

Annual Report

July 1, 2024 – June 30, 2025

Viticulture and Enology programs for the Colorado Wine Industry

Principal Investigators

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Collaborating Institutions

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

Summary

The majority of the work performed during the reporting period included seasonal vineyard tasks such as vine training, canopy management, crop thinning, harvest, preparing vineyards for dormant season, bud cold hardiness evaluations, data entry and analysis, and the annual Colorado Grape Grower Survey. Most of the vineyard work was performed by CSU staff at the Western Colorado Research Center (WCRC) as well as seasonal temporary staff.

Weather conditions in spring 2024 were the exact opposite compared to 2023. March and April 2024 were warmer than average, May cooler, and June again warmer. Timing of bud break was close to average and earlier than in 2023. Weather conditions in the Grand Valley were warmer than average from July to October. September 2024 was the third warmest September and October 2024 the warmest October since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964. The average daily maximum temperature during an early fall heat wave lasting from 26 September to 16 October was 84.3 °F which was 12 °F above average. This was the longest period on record of such a large deviation from average.

Vine development was close to average in 2024. First bloom of early cultivars was observed in the third week of May with veraison starting in the second week of July. The first cultivar to be harvested was Itasca on 30 July. Harvest was completed on 7 October, 16 days ahead of 2023. Averaged across all cultivars harvest was 8 days earlier than in 2023, ranging from 28 days earlier for Corot noir and 5 days later for Barbera. A killing frost didn't occur until 7 November, one month after the last harvest.

Data from the 2024 Colorado Grape Grower Survey indicate an average yield of 3.3 ton/acre. However, the results come from 400 acre of mature vineyards, of which 354 acre are in Mesa County. The actual average state-wide yield is lower as yields in all other counties are significantly less than in Mesa County. Nevertheless, the data indicate a decline of 0.9 ton/acre (20 %) compared to the 2023 season. Even with this drop in production there

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was once again a surplus of grapes. Survey respondents reported a total production of 1,169 ton with 166 ton (12.4 %) not harvested. This is a nearly 3-fold increase in the percentage of grapes not utilized. In response, we continue to see removals of mature vineyards especially in the Grand Valley and a change in the land use to other high value crops. Taking into account non-responses to the survey we estimate a total production in 2024 of 1,500-1,600 ton, and a utilized production of 1,300-1,400 ton.

There were no extreme low temperature events during the 2024/25 dormant season and no bud damage has been observed on any of the cultivars we monitor. While November's mean temperature of 38.5 °F was 2.3 °F below average December's mean temperature of 33.6 °F was 3.4 °F above average, making it the 9th warmest December in our records going back to 1964. There were four nights in January when the temperature dipped below 10 °F, with the lowest temperature of 4.4 °F recorded on 22 January 2025. Nevertheless, January's mean temperature of 39.4 °F was 0.5 °F above average. February 2025 was very warm with five daily maximum temperature records set in the first week, and a sixth record set on 25 February. The monthly mean temperature of 41.1 °F was 5.6 °F above the long-term average, making it the fifth warmest February on record. March and April also ended up with above average monthly mean temperatures. Very large temperature swings occurred on nearly a weekly basis from mid March to late April. Days with near record high temperatures were quickly followed by days with high temperatures that were near the lowest ever recorded. The official last frost at the Orchard Mesa site occurred on 20 April 2025. The pattern of large temperature swings continued in May but without late freeze events. Very warm temperatures towards the end of the month raised the average monthly temperature for May to 65.4 °F. June started cool and wet with 1.42" of precipitation in the first week – more than the total for January to May.

The 2024/25 dormant season was extremely dry. While 1.07" of precipitation were recorded after the killing frost up until 31 December 2024, the new year started with only a trace of precipitation in January and about 0.25" per month for February to April. Such low precipitation led to dry to very dry soil conditions at the beginning of the growing season. Dry soil conditions cause erratic, prolonged and irregular bud break both between vines and within the same vine. Although we applied irrigation as soon as clean water was available in our irrigation canal, we still had a very extended bud break period. For example, the first Chardonnay buds opened in mid April but complete bud break didn't occur until the second week of May. We are aware of commercial vineyards with severe vine damage, including trunks splitting and requiring retraining from the ground. We assume that this severe damage is the result of a delayed start of irrigation in spring.

Although temperatures were warmer than average from February to April, bud break in 2025 was near average. The last spring frost on 20 April did not cause any damage as it occurred prior to bud break of most cultivars. Flowering started on Marquette on 12 May, which was one week earlier than in 2024. Marquette was quickly followed by Brianna, Itasca, and La Crescent. Growing degree accumulation was 122 degree days above average by the end of May. The warmer temperatures resulted in quick canopy growth with some cultivars having shoots reaching the top canopy wire in early June. However, a severe hailstorm on 6 June resulted in >90 % loss of leaf area with most of the remaining leaf area consisting of partial leaves. Many developing clusters or inflorescences (depending on cultivar) were knocked off by the hail and most clusters/inflorescences remaining on the shoots either had few remaining berries or flowers, or many split berries. Consequently, the

decision was made to drop all remaining clusters and inflorescences to aid the vines in their recovery.

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Growing conditions, 2024 season

Timing of bud break in the Grand Valley was near average. Warmer than average temperatures in March and April were followed by a cool May. Monthly mean temperatures were above average for June through October. The mean monthly temperature of 71.4 °F for September was the third-highest and 61.2 °F for October the highest ever recorded at the Western Colorado Research Center – Orchard Mesa. Cumulative Growing Degree Day (GDD) accumulation started slow due to a cool May but was near record values by late July. By the time of the killing frost on 7 November GDD accumulation had reached a record value of 4,172, which is 465 GDD higher than the long-term average.

Precipitation records from the Western Colorado Research Center – Orchard Mesa (WCRC-OM) show above average values from 1 May to 30 October. More than 40 % (2.64”) of the seasonal precipitation was received during six days at the end of June into early July. May, July, and September had below average precipitation, October was near average, and June and August well above average. Total seasonal precipitation was 5.97” compared to the long-term (1962-2016) average of 4.92”.

Dormant season 2024-2025

A killing frost occurred at WCRC-OM on the morning of 7 November 2024. Monthly mean temperatures were below average in November 2024, average in January 2025, and above average in December 2024 and February to April 2025. The lowest dormant season temperature of 4.4 °F was recorded on 22 January 2025. No bud cold damage has been observed throughout the dormant season on any of the cultivars we monitor.

The 2024/25 dormant season was rather dry. There were few snowfall events with only 0.7” received compared to the long-term average of 13.07”. While November 2024 had above-average precipitation of 1.24” there were only 0.16” recorded in December 2024. January 2025 was especially dry with only a trace recorded at WCRC-OM, the lowest January total in our recording period (since 1964). Precipitation of just over 0.25” per month for February, March, and April also was well below average. Only 0.82” of precipitation was measured during the first four month of 2025. The lack of snow cover on the soil combined with the very low precipitation resulted in very dry soil water status at the start of the 2025 growing season.

Growing conditions, early part of 2025 season

Temperatures in April varied from well below to well above average. The first week was cool but was followed by a 10-day period of well above temperatures, including a daily record high of 84.9 °F on 12 April. In contrast, the high of 46.1 °F on 18 April was the third lowest recorded. This swing from well above to well below temperatures continued on roughly a weekly basis through the later part of April and throughout May. Overall, April and May ended with above average temperatures. The first week in June was cool and cloudy and brought a couple of heavy rainfall events. On 6 June a severe hailstorm crossed the Grand Valley in a NW to SE direction causing widespread damage from Fruita in the West to just East of 32 Rd in the East. This was the most severe hailstorm to hit WCRC-OM in more than 25 years resulting in near 100 % crop loss to all of the crops (grapes, tree fruit, vegetables).

Although temperatures were warmer than average from February to April, bud break was near average. The last spring frost on 20 April did not cause any damage as it occurred prior to bud break of most cultivars. Flowering started on Marquette on 12 May, which was one week earlier than in 2024. Marquette was quickly followed by

Brianna, Itasca, and La Crescent. Growing degree accumulation was 122 degree days above average by the end of May. The warmer temperatures resulted in quick canopy growth with some cultivars having shoots reaching the top canopy wire in early June. However, a severe hailstorm on 6 June resulted in >90 % loss of leaf area with most of the remaining leaf area consisting of partial leaves.

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 (WCRC-RM) 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-OM 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. A new cultivar trial block was started at WCRC-OM in April 2022 with the planting of Cabernet Volos, Fleurtaï, and Soreli. This block was extended in April 2024 to include four additional cultivars: Clarion, Merlot Kanthus, Sauvignon Kretos, and Sauvignon Rytos. A duplicate trial of the seven cultivars planted at WCRC-OM between 2022 and 2024 was established at WRCR-RM in May 2024.

Yields in our cultivar trials were down compared to 2023 due damage from two late spring frosts and a severe hail storm in late June. The average yield of *Vitis vinifera* cultivars in 2024 at WCRC-OM was 2.3 ton/acre compared to 3.3 ton/acre in 2023. Yields of cold-hardy, interspecific cultivars were 3.5 ton/acre, down 0.4 ton/acre on 2023.

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

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 WCRC-RM, and 25 cultivars at WCRC-OM between 2008 and 2012. At WCRC-OM, 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 WCRC-RM, four cultivars produced a crop although Aravelle yielded only 0.03 ton/acre (Table 1). Table 2 shows fruit composition at harvest. No wines were produced. This trial is now completed and vines were removed prior to the start of the 2025 growing season.

Note that the breeding line NY 81.0315.17, planted at Rogers Mesa in 2008, was named Aravelle by Cornell University in early 2023. Aravelle is a cross of Cayuga White and Riesling.

Table 1: Harvest dates and yield information for 4 (out of 10) grape cultivars planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Cultivar	Harvest date 2023	Yield (ton/acre)
Aravelle (NY 81.0315.17)	1 October	0.03
Aromella	19 September	1.79
Marquette	18 September	0.40
MN 1200	10 September	1.08

Table 2: Fruit composition at harvest in 2024 for 3 mature grape cultivars planted at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Cultivar	Soluble solids (Brix)	pH	Titrateable acidity (g l ⁻¹)	Tartaric acid (g l ⁻¹)	Malic acid (g l ⁻¹)	Alpha amino nitrogen (mg l ⁻¹)	Ammonia (mg l ⁻¹)
Aromella	21.5	3.03	12.5	7.3	7.4	111	57
Marquette	29.1	3.11	10.6	6.4	6.0	155	93
MN 1200	26.5	3.15	9.2	9.0	4.0	106	86

At WCRC-OM, all mature cultivars produced a crop. Harvest started with Itasca on 30 July 2024 and ended with Barbera, Cinsaut, and Mourvedre on 2 October 2024 (Table 3). Earlier bud break and much higher growing degree accumulations compared to the previous year resulted in an earlier harvest. A lighter crop due to damage from two late spring frosts in early May and from a severe hail storm in late June likely contributed to the advancement of fruit ripening in 2024. On average, harvest date in 2024 was six days earlier than in 2023. Averaged across all cultivars, yields were down 24 % compared to the 2023 season. Only Itasca (+ 76 %) and Marsanne (+10 %) had higher yields in 2024 compared to 2023; all other cultivars had lower yields. A summary of fruit composition is presented in Table 4. The 2024 data confirmed what we reported last year: Zweigelt fruit has very low malic acid but high tartaric acid concentration. In the last 10 vintages Zweigelt had the lowest (7 times) or second lowest (3 times) malic acid concentration of all cultivars in this trial while having the highest concentration of tartaric acid in seven vintages. Ten varietal wines were produced in 2024 using micro-vinification techniques.

Table 3: Harvest dates and yield information for 18 grape cultivars planted in 2008 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Harvest date 2024	Yield per vine (lb)	Yield (ton/acre) ¹
Albarino	5 September	7.50	3.91
Barbera	2 October	7.57	2.47
Cabernet Dorsa ²	5 September	4.65	1.79
Cabernet Sauvignon	25 September	3.83	1.91
Chambourcin ²	16 September	9.77	3.99
Cinsault	2 October	9.54	3.25

Table 3 continued

Cultivar	Harvest date 2024	Yield per vine (lb)	Yield (ton/acre) ¹
Durif	25 September	5.16	2.67
Itasca ³	30 July	4.02	2.01
Malvasia bianca	5 September	3.23	1.32
Marquette ²	9 August	8.51	3.09
Marsanne	10 September	8.04	2.63
Merlot	5 September	2.56	1.16
Mourvedre	2 October	4.04	1.98
Roussanne	10 September	9.15	2.70
Souzao	25 September	4.79	1.96
Touriga national	25 September	3.76	1.13
Verdelho	5 September	8.50	3.24
Zweigelt ²	9 September	3.65	1.90

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.

² Planted in 2011 and 2012.

³ Planted in 2017, 2018, and 2019.

Table 4: Fruit composition at harvest in 2024 for 18 mature grape cultivars planted at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Soluble solids (Brix)	pH	Titrateable acidity (g l ⁻¹)	Tartaric acid (g l ⁻¹)	Malic acid (g l ⁻¹)	Alpha amino nitrogen (mg l ⁻¹)	Ammonia (mg l ⁻¹)
Albarino	25.1	3.34	7.59	7.50	2.97	114	95
Barbera	29.3	3.49	6.73	6.70	2.86	174	123
Cab. Dorsa ¹	26.3	3.75	5.90	6.62	3.25	146	91
Cab. Sauvignon	26.7	3.42	6.63	7.23	1.63	95	97
Chambourcin ¹	25.8	3.16	9.04	7.55	3.26	149	104
Cinsault	27.2	3.60	5.20	5.05	0.70	214	154
Durif	25.5	3.28	7.76	7.87	1.91	116	86
Itasca ²	24.2	3.28	11.80	7.60	7.39	171	85
Malvasia bianca	24.1	3.43	6.52	7.02	2.61	87	83
Marquette ¹	28.1	3.20	10.34	4.06	5.36	354	142
Marsanne	21.3	3.43	6.58	5.97	2.59	93	67
Merlot	24.7	3.40	6.52	7.36	1.65	68	86
Mourvedre	27.2	3.50	6.40	7.01	1.40	139	93
Roussanne	24.2	3.34	7.65	6.58	2.69	116	87
Souzao	26.0	3.37	7.32	8.83	1.54	110	104
Touriga national	25.4	3.53	6.54	7.33	1.48	141	99
Verdelho	26.5	3.29	7.56	7.51	2.72	155	124
Zweigelt ¹	26.5	3.42	6.68	8.12	0.57	127	103

¹Planted in 2011 and 2012.

²Planted in 2017, 2018, and 2019.

- New disease tolerant and cold-hardy cultivars (Caspari, Bertin, Braddy, Gardner, and Gautam)

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 at WCRC-OM. 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 Fleurtaï (Tocai Friulano x Kozma 20-3) and Soreli (Tocai Friulano x Kozma 20-3), both grafted to 101-14. Although these cultivars were not planted within the same block where the NE-2220 trial is located, the same experimental protocols are being followed.

In April 2024, this trial was expanded by the addition of four cultivars. The cultivar Clarion is a recent release from the University of Minnesota. The other three cultivars are recent releases from the University of Udine and Institute of Applied Genetics, Udine, Italy. The cultivars are Merlot Kanthus (Merlot x Kozma 20-3), Sauvignon Kretos (Sauvignon blanc x Kozma 20-3), and Sauvignon Rytos (Sauvignon blanc x Bianca), all grafted to 101-14.

In May 2024, the seven cultivars mentioned above were planted at the WCRC-RM site, providing a duplicate planting in a cooler growing region.

The three cultivars planted in 2022 at WCRC-OM produced their first crop in 2024 (Table 5). The three cultivars sustained the highest hail damage of any of the cultivars grown at our site due to the fact that the 3-year old vines had a very open canopy and that they are planted in the western outside row in one of our blocks. The hail storm that hit in the afternoon of 27 June 2024 had very strong westerly winds and caused massive damage to exposed clusters on the West side of the canopy. Almost all west facing berries were shredded while there was only minor damage to berries on clusters on the East side of the canopy. We estimated a crop loss due to the hail storm of 25 %.

Harvest timing was early for all three cultivars, even Cabernet Volos. With a comparable crop between Cabernet Volos and Cabernet Sauvignon grown in a different block at the Orchard Mesa site (1.77 vs 1.91 ton/acre), harvest of Cabernet Volos was 20 days earlier.

Table 5: Harvest dates and yield information for three disease tolerant grape cultivars planted in 2022 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Harvest date 2024	Yield per vine (lb)	Yield (ton/acre) ¹
Cabernet Volos	5 September	3.82	1.77
Fleurtaï	19 August	3.73	1.73
Soreli	30 August	5.44	2.52

Cabernet Volos ripened very quickly and earlier than expected. By the time of harvest berries had started to shrivel and at 28.5 Brix the concentration of soluble solids was higher than desired (Table 6). Fruit from all three cultivars had rather low nitrogen concentrations. Wines were produced in 2024 from all three cultivars using micro-vinification techniques. For Soreli only, two wines were produced using two different yeast strains (58W3 or Vin13).

Table 6: Fruit composition at harvest in 2024 for three disease tolerant grape cultivars planted in 2022 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Soluble solids (Brix)	pH	Titrateable acidity (g l ⁻¹)	Tartaric acid (g l ⁻¹)	Malic acid (g l ⁻¹)	Alpha amino nitrogen (mg l ⁻¹)	Ammonia (mg l ⁻¹)
Cabernet Volos	28.5	3.64	6.20	7.88	2.64	76	62
Fleurtaï	21.4	3.61	5.74	6.48	2.16	110	52
Soreli	23.0	3.38	7.09	7.19	1.89	110	84

- Cultivar evaluation for Front Range locations, Fort Collins (Caspari, Oliver, Sayyadzadeh, and grower cooperater)

A new vineyard was established on a grower cooperater 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. There was some cold damage during the 2023/24 dormant season but vines grew better than in the previous years. While vine vigor at this site is improving it continues to be too weak. In the absence of cold damage the low vigor is the main reason for low yields (<0.1 ton/acre for all cultivars).

- Cold-hardy, resistant cultivars for the Grand Valley (Caspari, Bertin, Gardner, Gautam, and grower cooperater)

A new replicated cultivar trial was established in 2014 on a grower cooperater site near Clifton to identify grape cultivars that can be grown successfully in cold Grand Valley sites. The 2024 season was the final year of observation at this site.

There was again no cold temperature damage during the 2023/24 dormant season. The average yield of 2.1 ton/acre was down 35 % compared to 2023 (Table 7). This relatively low yield was due to several factors. First, there was significant damage from a late spring frost on 8 May 2024. Further, the vineyard was hit by a hail storm on 27 June 2024 which resulted in an estimated average crop loss of 14 %, ranging from 5 % for Vignoles to 26 % for Cayuga White. And third, crop losses from wildlife damage (presumably ground squirrels) have increased substantially over the last few years at this site, resulting in about

60 % crop loss with Cayuga White and Marquette, and 100 % crop loss with Brianna. On average, harvest was earlier by 13 days compared to 2023. A summary of fruit composition is presented in Table 8. No wines were produced from this trial.

Table 7: Harvest dates in 2024 and yield information for twelve grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	Harvest date 2024	Yield (ton/acre) ¹
Arandell	12 September	1.01
Aromella	30 August	3.73
Brianna	No harvest	0.00 ²
Cayuga White	11 September	1.69
Chambourcin	7 October	2.59
Corot noir	11 September	3.42
La Crescent	16 August	3.40
Marquette	16 August	0.76
Noiret	27 September	4.08
St Vincent	7 October	1.53
Traminette	9 September	1.76
Vignoles	9 September	1.30

¹Yield calculation based on number of vines initially planted. Vine survival is >90 % for all cultivars except Chambourcin (75 %), Traminette (42 %) and St Vincent (29 %).

² 100 % crop loss due to wildlife damage

Table 8: Fruit composition at harvest in 2024 for twelve grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	Soluble solids (Brix)	pH	Titratable acidity (g l ⁻¹)	Tartaric acid (g l ⁻¹)	Malic acid (g l ⁻¹)	Alpha amino nitrogen (mg l ⁻¹)	Ammonia (mg l ⁻¹)
Arandell	22.7	3.73	6.0	5.3	3.0	219	81
Aromella	23.8	3.28	9.0	6.1	3.4	257	119
Brianna	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cayuga White	21.5	3.29	6.8	6.7	1.0	208	98
Chambourcin	27.7	3.14	7.0	5.5	0.5	208	118
Corot noir	22.5	3.59	5.4	5.6	0.7	237	108
La Crescent	25.8	3.22	12.2	5.5	8.0	242	82
Marquette	25.0	3.14	13.8	6.2	8.5	408	161
Noiret	21.6	3.55	6.4	7.0	2.2	217	116
St Vincent	24.9	3.19	7.5	7.3	1.5	167	105
Traminette	25.2	3.32	7.1	7.8	0.9	177	111
Vignoles	29.6	3.20	9.4	5.8	3.9	144	92

The cold-hardy cultivar experiment was started in 2014 and the 2024 season was the ninth and final harvest for this trial. The main results from this study are as follows. There were large year-to-year fluctuations in yield for all cultivars (Fig. 1). Following the extreme

cold event in late October 2020 all cultivars produced a crop in 2021, albeit less than 3 ton/acre for all cultivars except Aromella.

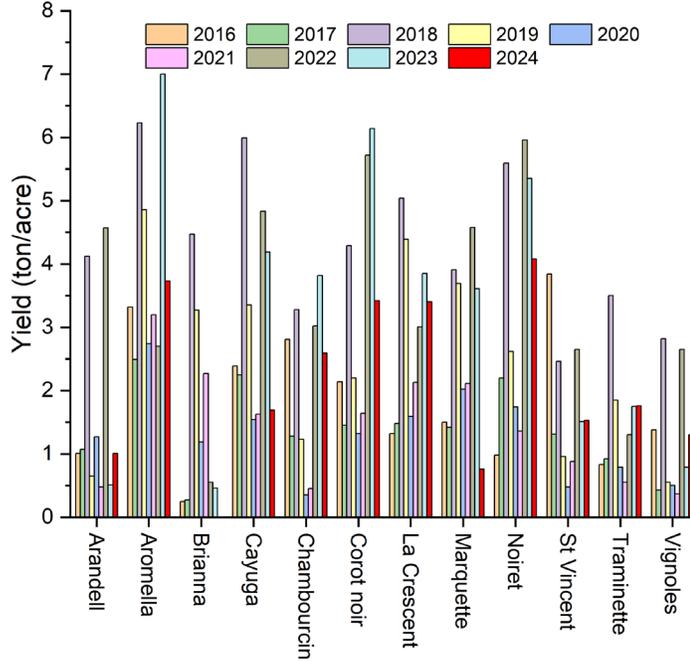


Fig. 1: Yield per acre for the period 2016 to 2024 of twelve cold-hardy cultivars planted in 2014 in a vineyard near Clifton, Colorado.

Aromella was the only cultivar with a long-term average yield of 4 ton/acre (Fig. 2). Cayuga White, Corot noir, and Noiret had average yields of 3.1 to 3.3 ton/acre. The average yield of Chambourcin, Marquette and La Crescent was between 2.1 to 2.9 ton/acre while all remaining cultivars yielded less than 2 ton/acre.

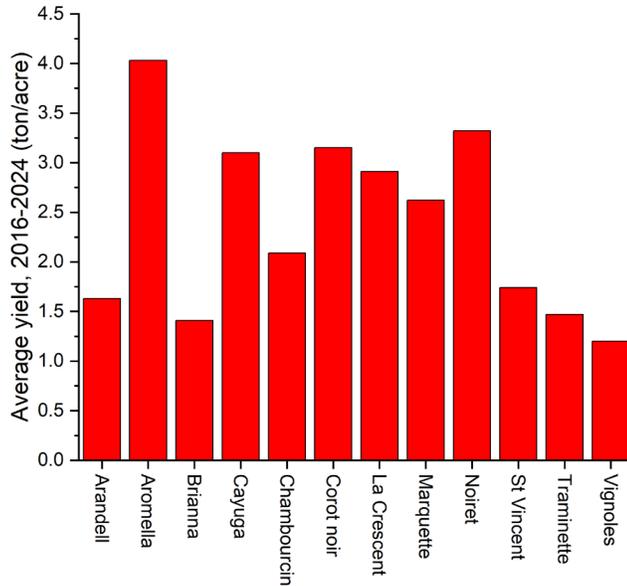


Fig. 2: Average yield between 2016 to 2024 of twelve cold-hardy cultivars planted in 2014 in a vineyard near Clifton, Colorado.

In comparison, the average yield for *V. vinifera* cultivars in Mesa County between 2016 and 2024 was 3.27 ton/acre and cold-hardy interspecific cultivars averaged 3.34 ton/acre. During the first five years of this period, *V. vinifera* cultivars had higher average yields than interspecific cultivars (3.75 versus 2.79 ton/acre) whereas the opposite was true during the last four years (2.69 versus 4.04 ton/acre). Lower yields of interspecific cultivars from 2016 to 2020 are at least in part explained by the younger age of the vines as most Mesa County vineyards with cold-hardy interspecific cultivars were planted in the past ten years.

One unexpected observation at this site was a very high percentage of vine losses with St Vincent. St Vincent was the cultivar with the best establishment in years 1 and 2. However, at the end of the 2024 season 81 % of the vines planted in 2014 were dead. High vine mortality with St Vincent has also been reported from several commercial vineyards in the Grand Valley. The reason(s) for the high vine mortality has not been determined.

The second highest vine mortality with 58 % was for Traminette followed by 21 % for Chambourcin. It should be noted that there were some unexplained vine losses with Traminette. 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. There was no vine mortality with Corot noir, La Crescent, Marquette, and Noiret, and 4 % for all remaining cultivars.

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 inter-specific 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 inter-specific as well as *Vitis vinifera* cultivars. More vineyards infested with phylloxera were found in further surveys in 2017, 2018, and 2019. At the end of the survey period there were 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. At the time phylloxera was discovered more than 90 % of these vineyards were planted with own-rooted vines of European cultivars, making them susceptible to phylloxera damage. Since then the percentage of vineyards with own-rooted *V. vinifera* vines has declined but still exceeds 50 %. 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 phytosanitary 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 interspecific cultivars) and then replanting with susceptible cultivars grafted to tolerant rootstocks or with tolerant interspecific 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 WCRC-OM in 1992/93. The second, planted in 2009 also at WCRC-OM, used 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.

Low temperatures can kill vine trunks down to the soil or snow line. When using own-rooted vines suckers originating from below or at soil level can be used to retrain damaged vines. When using grafted vines new shoots used for retraining need to come from the scion part, i.e. from the part above the graft union. If low temperatures kill the graft union the whole vine needs to be replaced. In regions where the graft union might get damaged by low temperatures the graft union has to be protected. The standard method for protecting the graft union is to hill up soil in fall. 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. In a second phylloxera-related study we are investigating alternative methods to the annual hilling and uncovering to protect the graft union from cold temperature injury.

- 2017 Rootstock trial with Cabernet Sauvignon (Caspari, Bertin, Gardner, Gautam, 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. Graft unions are protected by hilling over with soil in fall and uncovering the following spring.

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.

Vine assessment in spring 2019 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 were mistakenly harvested by a picking crew after the early freeze event on 10 October 2019.

Seven more vines were lost during the 2019/20 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 had no missing vines: 1616C, 3309, and 101-14. The highest percentage of missing vines was 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.

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

There was no bud damage and no vine losses during the 2022/23 dormant season. Yields in 2023 averaged 2.16 ton/acre, ranging from 1.44 ton/acre with 140Ru to 2.90 ton/acre with SO4.

While there was again no bud damage eleven vines were lost during the 2023/24 dormant season. Vines were dormant pruned in February 2024. Except for some shoot and fruit thinning most of the seasonal vineyard work was performed by the cooperating grower. Fruit was harvested on 30 Sep 2024. Yields were reduced through a combination of late spring frost and hail (Table 9). Vines grafted to 1616C, Riparia Gloire, and SO4 had both the highest yield per cropping vine and yield per acre. (Table 9). Vines on 140Ru had the lowest yield per cropping vine and per acre followed by vines grafted to 1103P. Vines on rootstock 140 Ru had the lowest survival rate of 61 %. All other rootstocks have survival rates above 80 %.

Table 9: Effect of rootstock on vine survival after eight years and yield in 2024 of Cabernet Sauvignon growing in a commercial vineyard in the western part of Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield per cropping vine (lb)	Yield (ton/acre) ¹
110R	96	3.19	1.39
140Ru	61	0.80	0.17
1103P	96	1.51	0.63
1616C	88	5.04	2.35
101-14	96	3.15	1.32
3309	100	3.85	1.68
5C	83	3.18	1.27
Riparia Gloire	87	6.07	2.21
Salt Creek	96	2.48	1.10
Schwarzmann	88	3.55	1.48
SO4	87	4.66	1.82

¹Yield calculation based on number of vines initially planted.

Fruit composition of Cabernet Sauvignon at harvest was very similar irrespective of the rootstock used (Table 10). Berry nitrogen levels (α amino nitrogen and ammonia) were rather high resulting in Yeast Assimilable Nitrogen (YAN) levels of 347 to 484 mg l⁻¹.

Table 10: Effect of rootstock on fruit composition at harvest in 2024 of Cabernet Sauvignon growing in a commercial vineyard in the western part of Orchard Mesa near Grand Junction, CO.

Rootstock	Soluble solids (Brix)	pH	Titrateable 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	26.6	3.62	6.4	7.0	2.7	202	176
140Ru	26.0	3.69	6.2	6.7	3.0	251	196
1103P	25.7	3.72	6.4	7.1	3.5	284	216
1616C	26.2	3.72	6.0	6.9	3.1	266	200
101-14	25.5	3.65	6.3	6.9	3.1	246	196
3309	26.4	3.59	6.5	7.2	2.7	215	183
5C	25.7	3.64	6.6	6.9	3.4	288	220
Riparia Gloire	26.2	3.66	6.2	6.9	2.7	247	204
Salt Creek	25.9	3.71	5.8	6.4	2.6	295	224
Schwarzmann	26.7	3.74	5.9	6.8	2.9	272	208
SO4	26.1	3.66	6.5	7.0	3.3	291	236

- 2018 Rootstock trial with Cabernet Sauvignon (Caspari, Bertin, Gardner, Gautam, and grower cooperater)

A new rootstock trial with Cabernet Sauvignon (clone 33) grafted to 11 different rootstocks was established in May/June 2018 on a grower cooperater'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. Row x vine spacing is 8' x 5'. 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 were 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 54 % with Riparia Gloire. Due to labor shortages we were unable to harvest this trial in 2022 and the fruit was harvested by the grower cooperater.

Although there were no extreme low temperatures during the 2022/23 dormant season, four vines – all 2021 replants – did not resume growth in the spring of 2023. On the other hand, several vines that were presumed to be dead in 2022 started regrowing from buds right above the graft union in the spring of 2023. At harvest time in 2023 there were 212 vines alive (80 %). Vine survival ranged from 58 % with rootstocks Riparia Gloire and 101-14 to 100 % for 1616C.

Only 39 out of 66 entries (6 replications of 11 rootstocks) produced a crop in 2023. The average yield across all rootstocks in 2023 was 1.73 ton/acre. Yields ranged from 0.46 ton/acre with rootstock 3309 to 2.36 ton/acre with rootstock Schwarzmann.

Three more vines died during the 2023/24 dormant season. At harvest in 2024 it was also discovered that some of the vines grafted to 1103P were not Cabernet Sauvignon but appear to be a seedless table grape cultivar. Vine survival is highest with 1616C (100 %) and lowest at 54 % with 1103P and Riparia Gloire (Table 13).

Yields in 2024 ranged from 1.07 ton/acre with rootstock 1103P to 5.03 ton/acre with 1616C (Table 13). Four rootstocks (1616C, SO4, 5C, and Schwarzmann) produced crops greater than 4 ton/acre. Vines grafted to 110R and 140Ru yielded slightly over 3 ton/acre with the remaining rootstock entries except 1103P producing between 2.4 and 2.9 ton/acre.

Table 13: Effect of rootstock on vine survival after seven years and yield in 2024 of Cabernet Sauvignon growing in a commercial vineyard in the central part of Orchard Mesa near Palisade, CO.

Rootstock	Vine survival (%)	Yield per cropping vine (lb)	Yield (ton/acre) ¹
110R	79	8.87	3.35
140Ru	83	7.33	3.14
1103P	46	7.61	1.07
1616C	100	9.69	5.03
101-14	58	8.10	2.44
3309	71	6.36	2.61
5C	88	10.45	4.85
Riparia Gloire	54	9.69	2.75
Salt Creek	67	7.85	2.87
Schwarzmann	79	11.06	4.56
SO4	96	9.88	4.85

¹Yield calculation based on number of vines initially planted.

Differences in fruit composition of Cabernet Sauvignon due to rootstock were much smaller in 2024 compared to the 2023 season (Table 14). The main difference between years was an earlier harvest in 2024 at a mean soluble solids concentration of 23.8 Brix compared to 27.3 Brix in 2023. Similar to the results from 2023, titratable acidity and the concentration of malic acid was highest with 1103P. Yeast Assimilable Nitrogen concentrations were

lower than in the 2017 companion study (see above) but still high at a mean concentration of 368 mg/l (range 307 to 435 mg l⁻¹).

Table 14: Effect of rootstock on fruit composition at harvest in 2024 of Cabernet Sauvignon growing in a commercial vineyard in the central part of Orchard Mesa near Palisade, CO.

Rootstock	Soluble solids (Brix)	pH	Titrateable 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	24.2	3.51	7.0	6.6	3.7	187	179
140Ru	24.3	3.64	6.9	6.5	4.3	208	179
1103P	23.7	3.64	7.6	6.7	5.6	257	217
1616C	23.3	3.47	7.0	6.1	3.6	179	156
101-14	24.1	3.61	6.7	6.1	4.2	191	176
3309	23.8	3.56	6.7	5.9	3.7	197	182
5C	23.1	3.54	7.5	6.1	4.9	203	191
Riparia Gloire	24.4	3.67	7.0	7.0	4.8	246	201
Salt Creek	23.6	3.57	7.4	6.6	4.8	233	219
Schwarzmann	23.6	3.59	7.2	7.1	4.6	226	207
SO4	23.4	3.55	7.2	6.3	4.4	228	193

- 2019 Rootstock trial with Souzao in a challenging soil. (Caspari, Bertin, Gardner, Gautam, 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 had 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 the time of planting 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*) are being 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, leftovers from the 2019 planting that were grown in pots at WCRC-OM for two years, 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 following the 2021/22 dormant season. Three vines grafted to 5C were planted in spring 2023. In the summer of 2023, overall vine survival of the original 2019 planting was 80 %, ranging from 50 % with 1103P to 96 % with 101-14. More replacement vines were ordered in April 2023 and planted in May 2024.

With the exception of 101-14 there were only minor differences in yield per cropping vine between the rootstocks in 2024 (Table 15). Five rootstocks produced about 2.6 to 2.8 ton/acre (Table 15). For the second year in a row the lowest yield per cropping vine was with rootstock 101-14 but the lowest yield per acre was with 1103P due to its low vine survival rate of only 50 %. As with almost all of our trials in the Grand Valley the yields were severely reduced due to the damage from two late spring frosts and the hailstorm on 27 Jun 2024. Averaged across all rootstocks the yield in 2024 was 1.82 ton/acre, a reduction of 60 % compared to the previous year.

Table 15: Effect of rootstock on vine survival after 6 years and yield in 2024 of Souzao growing in a commercial vineyard on Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival of 2019 planting (%)	Yield per cropping vine (lb)	Yield (ton/acre) ¹
110R	83	4.11	2.24
1103P	50	4.29	0.68
1616C	71	4.19	1.83
101-14	92	2.49	1.47
3309	92	3.87	2.08
5C	83	3.85	2.18
SO4	88	4.16	2.55

¹Yield calculation based on number of vines initially planted.

Rootstock effects on fruit composition at harvest were generally small (Table 16). Similar to the 2023 results, and again similar to the results from the 2018 Cabernet Sauvignon rootstock study (Table 14), Souzao grafted to 1103P produced fruit with the highest titratable acidity and highest malic acid concentration. Yeast Assimilable Nitrogen concentrations were up slightly compared to the 2023 season with an average value of 352 mg l⁻¹.

Table 16: Effect of rootstock on fruit composition of Souzao growing in a commercial vineyard on Orchard Mesa near Grand Junction, CO.

Cultivar	Soluble solids (Brix)	pH	Titrateable 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	23.4	3.40	7.7	7.3	3.3	194	155
1103P	24.4	3.40	8.0	7.7	3.6	202	129
1616C	23.6	3.52	7.3	7.4	3.2	216	149
101-14	24.1	3.46	7.4	8.2	2.9	213	155
3309	23.1	3.50	7.5	7.5	3.4	256	167
5C	23.0	3.48	7.3	7.4	3.3	250	163
SO4	23.3	3.47	7.8	7.6	3.2	228	162

- Inter-planting with 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 initial 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 in 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. Even the combined yield of 1.76 ton per acre is 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 20 % 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 growing in the North half of this block 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. Survey data for 2021 show that all but one other Chardonnay block in Mesa County produced no crop at all, and a county average of 0.14 ton per 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.

In 2023 there was a small reduction in yield to 3.76 ton/acre. The 31-year old grafted vines growing in the same block produced 3.02 ton/acre. This is in contrast to 2022 when the previously interplanted vines produced less than the mature grafted vines. However, in 2024 the mature grafted vines again produced more than the inter-planted vines (3.23 versus 2.62 ton/acre).

The cumulative yield after eight years from the combination of grafted inter-planted and mature own-rooted vines (removed at the end of year four) is 21.2 ton/acre. In comparison, Chardonnay vines of the same age used for a study on graft union management (see below) that were planted in an open field (mature vines had been removed several years earlier) had a cumulative yield of 19.1 ton/acre. This difference in favor of inter-planting is largely due to the 7.9 ton produced by the mature own-rooted vines in 2017 and 2018 when the vines planted in 2017 did not produce a crop. Since own-rooted vines were removed after the 2020 harvest, inter-planted Chardonnay vines produced an average of 2.7 ton per acre whereas vines planted in open ground produced 4.0 ton per acre. We expect differences in annual yields to diminish when the replacement vines planted in 2021 reach full production.

It should be noted 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 – 2017 study (Caspari, Bertin, Gardner, and Gautam)

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.

In the planting year, 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 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 union located 2” above soil level were hilled up in fall and uncovered the following spring.

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.



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.

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 falls of 2021, 2022, 2023, and 2024 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 in any of the years.

So far the results from this second part of the study are promising. No scion rooting has been observed after five 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. As the wood chips decompose there is the risk that scion rooting may occur over time. 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, Gardner, and Gautam).

Based on the promising results with wood chips to protect the graft union from the 2017 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. Like the 2017 study, the planting holes for the treatment 2” below soil surface were not filled up entirely after planting, 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 in the spring and recovered again in the fall. These annual covering / uncovering treatments will be applied to the same Control vines for the remainder of the experiment. The other half of the Control treatment will remain covered throughout the experiment (treatment CC), as will the graft unions placed 2” below ground, except for brief moments when soil or mulch is removed to check if scion roots are occurring.

In mid September 2023, all covered graft unions were briefly uncovered to determine if there was any root emergence from the scion part of the vines. As expected, no scion roots were observed on Control vines (annual covering / uncovering of the graft union). There was also no scion rooting on vines planted with the graft union above ground and continuously covered with wood chips. However, 3 out of 10 vines with the graft union above ground and continuously covered with soil had small roots emerging from the scion. The vast majority of vines planted with the graft union 2” below the soil surface and covered up with either soil or mulch had roots emerging from the scion.

Root observations were repeated in mid October 2024. Once again, no scion roots were found on Control vines and vines where the graft union was continuously covered with wood chips. However, scion rooting was observed on one out of 15 Control vines with continuous soil cover, and nearly all vines with the graft union 2” below soil surface.

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, Gardner, and Gautam)

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 seven entries in the NE-1720 trial at Orchard Mesa (Albarino, Cabernet Dorsa, Cabernet Sauvignon, Carmenere, Souzao, Verdelho, 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. From the 2020/21 to 2022/23 dormant season we have tested Frontenac and Vidal blanc from a grower cooperator vineyard. Since the 2020/21 dormant season we have included Itasca in regular tests. 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 started on 18 Sep 2024 to ascertain baseline values of bud cold hardiness late in the growing season and prior to a killing frost. Initial cold hardiness values from Washington State University (WSU) (<https://wine.wsu.edu/extension/cold-hardiness/>) are way too low and differ substantially from recently published values from Cornell University. We consistently find bud hardiness in fall to be much less than what is indicated by WSU. Determining initial bud cold hardiness and the acclimation pattern of key cultivars is critical information for Colorado grape growers as most damaging cold events of the past 30 years have occurred during the cold acclimation phase.

Bud cold hardiness tests with cultivars Chardonnay and Syrah are conducted on about a weekly basis with other cultivars tested less frequently. For further information and updates visit: <https://aes.colostate.edu/wcrc/stations/orchard-mesa/viticulture/cold-hardiness/>

We are collaborating with Dr. Amaya Atucha (University of Wisconsin) and Dr. Jason Londo (Cornell University) on a project to improve a grape bud cold hardiness model. Buds from 5 cultivars from local vineyards were sampled four times during dormance and shipped to Dr. Atucha's laboratory where parts of the samples were used to determine bud cold hardiness while other parts were used for deacclimation studies. At each time point, cold hardiness tests were performed at WCRC-OM using the oxidative browning method and results compared to those of Dr. Atucha's laboratory using the differential thermal analysis method.

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

This report details a multi-faceted investigation into temperature patterns and their implications for viticulture across Colorado, focusing on vineyard-scale microclimates and the accuracy of gridded temperature models during critical cold events. The work builds on previous Colorado Wine Industry Development Board (CWIDB) projects to determine where viticultural activity shows promise of expansion in current and future climates. This research is broken into three tasks: 1. Investigating the relationship between observed and modeled temperatures at vineyard scale, 2. A brief report on the completion of CWIDB funded maintenance to key Colorado Agricultural Meteorological Network (CoAgMET) sites, and 3. A detailed look at temperatures in current and prospective viticultural locations during potential Low Temperature Injury Events (LTIEs), or conditions cold enough to damage grapes and vines.

Key Findings:

- **Vineyard Microclimates are Critical:** Analysis of the Orchard Mesa vineyard revealed significant temperature variability (average daily minimum spread of 5.8 °F) even across small elevation differences. This fine-scale variability, crucial for grape cultivation, is often underestimated by coarser resolution models.
- **PRISM Model Limitations at Vineyard Scale:** While the PRISM model is suitable for county-scale climate analysis, when used at Orchard Mesa it exhibited a warm bias (average 2.0 °F warmer) and missed critical cold snaps at the vineyard level, highlighting its limitations for precise vineyard management and risk assessment.
- **Weather Station Infrastructure Improvements:** Essential maintenance was conducted on CoAgMET stations in key viticultural areas (Canyon of the Ancients (CYA01), Dolores (DLR01), Ignacio (IGN01)) to ensure reliable data collection.
- **Anomalous Cold Nights and LTIEs:** The study tracked Low Temperature Injury Events (LTIEs) using updated thresholds for different grape varieties across three areas of interest (Fremont, Delta/Mesa, La Plata/Montezuma counties) over the water year 2025 cold season.
 - **Winter (Jan/Feb) Events:** Western Colorado generally avoided severe winter LTIEs, but Eastern Colorado (Fremont County) experienced temperatures impacting European grape varieties.
 - **Late Spring (May) Freezes:** A significant late-season hard freeze after bud break severely impacted parts of Montezuma and La Plata Counties, underscoring the ongoing risk even in seemingly milder years.
 - **PRISM vs. Observations:** While PRISM generally showed good large-scale correlation with observed temperatures, it frequently underestimated the severity of localized cold events. A notable outlier, the Nucla CoAgMET-lite station, consistently recorded significantly cooler temperatures than PRISM, prompting further investigation into its siting and the viticultural potential of the San Miguel River Valley.
- **Future Viticultural Potential:** PRISM data continues to suggest promising viticultural conditions in far southwest Montezuma County and western McElmo Canyon, areas that warrant further long-term instrumentation and study.

This research underscores that while regional climate models like PRISM provide valuable broad-scale insights, localized, high-quality temperature monitoring is

Minimum daily temperature observations for the 44 sensors were compared with minimum daily temperature data from the PRISM model. We analyzed 1. The correlation and statistical significance of the relationship between temperature sensor elevation and minimum daily temperatures, 2. The correlation and statistical significance of the relationship between mean observed minimum daily temperatures of and the nearest PRISM gridpoint, 3. The correlation and significance of the relationship between the lowest observed minimum daily temperatures and the lowest temperature from the nearest PRISM gridpoint, 4. The average difference between observed and modeled temperatures, 5. The average daily spread in observed and modeled temperatures, and finally 6. The difference between observed and modeled temperatures for specific cold snaps.

While elevation differences across the vineyard are relatively small (30 ft spread from top-to-bottom), there was a positive correlation between station elevation and minimum daily temperatures. The correlation between elevation and average daily minimum temperature was 0.66, which is statistically significant at 99 % confidence. The correlation between elevation and the lowest recorded winter temperature was 0.34, which is significant at 90 % confidence. Figure 4 shows the annual minimum temperature. These results imply, as expected, that the vines at the bottom of the vineyard face the highest low temperature injury event (LTIE - defined in more detail in task 3) risk.

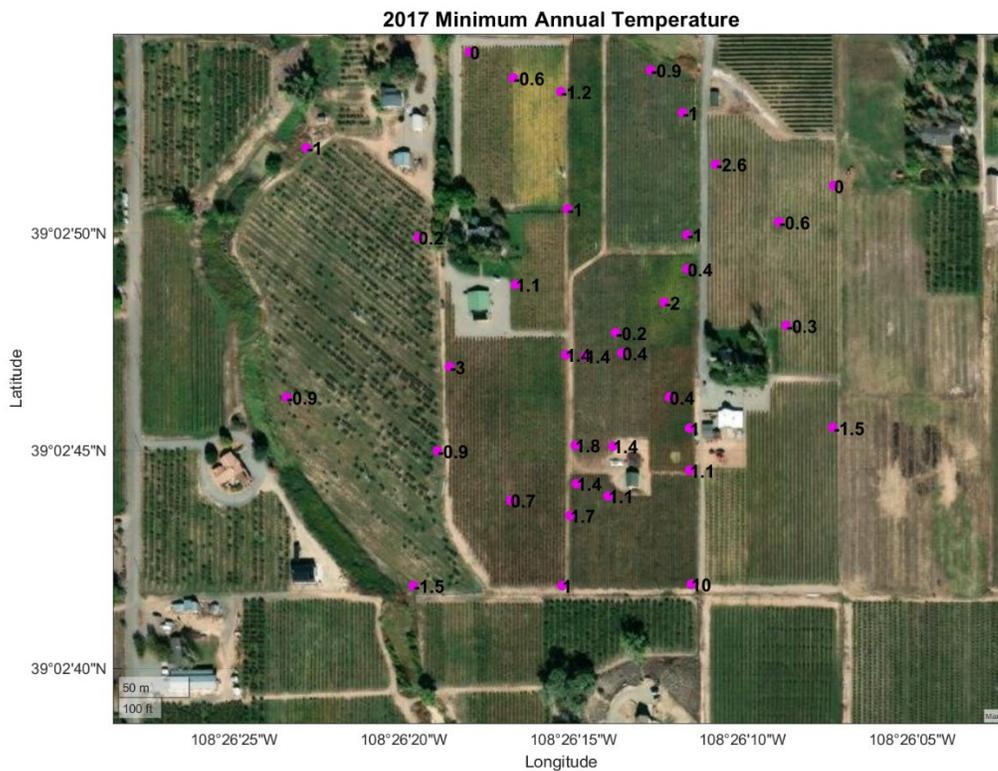


Fig. 4: Minimum annual temperatures from USB-501-PRO sensors for 11 November 2016 – 22 May 2017.

PRISM data are relatively coarse resolution (800 meters, ~½ mile) in comparison to the spacing of the sensors. Therefore, when matching temperature sensors to the nearest

gridpoint, only four PRISM gridpoints were relevant. The difference between daily minimum temperature among the gridpoints used were small. On average, the difference between the highest and lowest of the four PRISM gridpoints used was only 0.7 °F. The maximum difference between the highest and lowest PRISM gridpoint touching Orchard Mesa was 1.8 °F (Figure 5). The average difference between the highest and lowest minimum daily temperature reading in observations was 5.8 °F. It is likely that this number is somewhat inflated by sensor errors implicit in the observations dataset. For example, some of the 10 +°F daily temperature spreads shown in Figure 5 (blue) likely include bad data. However the much larger variability in observed data is not the product of one or several large outlying errors: the median spread in daily minimum temperatures from observations was 5.6 °F (similar to the mean), and every day saw a spread in observations of 1.1 °F or greater. This suggests that real temperature variations at Orchard Mesa, and likely any large vineyard, are much greater than what is seen in PRISM.

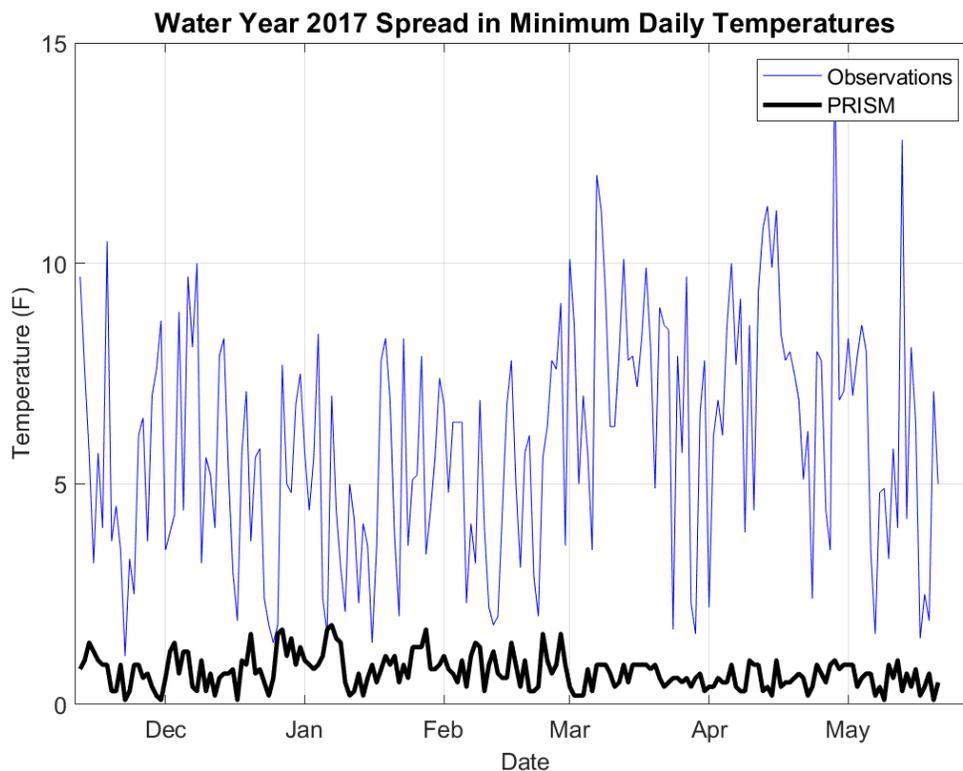


Fig. 5: Difference between highest and lowest minimum daily temperatures from USB-501-PRO observations (blue), and PRISM gridpoints covering Orchard Mesa (black) (11 November 2016 – 22 May 2017).

PRISM data were also subject to a warm bias at Orchard Mesa. The average daily minimum temperature from PRISM was 2.0 °F degrees greater than the average observed daily minimum temperatures. Moreover, there were several cold events where PRISM nearly or completely missed the range of temperatures captured in observations. Figure 6 shows the minimum daily temperatures for each sensor (blue) and each PRISM gridpoint (black) across the vineyard.

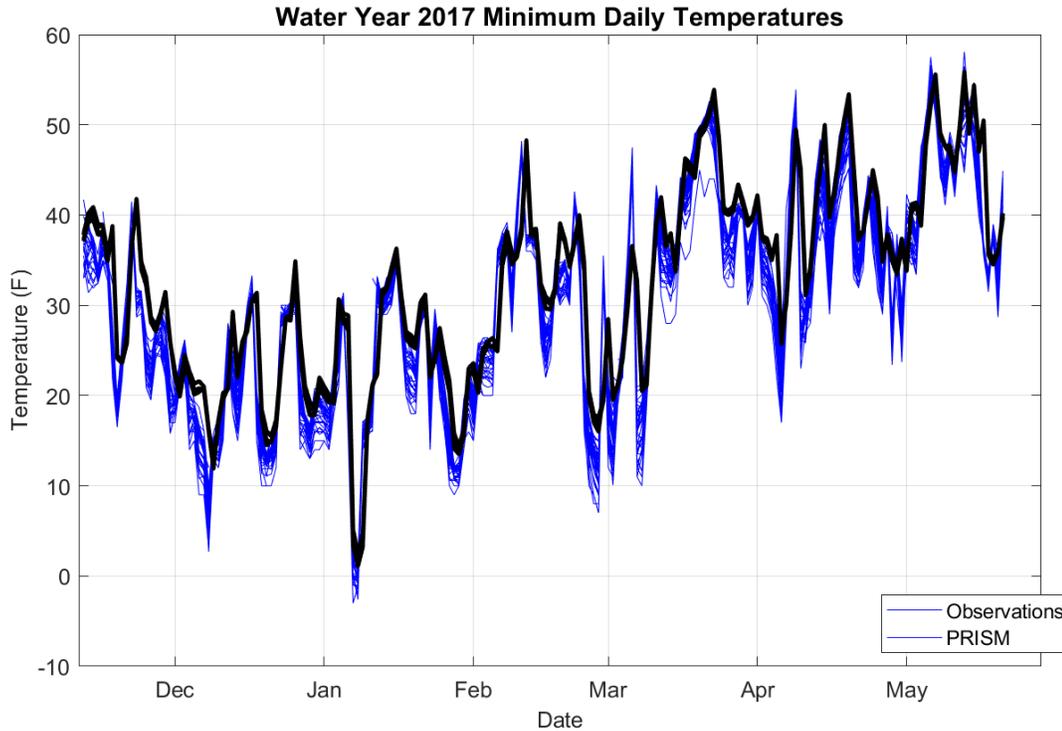


Fig. 6: Daily minimum temperatures from USB-501-PRO observations (blue), and nearest PRISM gridpoints (black) (11 November 2016 – 22 May 2017).

While PRISM often tracks closely with observations, several missed cold snaps stand out: 18 November, 16 January, 26 February, 8 March, and 29 April.

18 November 2016: Observed temperatures spanned a smaller spread than usual, with temperatures ranging from 16.5 °F to 20.2 °F. PRISM missed this window completely with a minimum temperature across all gridpoints touching Orchard Mesa of 23.6 °F.

6 January 2017: The cold snap on 6-7 January stood out because it was the coldest of the season, but PRISM did correctly capture this event. Minimum observed temperatures ranged from -3 °F to + 1.8 °F during this event. PRISM recorded a minimum temperature of +1.1 °F.

26 February 2017: Observed temperatures spanned a relatively large range from 7 °F to 15.1 °F. PRISM recorded a low of 16 °F, narrowly missing the window, albeit a wide window, of observed temperatures.

8 March 2017: Observed temperatures across the vineyard spanned an even wider range from 10 °F to 21.2 °F. PRISM gridpoints showed a minimum temperature of 20.5 °F, which is inside the observed range of variability, but more than ten degrees warmer than the lowest observation.

29 April 2017: The lowest observed temperature across the vineyard from 29 April to 1 May was 23.3 °F. The lowest recorded PRISM temperature was a full ten degrees warmer (33.3 °F).

While the findings above may make identifying areas in the state with potential for viticultural expansion seem more dubious, it should be noted that PRISM reproduces temperature patterns on a large scale (state or county) quite well, and that warm biases are

not universal. Goble et al. 2023 shows that for Montezuma County, cool biases in the PRISM data set occur as well. This research does underscore the importance of taking high quality temperature readings on any given vineyard. Spatial and temporal temperature variability across the vineyard are highly likely to exceed what is shown in PRISM or other gridded temperature datasets.

Using data from Orchard Mesa vineyard, this task highlights the significant spatial variability of temperatures within vineyards, even across relatively small elevation changes. Our findings reveal that observed temperature spreads, particularly during critical cold snaps, can be substantially greater than what coarse-resolution models like PRISM can capture. While PRISM remains a valuable tool for analyzing temperature patterns at broader scales (county or state), its inherent resolution limitations and tendency for warm biases, as observed in this study, underscore the necessity of collecting high-quality, localized temperature data for precise vineyard-scale climate assessments. Understanding this fine-scale variability is crucial for accurate risk assessment, especially concerning cold-sensitive crops like grapevines. This research emphasizes that relying solely on gridded temperature datasets for vineyard management may lead to an underestimation of temperature extremes and the associated risks.

Additional findings: The Colorado Climate Center created an animation of minimum daily temperatures over the 2016-2017 season by day. This animation will be shared with the final report.

Task 2 (Upgrading CWIDB CoAgMET Infrastructure):

Colorado Climate Center weather station technician staff replaced temperature/relative humidity sensors at the Canyon of the Ancients (CYA01), Dolores (DLR01), and Ignacio (IGN02) CoAgMET sites.

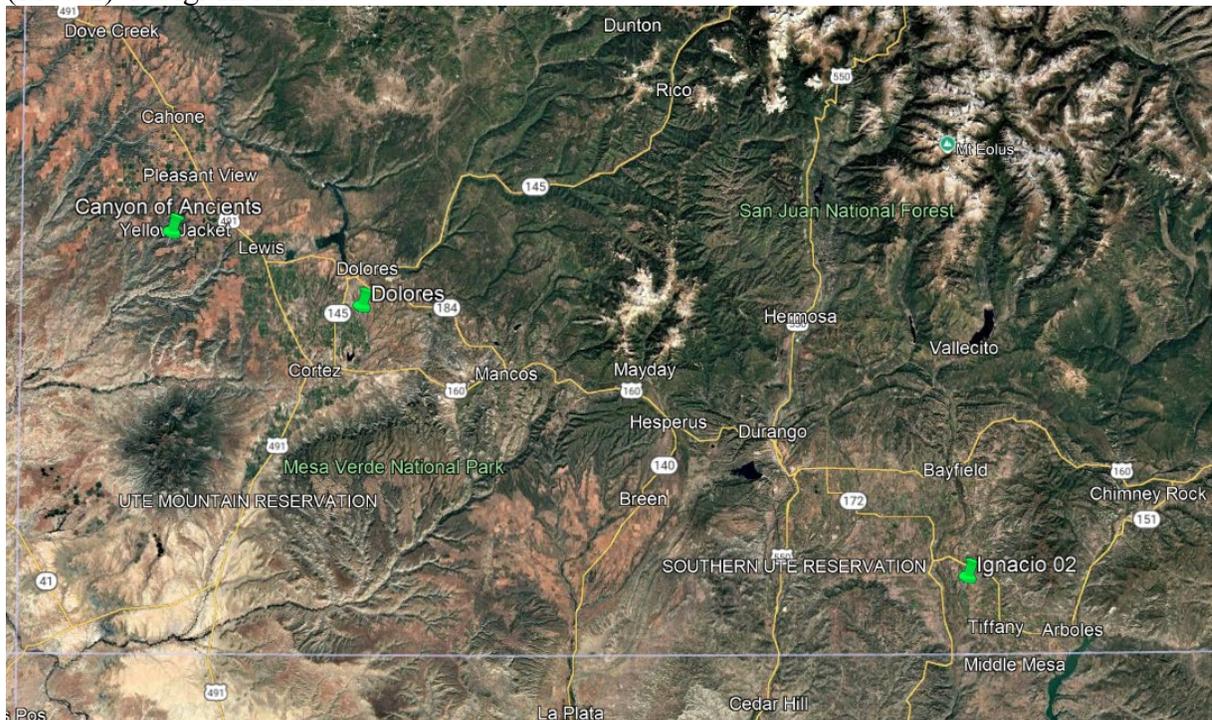


Fig. 7: CoAgMET stations serviced. Locations shown with green pins.

Task 3 (Mapping Temperature Patterns on Anomalously Cold Winter and Shoulder Season Nights):

Motivation: Task 3 is a continuation of previous statements of work in which temperature conditions are monitored in wine production locations across Colorado. Tracking potential LTIEs across the state through time allows the CWIDB to stay up to date with which areas of the state are, and are not, becoming more suitable for grape production.

Methods: 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 17 shows the LTIE thresholds used to approximate the success of European grape varieties, mixed cultivars, and hardy mixed cultivars. Temperatures are given in Fahrenheit.

Table 17: LTIE temperature thresholds for *Vitis vinifera*, moderately cold-hardy, and super cold-hardy interspecific cultivars. Adapted from Goble et al. 2023.

<i>Vitis vinifera</i> cultivars	Medium cold-hardy interspecific cultivars	Super cold-hardy interspecific cultivars
$T_{\min} < 10\text{ }^{\circ}\text{F}$ before October 31 st	$T_{\min} < 8\text{ }^{\circ}\text{F}$ before October 31 st	$T_{\min} < 3\text{ }^{\circ}\text{F}$ before October 31 st
$T_{\min} < 5\text{ }^{\circ}\text{F}$ before November 15 th	$T_{\min} < 0\text{ }^{\circ}\text{F}$ before November 15 th	$T_{\min} < -6\text{ }^{\circ}\text{F}$ before November 15 th
$T_{\min} < 0\text{ }^{\circ}\text{F}$ before December 1 st	$T_{\min} < -8\text{ }^{\circ}\text{F}$ before December 1 st	$T_{\min} < -15\text{ }^{\circ}\text{F}$ before December 1 st
$T_{\min} < -8\text{ }^{\circ}\text{F}$ at any point	$T_{\min} < -13\text{ }^{\circ}\text{F}$ at any point	$T_{\min} < -22\text{ }^{\circ}\text{F}$ at any point
$T_{\min} < 28\text{ }^{\circ}\text{F}$ between May 15 th and September 30 th	$T_{\min} < 28\text{ }^{\circ}\text{F}$ between May 15 th and September 30 th	$T_{\min} < 28\text{ }^{\circ}\text{F}$ between May 15 th and September 30 th

This fiscal year we investigated three weather events with potentially damaging impacts: 1. 19-20 January; 2. 12-13 February; and 3. 19-20 May. These investigations cover three areas of interest (AOI): 1. Fremont County, 2. Delta and Mesa Counties, and 3. LaPlata and Montezuma Counties. Figure 8 shows the locations of 37 weather stations across the three AOIs. Observed temperatures are compared to, and analyzed alongside, Parameter-elevation Regression on Independent Slopes Model (PRISM) temperature data at 800 meter (roughly half mile) resolution.

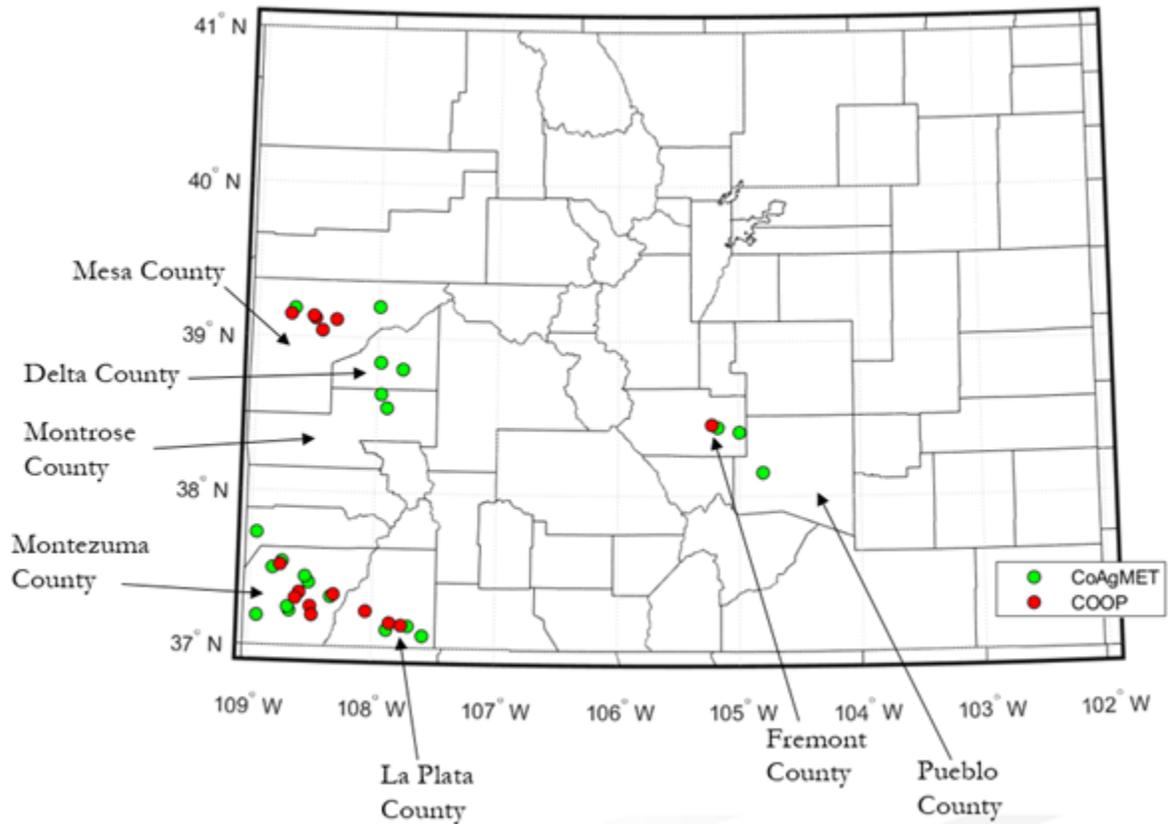


Fig. 8: Map of Colorado with referenced counties labeled. Weather stations used in the study are color coded by network. Green = CoAgMET. Red = COOP.

The three weather events chosen for investigation were chosen because these events were likely to have impacts for at least some grape producers. Figure 9 shows the daily minimum temperatures from the 37 weather stations used for the period 1 October through to the middle of June. Stations in the Montezuma/La Plata County area are shown in blue. Stations in the Mesa/Delta County area are shown in red. Stations in the Fremont County area are shown in beige. The January and February events were cold enough to cause damage to some grape varieties, and temperatures on 19 and 20 May were cold enough to cause hard freezes for some locations after bud break. Moreover, according to the PRISM model, the spring freezes may have damaged newly budding grapes across much of our study area (Figure 9).

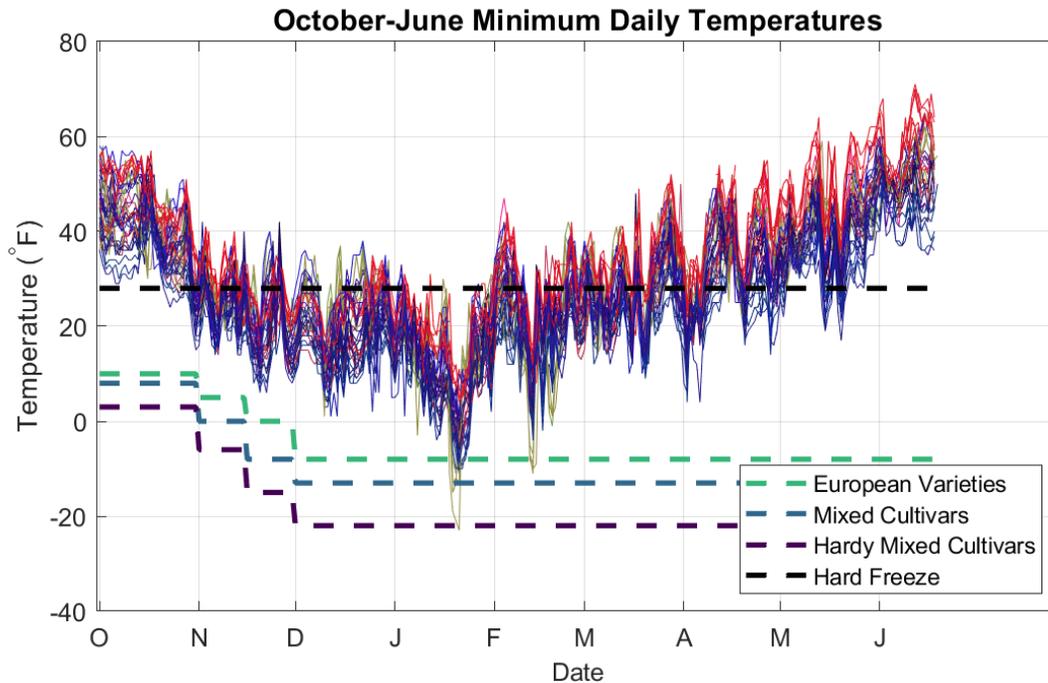


Fig. 9: Daily minimum temperatures for 37 locations (shown in Figure 8) from our 3 AOIs: Blue lines are from stations in Montezuma/La Plata Counties. Red lines are stations from Mesa/Delta Counties. Beige lines are stations from Fremont/Pueblo Counties. Dashed lines show various important LTIE thresholds developed in previous reports for European grapes (green), medium hardy (blue), and super hardy cultivars (purple) as well as a hard spring freeze threshold of 28 °F.

PRISM data suggests that much of western Colorado in active *Vitis vinifera* production regions did not experience a LTIE in water year 2025 (Figure 10). This includes growing regions in Mesa, Delta Counties. Fremont County in eastern Colorado did experience winter temperatures capable of injuring European grape varieties, but temperatures were warm enough to not cause damage to medium and super-hardy cultivars. Montezuma County, southern La Plata County, and western Montrose County did not experience LTIEs through winter in viticultural production areas, but were subject to a two-part hard freeze event after 15 May 2025. The Cortez Cooperative Observing Network Station recorded minimum temperatures of 30 °F on 15 May, and 29 °F on 20 May, narrowly missing the LTIE threshold of a “hard freeze” (28 °F) on or after 15 May. Many other weather stations in the area did receive a hard freeze.

**Low Temperature Injury Events (LTIEs) Experienced
in Water Year 2025 Across Colorado as a
Function of Grape Type**

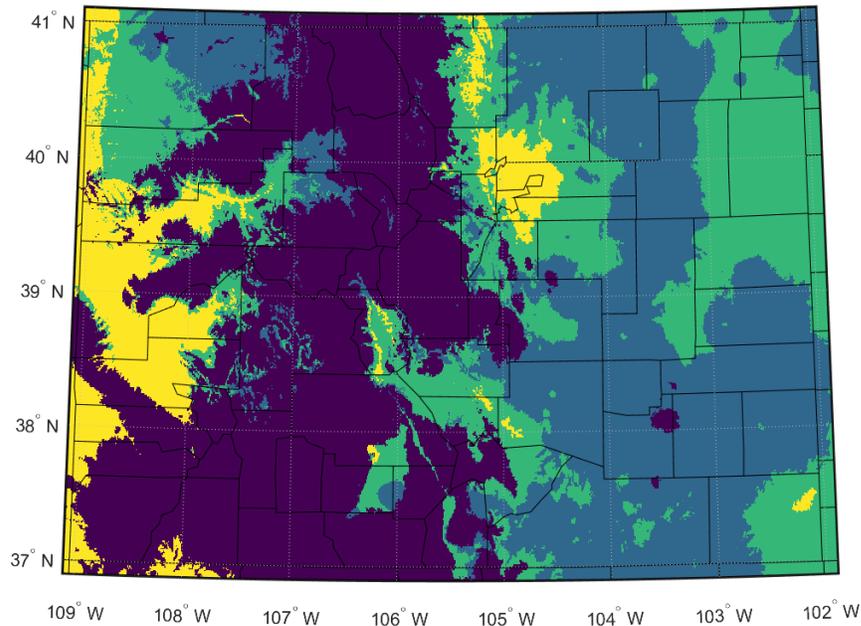


Fig. 10: Areas of Colorado experiencing a Low Temperature Injury Event in Water Year 2025 to date (October-May). LTIE thresholds defined in Table 3.1. Yellow = No LTIE. Green = LTIE for European varieties. Blue = LTIE for medium hardy cultivars. Purple = LTIE for super hardy cultivars.

Figures 11-22 explore these three freeze events across the three AOIs in further detail. Figures 11, 15, and 19 show the large-scale weather patterns on the mornings of 20 January, 13 February, and 20 May respectively using ERA-5 Interim Regional Reanalysis data from the European Center for Medium-Range Weather Forecasts. These figures show temperature, pressure, and windspeed information across Colorado and surrounding states. Figures 12, 16, and 20 show minimum temperatures for 19-20 January, 12-13 February, and 19-20 May respectively for Fremont and Pueblo Counties. The point data shows minimum temperatures measured by weather stations, and the background color shading shows PRISM model data. Figures 13, 17, and 21 do the same for Mesa and Delta Counties. Figures 14, 18, and 22 show the same for Montezuma and La Plata Counties.

19-20 January 2025: This was the first potential LTIE of interest in water year 2025. The cold air outbreak was made possible by a high pressure arctic airmass pushing southward from northwestern Canada, and spreading cold air across the north-central portion of the contiguous United States. (Figure 11). Some cold air did spill over the Continental Divide into western Colorado, but colder temperatures generally occurred in eastern Colorado.

Fremont County minimum temperatures during this cold snap ranged from -11 °F to -21 °F at COOP and CoAgMET sites included in this study (Figure 12). Pueblo West (PBW01) recorded the highest, and Penrose (PNR01) recorded the lowest temperature. PRISM temperature estimates were generally higher than observations for this LTIE.

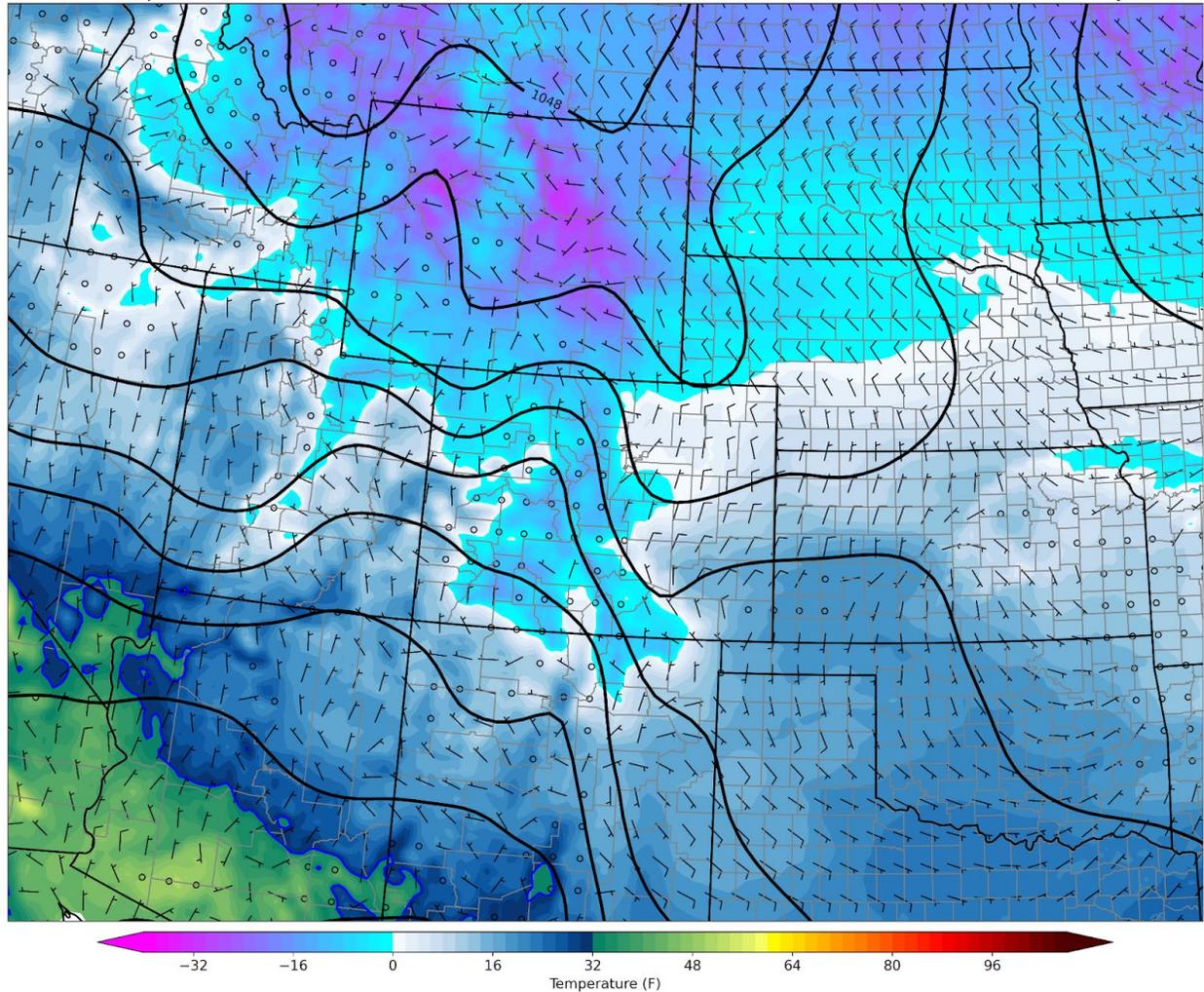


Fig. 11: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 1200 Universal Time Coordinate (UTC) on 20 January 2025. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. $\frac{1}{2}$ flag = 5 knots. Open circles indicate calm winds. Local time is UTC -7 hours.

Mesa, Delta, and Montrose County weather station temperatures ranged from -3 to +11 °F (Figure 13). These temperatures are generally safe in mid-January even for European grape varieties. PRISM shows some areas with much cooler temperatures at higher elevations and in the Gunnison River Valley, but these areas are not prospective viticultural locations.

Montezuma and La Plata County temperatures ranged from -10 °F to +6 °F (Figure 14). Based on Table 17, these temperatures are also unlikely to cause damage even for European varieties across nearly all sites with the exception of Durango (DRG 01). All sites in Montezuma County stayed above mid-winter LTIE thresholds, but perhaps worth noting is the higher minimum temperatures at higher elevation sites such as the Mesa Verde (+6°F) and Cortez 8 SE (+3°F) stations, both of which sit above 7,000 ft elevation. PRISM data corroborate these station findings, including showing a halo of relatively warm air around

the Sleeping Ute Mountain and relatively warm temperatures both atop the Mesa Verde and in the mesa terrain above the Canyon of the Ancients.

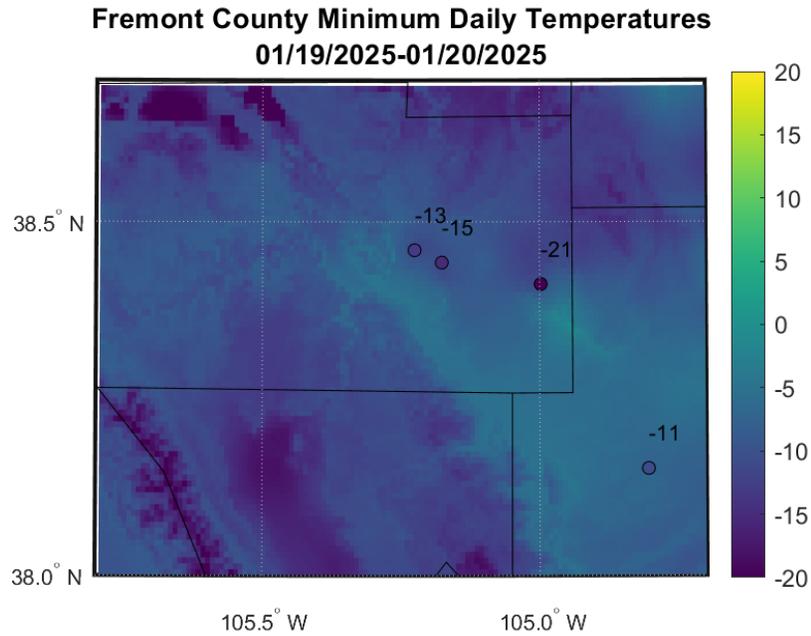


Fig. 12: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Fremont and Pueblo Counties for 19-20 January 2025.

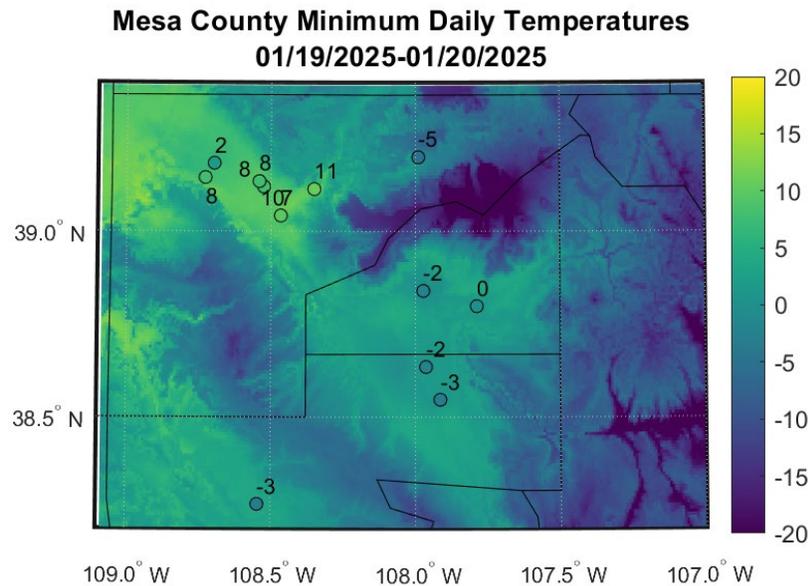


Fig. 13: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Mesa, Delta, and Montrose Counties for 19-20 January 2025.

**Montezuma County Minimum Daily Temperatures
01/19/2025-01/20/2025**

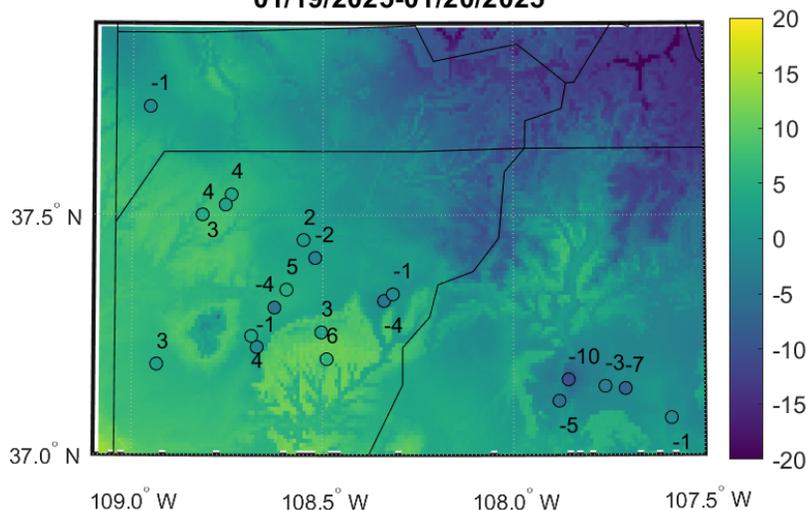


Fig. 14: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Montezuma, La Plata, and Dolores Counties for 19-20 January 2025.

12-13 February 2025: The second potential LTIE of interest for water year 2025 was 12-13 February with impacts largely east of the Continental Divide. Similar to LTIE event one, this event was characterized by arctic high pressure descending over the contiguous United States from northern latitudes, and spreading cold air across the interior continent. However, in this case, the center of high pressure dug all the way south to Oklahoma (Figure 15). The cold air associated with this airmass was relatively shallow, and less cold air spilled over the Continental Divide. As such, impacts were much greater for eastern Colorado than western Colorado.

Fremont County weather station readings ranged from -7 °F to -11 °F (Figure 16). These temperatures are likely safe mid-to-late-winter temperatures for medium hardy cultivars, but would be dangerous for European cultivars of *Vitis vinifera*. Once again, PBW01 was the warmest of the active weather stations and PNR01 was the coldest, and once again, weather station readings indicated slightly lower temperatures than PRISM.

Temperatures were not as cold for western Colorado. Temperatures at weather stations across low-lying portions of Mesa, Montrose, and Delta Counties ranged from +1 °F to +16 °F (Figure 17). Montezuma and La Plata County temperatures were a little cooler, ranging from -4 °F to +12 °F (Figure 18). These temperatures are not only safe for fully dormant grapes, they are arguably not even unseasonably cold for mid-February.

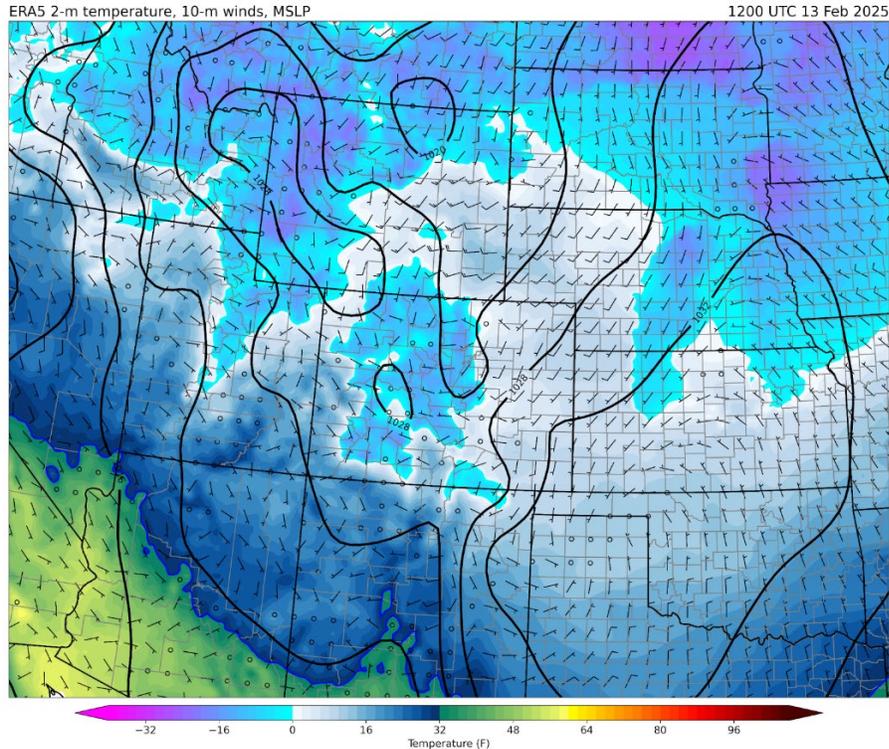


Fig. 15: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 1200 Universal Time Coordinate (UTC) 13 February 2025. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. ½ flag = 5 knots. Open circles indicate calm winds. Local time is UTC -7 hours.

**Fremont County Minimum Daily Temperatures
02/12/2025-02/13/2025**

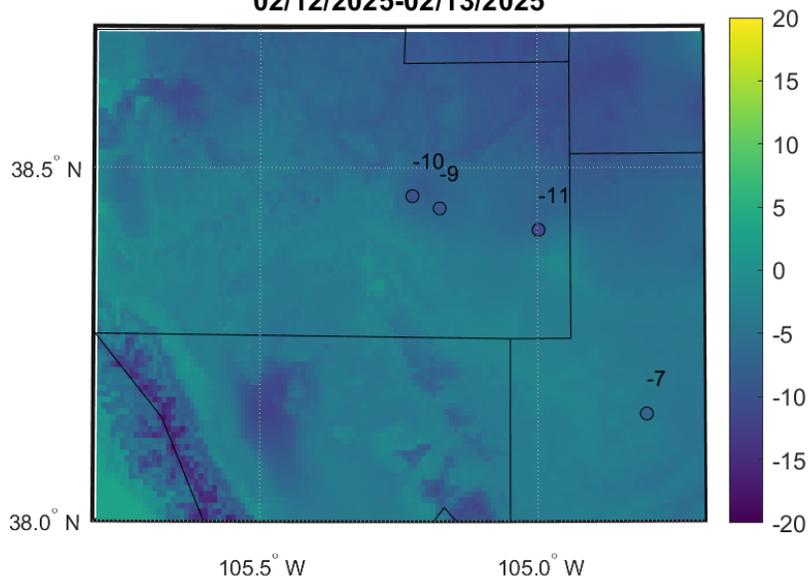


Fig. 16: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Fremont and Pueblo Counties for 12-13 February 2025.

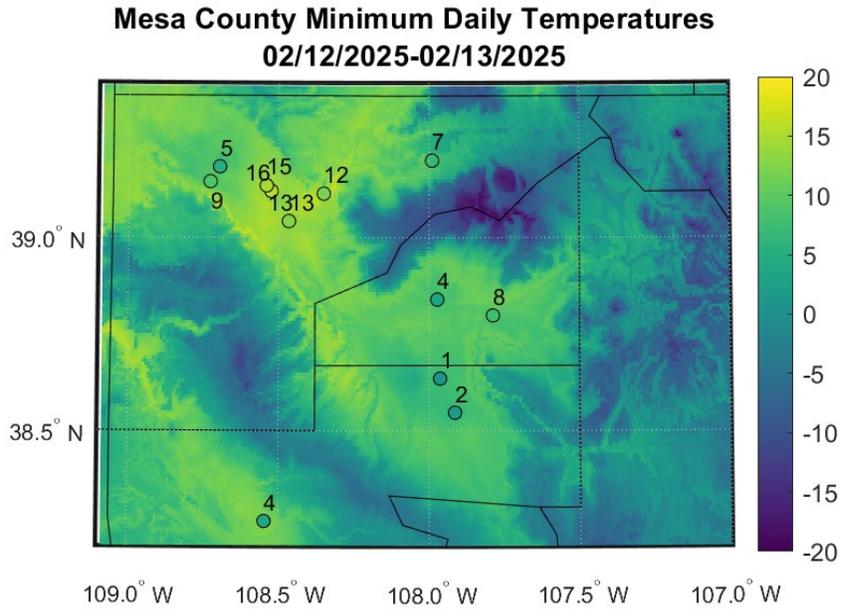


Fig. 17: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Mesa, Delta, and Montrose Counties for 12-13 February 2025.

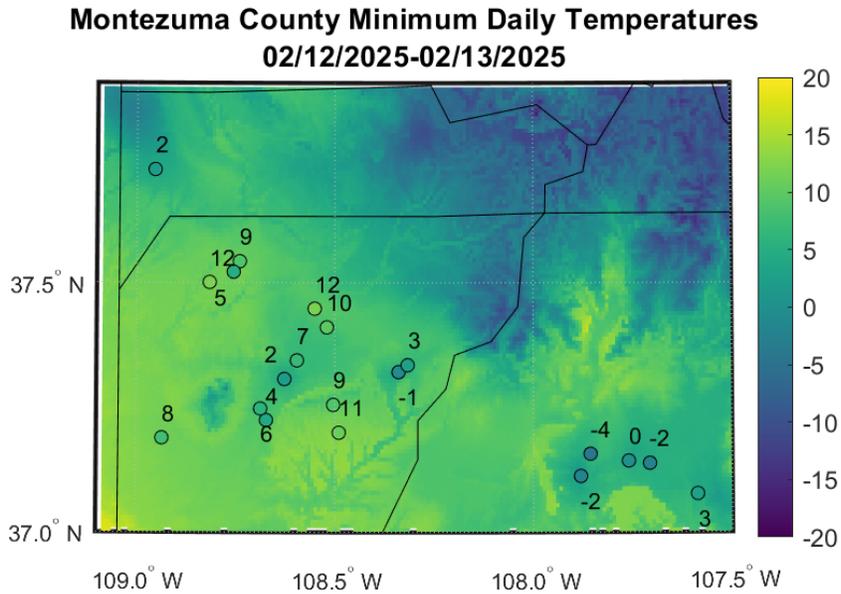


Fig. 18: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Montezuma, La Plata, and Dolores Counties for 12-13 February 2025.

19-20 May 2025: While winter temperatures were relatively mild, Colorado did experience a late cold snap. Below freezing temperatures were recorded across much of Colorado on 15 May as well as 19 and 20 May. During the 19-20 May cold snap there was a strong low pressure system over the center of the contiguous United States drawing cold air inwards from the northwest (Figure 19). This pushed cold air against the west slopes of the Rocky Mountains and dammed cooler than normal air in the valleys of western Colorado. This led to hard freeze conditions after bud break in portions of western Colorado, especially La Plata and Montezuma County.

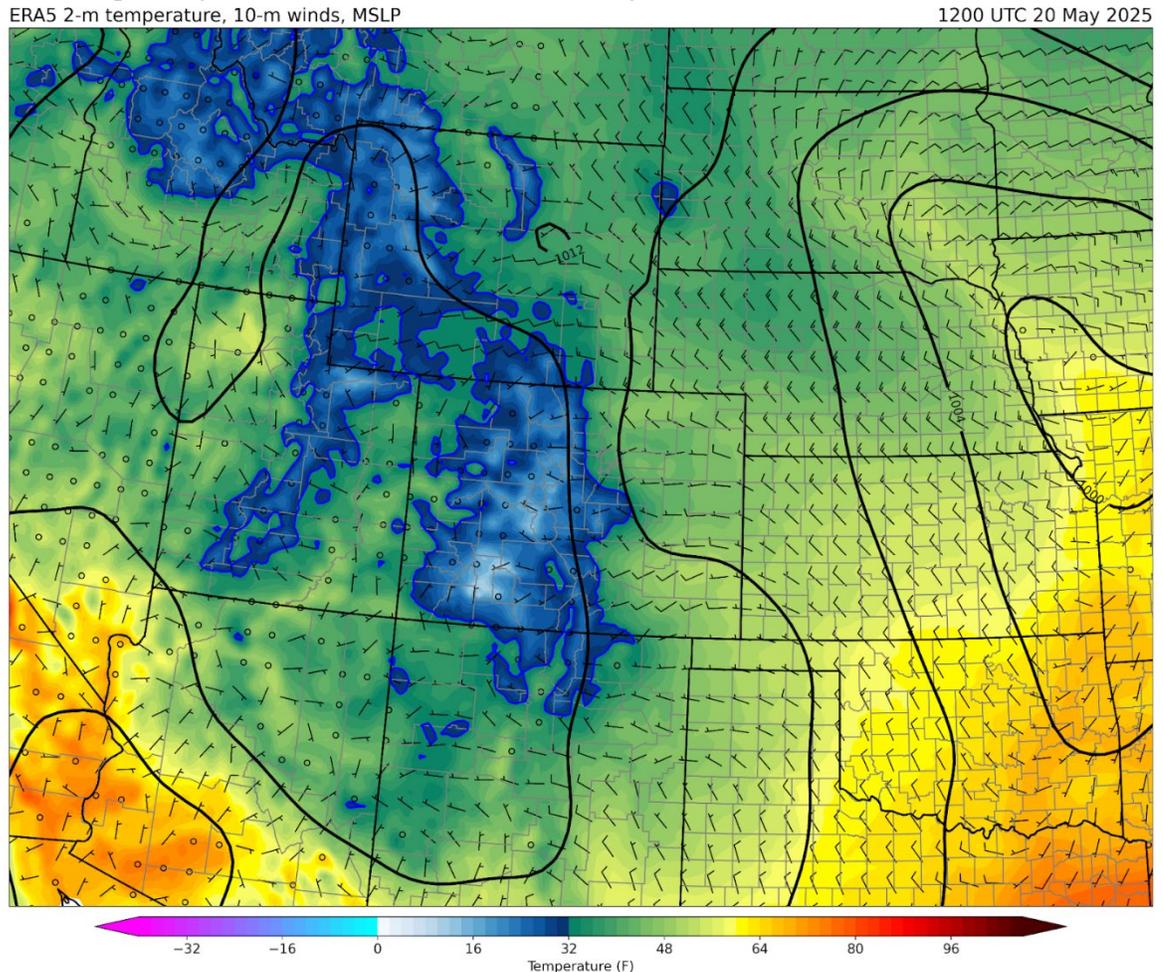


Fig. 19: ERA5 reanalysis temperature (color contours), pressure (black contours), and wind patterns (black barbs) for 1200 Universal Time Coordinate (UTC) on 20 May 2025. Wind barbs indicate wind direction of origin. Flags on wind barbs indicate speed. One flag = 10 knots. ½ flag = 5 knots. Open circles indicate calm winds. Local time is UTC -6 hours.

Fremont County, being east of the Continental Divide, was largely spared from this late season freeze. Weather station temperatures ranged from 35-39 °F (Figure 20). PRISM data indicates that lows in portions of Fremont County both south and west of Cañon City may have been as high as 40-45 °F.

Temperatures in low-lying areas of Mesa, Delta, and Montrose County were a little cooler (27-40 °F, Figure 21), but still generally stayed above hard freeze-level conditions

(approximated here as 28 °F). The one exception from station data was Delta County, which received an overnight low of 27 °F. Hard freeze conditions did occur at higher elevations, but not in typical grape growing areas.

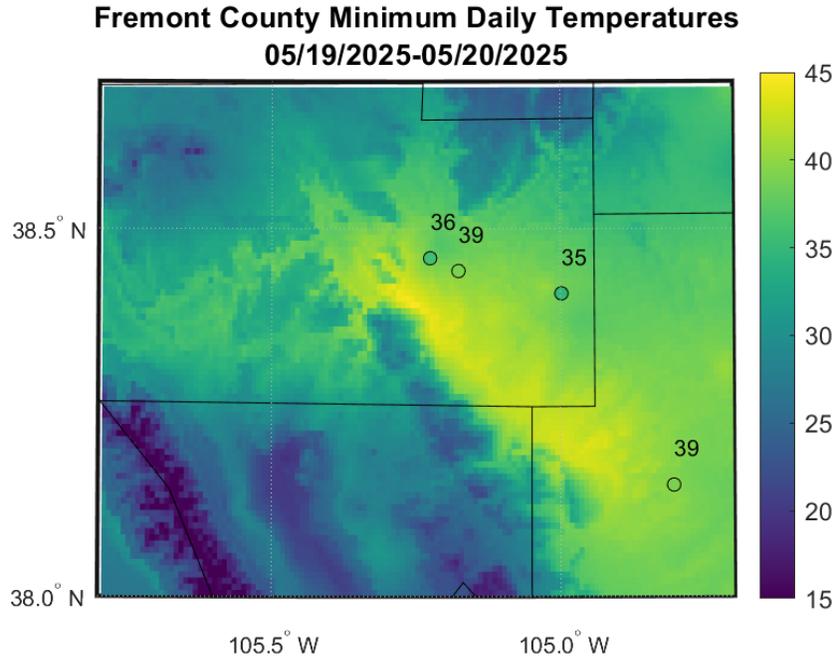


Fig. 20: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Fremont and Pueblo Counties for 19-20 May 2025.

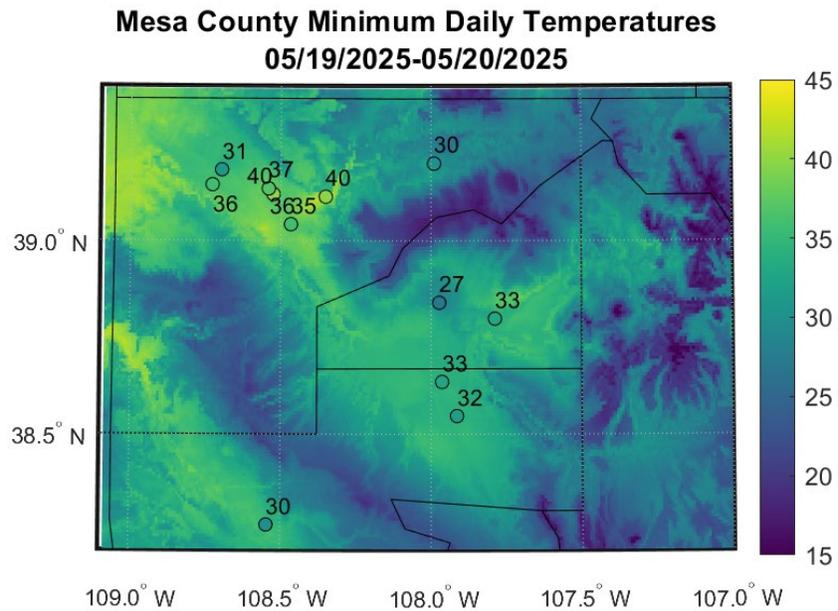


Fig. 21: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Mesa, Delta, and Montrose Counties for 19-20 May 2025.

Much of the current and prospective viticultural areas in Montezuma County and La Plata County did receive one (if not two) hard freezes after bud break in 2025. Low temperatures during the 19-20 May cold snap ranged from 17-34 °F (Figure 22) at weather stations. All five stations in La Plata County and both stations in Mancos received hard freezes with the coldest temperatures occurring in Mancos at 17-21 °F. As in the 2025 winter cold snaps, the stations with the warmest conditions were Mesa Verde and Cortez 8 SE at 34 and 32 °F respectively. The Towoac CoAgMET station on the Ute Mountain Farm and Ranch and Canyon of the Ancients (CYA 01) station were not far behind at 31 °F. Conditions in central Montezuma County from Cortez up to Lebanon were quite close to a hard freeze, ranging from 27-30 °F.

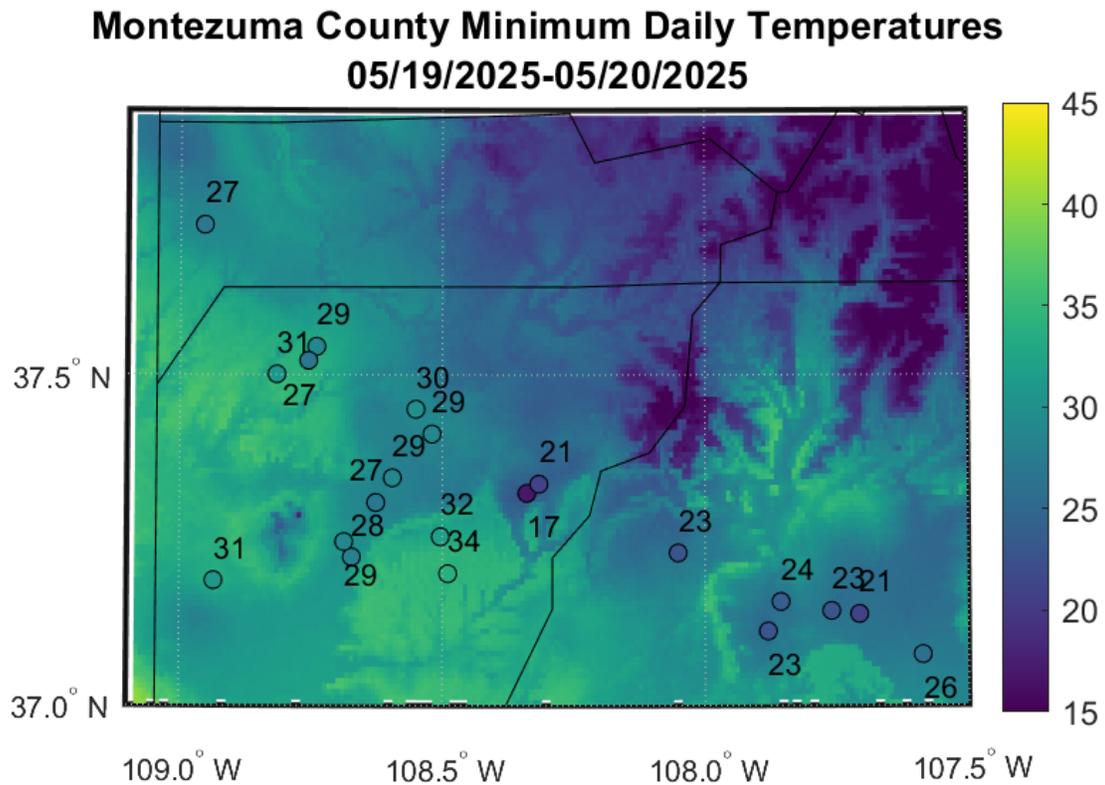


Fig. 22: Minimum temperatures (°F) from CoAgMET and COOP stations (dots) and PRISM (filled contours) in Montezuma, La Plata, and Dolores Counties for 19-20 May 2025.

Additional findings: From 1 October to 31 May the average correlation between a CoAgMET station and the nearest PRISM gridpoint was greater than 0.9. The average temperature difference was 0.94 °F (meaning temperatures were a little warmer on average from PRISM), and the average root mean squared error was 5.5 °F, so there was quite a bit of variability between whether PRISM or CoAgMET indicated warmer conditions. One outlier was the new Nucla CoAgMET-lite station (NUC01). The Nucla CoAgMET station was on average 5.7 °F cooler than indicated by the PRISM model, and notably cooler than

indicated by PRISM during all three potential LTIEs investigated here. We will review station siting in that area to see if the CoAgMET station may be incorrectly representing surrounding conditions for any reason, but on first glance, this is not a promising follow-up to the years of PRISM data that suggest conditions in the sparsely-instrumented San Miguel River Valley may be suitable for viticultural activity.

As in previous reports, PRISM data suggests far southwest Montezuma County and the west end of McElmo Canyon may have some of the most suitable temperature conditions for growing less hardy grapes outside of the well-known portions of eastern Mesa County such as Palisade and Grand Junction. Data collected from previous reports in western McElmo Canyon largely supports what PRISM shows there. While the area is difficult to instrument, it may be worth investing in more long-term equipment.

This analysis of Low Temperature Injury Events (LTIEs) in Colorado's wine regions for Water Year 2025 reveals varied impacts across the state. While PRISM data generally shows that much of western Colorado's active *Vitis vinifera* production regions avoided severe winter LTIEs, specific cold snaps in January, February, and particularly in May, presented significant challenges. Eastern Colorado (Fremont County) experienced winter temperatures impacting European varieties, while Montezuma and La Plata Counties faced a critical late-season hard freeze after bud break. Despite PRISM's good overall correlation with observed temperatures, instances of underestimation during cold events highlight its limitations for precise vineyard-level risk assessment. Continued ground-truthing, especially in promising but sparsely instrumented areas like the San Miguel River Valley and parts of Montezuma County, remains crucial for accurately identifying and tracking viticultural suitability across Colorado.

References:

Goble, P. E., H. W. Caspari, R. S. Schumacher, 2023: Using Climatological Data to Identify Locations with Viticultural Potential in Colorado. *Journal of Applied and Service Climatology*. Vol. 2023. No. 1. <https://doi.org/10.46275/JOASC.2023.04.001>

II. Development of Integrated Wine Grape Production

5. *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, Gardner, and Gautam)

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 quality².

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 had 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 was 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 only a small crop in the first four years but are now in full production (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 have been no vine losses to date (June 2025). All the vines are used for the 2021 study on alternative methods to protect the graft union (see above).

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 2024 season.

Vine vigor in this replant situation has been low and vines produced only a small crop of 0.5 ton/acre in the third growing season (2023) compared to 3.76 ton/acre for mature vines growing in adjacent rows. While vegetative vigor improved in the 2024 season the yield was still low at 0.81 ton/acre. Mature vines grafted to rootstock 5C that are part of this cover crop study produced 4.08 ton/acre.

Results from leaf samples taken at veraison showed all nutrients to be in the normal range with only minor differences between cover crop treatments. Leaves sampled from vines in legume plots had slightly higher nitrogen concentrations than leaves from plots with crested wheatgrass or orchard mix.

There are two interesting observations about the impact of cover crops on early yields and fruit composition in this replant situation. In both 2023 and 2024, vines with a legume cover crop in the interrow produced the highest yield. The difference was in large parts due to the higher vegetative vigor of vines in the legume plots that resulted in more canopy fill

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.

than with crested wheatgrass as cover crop. In 2024, both the dormant pruning weight, an indicator of vine vigor, and the yield of vines with a legume cover crop were more than double that of vines with a crested wheatgrass cover crop. The second observation was a significant increase in Yeast Assimilable Nitrogen in grape berries from the legume plots. This result from 4-year-old grafted vines in a replant condition confirms the results from our long-term study with 24- to 29-year-old own-rooted vines grown previously in this vineyard block.

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, Gardner, and Gautam)

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 drip 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 continue to provide a dense soil cover. There are a few patches where white clover has established but these appear random and not associated with any particular turf entry. As all the grasses in this cover crop trial are low growing species the entire block can be mowed quickly with an electric ride-on mower which eliminates the need for a tractor and mower.

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. Ten varietal wines were produced from the NE-2220 cultivar trial at

the Orchard Mesa site using micro-vinification techniques. An additional 4 wines were produced from the 2022 cultivar planting at WCRC-OM plus a further 8 wines from the long-term Chambourcin crop load trial that was replicated in two blocks. At the end of June 2025, all white wines have been bottled whereas all red wines are still in carboys. Red wines are scheduled to be bottled before the start of the 2025 harvest.

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 a large number 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.

We continue to use our web site and other internet resources such as our “Fruitfacts” messages as well as Dr. Oliver’s regular extension newsletter 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 three 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.

- Field demonstrations/workshops/tours

Drs. Oliver and Caspari presented a workshop “Late season scouting – how to find phylloxera & viruses” on 9 August 2024. The workshop included both formal presentations as well as a vineyard session where participants learned about scouting methods for viruses and sampled grape roots to inspect for phylloxera.

The CSU Western Campus held an Open House on 26 September 2024. Attendees were able to watch us operate the crusher/destemmer and grape press and sample freshly-pressed Chambourcin juice. Together with Dr. Analissa Sarno, PostDoc at WCRC-OM, we spoke to attendees about agrivoltaics in general, and our planned vineyard agrivoltaics research project specifically. Dr. Oliver spoke about table grape production and offered berry samples from four different table grape cultivars.

- 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 2024 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. 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.

- Media interviews

Initial interview by Walker Dawson, CBS News, for upcoming report on high-altitude wines in the Tarija region, 5 November 2024. Follow up interview and filming at WCRC-OM scheduled for summer 2025.

- Colorado Wine Grower Survey

Colorado State University has conducted this annual survey since 1984. Survey forms were sent out in late November 2024. All forms were sent electronically. We received 35 responses representing 85 vineyard sites and totaling 416 acres. The main results of the survey are:

- Average yield 3.3 ton/acre; down 20 % on 2023
- 1,342 ton production
- Expected total state production 1,500-1,700 ton
- About 12 % of production was not utilized
- Average price about \$50 higher compared to 2023
- Continued removal of vineyards