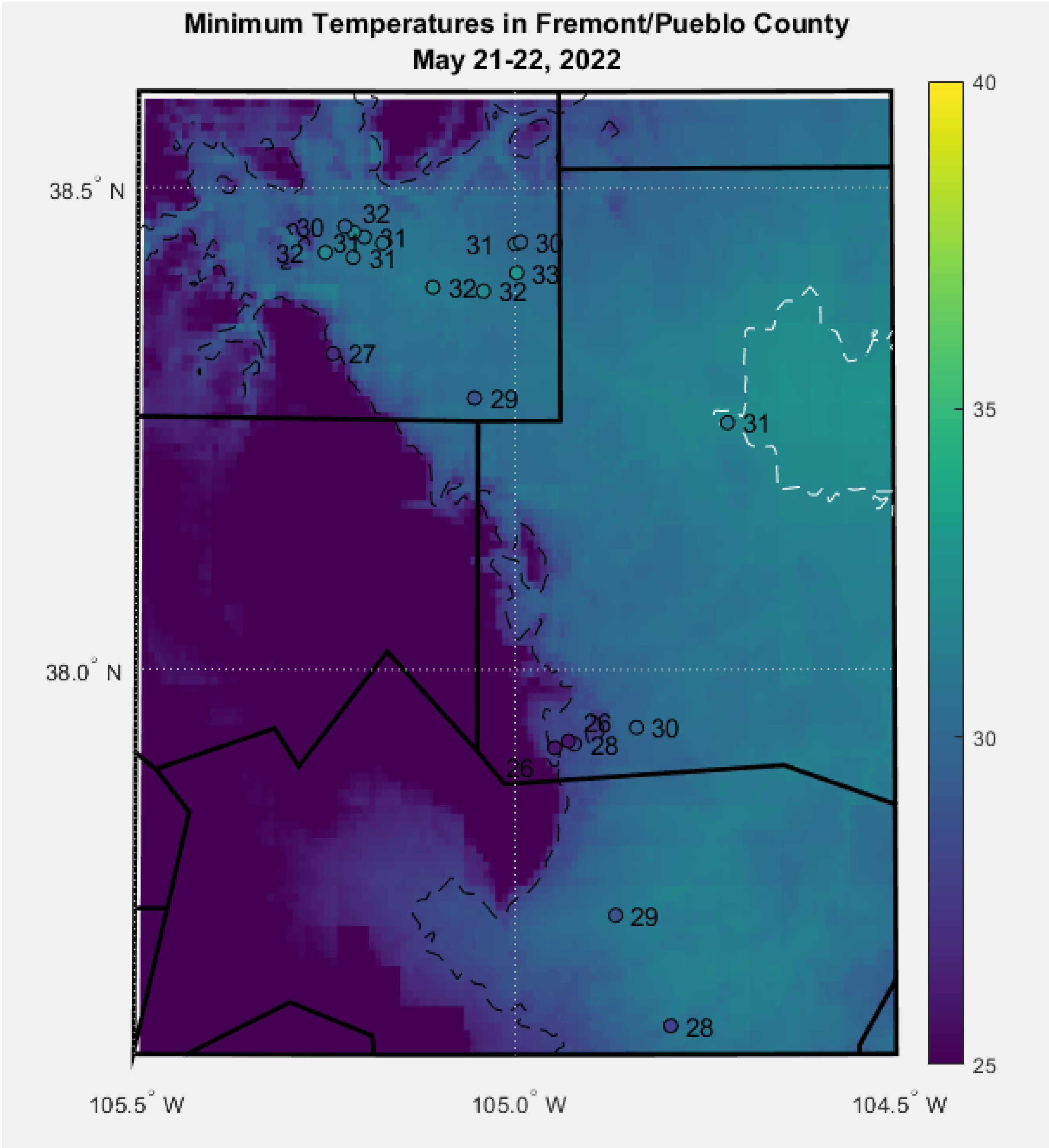

Fig. 11: Fremont, Huerfano, and Pueblo County minimum temperatures for May 21-22nd (Fahrenheit). Gridded data from PRISM. Labeled circles represent observations from COOP stations, CoAgMET stations, and project-specific sites. Black, dashed line = 28 F contour (hard freeze). White, dashed line = 32 F contour (freeze)

May 30-31: The last week of May, 2022 brought dry, cool air to western Colorado (Fig. 12). May 30th and 31st was not a freeze event for low elevations in eastern Colorado, or the Grand Valley, although freeze damage was observed in several vineyards. Temperatures did fall below freezing for much of Montezuma County, including Cortez, with a hard freeze in Mancos (Fig. 13). Much like events studied in previous years, areas to the north and west of Cortez experienced warmer nighttime conditions than the valley. The new CoAgMET sites, Canyon of the Ancients, and Lebanon, recorded lows of 33 and 31 F respectively.

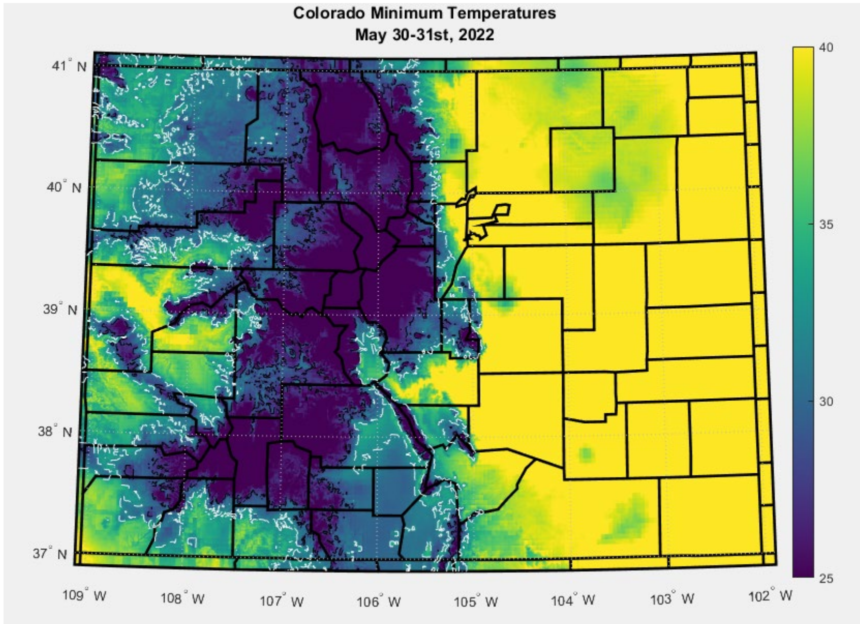

Fig. 12: Colorado PRISM minimum temperatures for May 30-31st (Fahrenheit). Black, dashed line = 28 F contour (hard freeze). White, dashed line = 32 F contour (freeze).

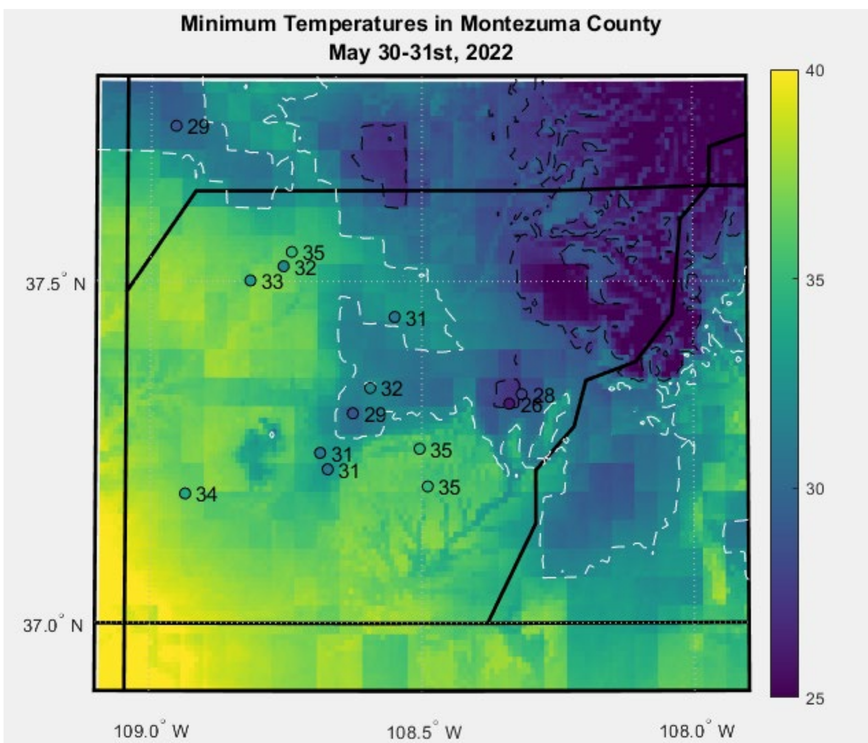

Fig. 13: Montezuma County minimum temperatures for May 30-31st (Fahrenheit). Gridded data from PRISM. Labeled circles represent observations from COOP stations and CoAgMET stations. Black, dashed line = 28 F contour (hard freeze). White, dashed line = 32 F contour (freeze).

Every year brings a unique set of weather patterns, and that usually includes some surprises. Based on thresholds for a killing freeze events used in previous years' reports, European grape cultivars would have withstood winter temperatures in 2022 across the Front Range and Eastern Plains, but not Cañon City. Figure 14 highlights the areas where European grape cultivars (red, -15 F winter threshold), and hardy hybrid cultivars (blue, -20 F winter threshold) would have survived the winter, and avoided hard freezes after bud break. The lowest wintertime temperature of -17 F in Cañon City was lower than any temperature recorded by Fort Collins, Boulder, Denver, Colorado Springs, and Pueblo COOP stations as well as numerous stations across the Eastern Plains.

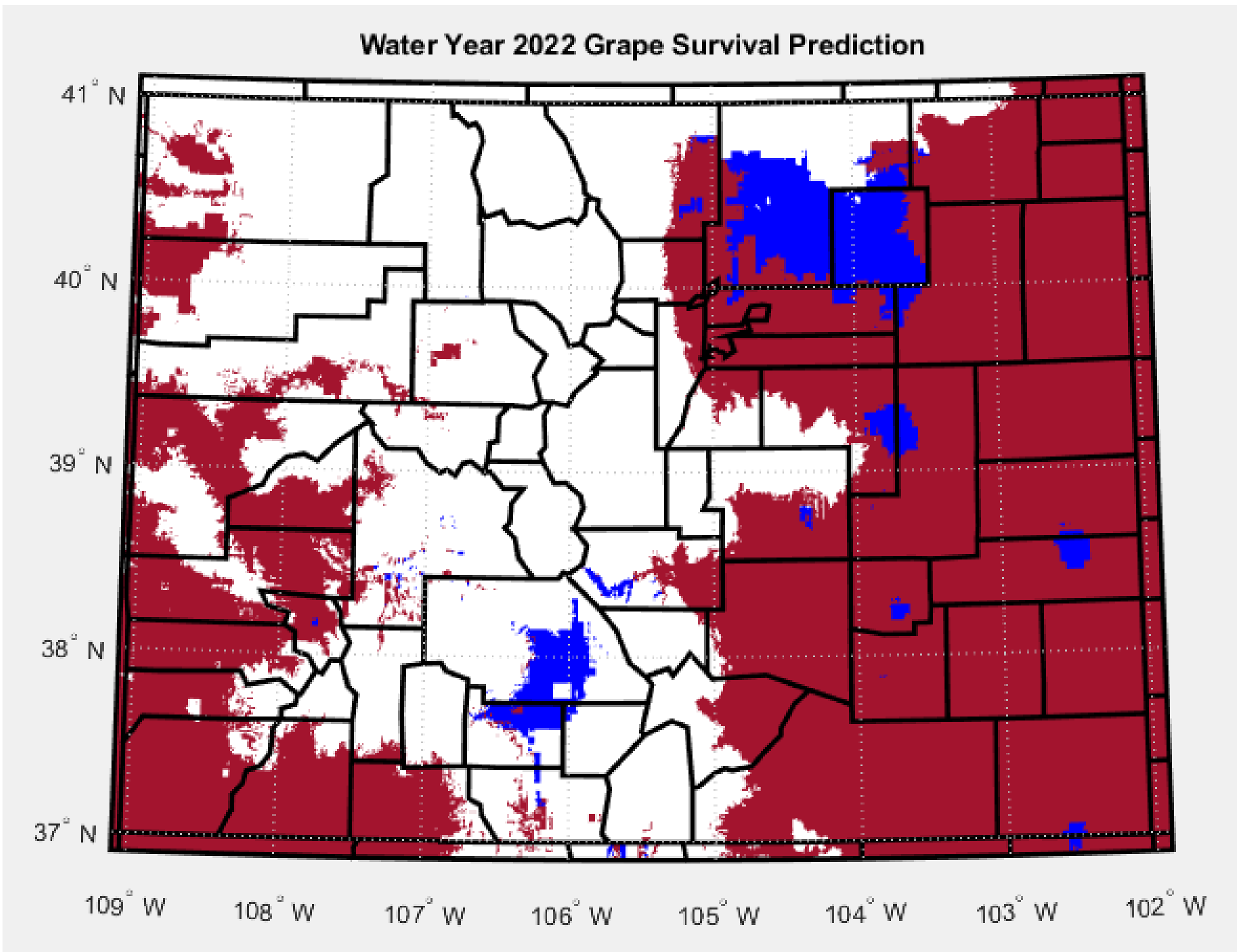

Fig. 14: Water Year 2022 grape freeze "survival predictions" based on the thresholds outlined below.

Hybrids only recommended (blue): In order to be contoured as an exploration opportunity for cold-hardy hybrids, a grid cell must avoid all of the following freeze conditions in at least 50 % of years:

- ✓ A hard spring freeze (28 F or lower) following bud break (estimated as May 15th)
- ✓ A fall freeze (32 F or lower) prior to harvest (estimated as September 30th)

- ✓ Rapid onset of seasonally-unprecedented cold air in fall (temperatures in October of less than 10 F where the previous seasonal minimum is at least 10 F higher, or temperatures of less than 0 F in November where the previous seasonal minimum is at least 10 F higher)
- ✓ Deep cold early in winter (below -15 F before January 1st)
- ✓ Extreme cold in mid-or-late winter (below -20 F after January 1st)

Exploration opportunities for European and hybrid grapes (red): In order to be contoured as an exploration opportunity for both European grapes and cold-hardy hybrids, a grid cell must avoid all of the following freeze conditions in at least 50 % of years:

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

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

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

[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.

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).

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 2021 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

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 have overwintered well. 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. The damage from the extreme cold temperature event in late October resulted in no or insufficient fruit on most cultivars for even small-scale wine making lots. A total of only 12 varietal wines were produced from all the cultivar trials. An additional 12 wines were produced from a Chambourcin crop load trial that was replicated at three sites. As of 30 June 2022, four wines have been bottled with the remaining wines still in carboys.

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 participated and presented in the (virtual) Eastern Viticulture and Enology Forum organized by Penn State and Cornell University.

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.

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 more than 20 years. Survey forms were sent out in early December 2021. All forms were sent electronically. By 30 June 2022 we had received 41 responses (representing 89 vineyard sites) totaling 434 acres. The results of the survey are:

- Approximately 80 % lower production compared to 2020
- 231 ton production reported
- 65 % of production is from cold-hardy, interspecific cultivars
- No surplus grapes
- Average yield of 0.5 ton/acre; down 1.9 ton/acre from 2020
- Lowest average yield per acre since 1991
- Average yield of *Vitis vinifera* cultivars was 0.19 ton/acre
- Average yield of cold-hardy, interspecific cultivars was 2.2 ton/acre
- Average price of $1,631/ton, about 3 % up on 2020
- Very few new plantings in 2021
- Vineyard area removed is larger than the area planted