Semi-annual Report

July 1, 2023 – December 31, 2023

Viticulture and Enology programs for the Colorado Wine Industry

Principal Investigators

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Collaborating Institutions

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

Summary

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

Following a cooler than average spring that resulted in late bud break, weather conditions in the Grand Valley were warmer than average from July to December. July 2023 was the third warmest July since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964.

Initially, vine development was late in 2023, due to below-average temperatures from February to April which resulted in a late bud break, and below-average temperatures in June. Warmer than average temperatures from July onwards resulted in harvest dates that were close to average, but later than in 2022 despite a lower crop load. Averaged across all cultivars harvest was 1 day later than in 2022, ranging from 19 days earlier for Barbera and 13 days later for Roussanne and Zweigelt. Harvest of early ripening cultivars tended to be delayed compared to 2022 whereas harvest of very late ripening cultivars tended to be earlier. All grapes were harvested prior to a killing frost on 30 October.

Very preliminary data from the 2023 Colorado Grape Grower Survey indicate an average yield of 4.18 ton/acre. However, those results come from only 346 acre, most of which are in Mesa County. The average yield is likely to decline when more returns are received.

There have been no extreme low temperature events during fall 2023 and early winter of 2023/24. December's mean temperature of 34.4 °F was 4.3 °F above average,

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making it the 5th warmest December in our records going back to 1964. By early January 2024, no bud cold damage has been observed on any of the cultivars we monitor.

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Growing conditions, 2023 season

Timing of bud break in the Grand Valley was late due to below-average temperatures from February to April. Warmer than average temperatures in May were followed by a cool June. Monthly mean temperatures were above average for the rest of 2023. July's mean monthly temperature of 82.1 F was the third-highest ever recorded at the Western Colorado Research Center – Orchard Mesa. Cumulative Growing Degree Day (GDD) accumulation was average or slightly below average until mid July. Thereafter, GDD accumulation continued to deviate more and more from the long-term average until a killing frost on 30 October. Seasonal GDD accumulation was 3,951, about 100 GDD less than in 2022 but still 278 GDD higher than the long-term average.

The 2023 growing season was very dry with only 2.08" of precipitation recorded at the Western Colorado Research Center – Orchard Mesa between 1 May and 30 October. May and July 2023 were some of the driest on record with only 0.04" and 0.03" of precipitation, respectively. Only 0.87" of precipitation was recorded after the killing frost for the remainder of the year. Annual precipitation was 5.88" compared to the long-term (1962-2006) average of 8.91".

Research Update

I. Cropping reliability

1. ***Grape cultivars and clones suited to Colorado temperature conditions***

Since 2004 we have greatly expanded the number of cultivars under testing. The first-ever replicated cultivar trial in Delta County was planted at the Western Colorado Research Center - Rogers Mesa site in 2004. This trial was expanded with new entries in 2008-2009 as part of the USDA Multistate NE-1020 project (see below). Also in 2008 and as a part of NE-1020, 26 "new" cultivars were planted at the WCRC Orchard Mesa site. An additional replicated trial focused on cold-hardy, resistant cultivars was established on a grower cooperator site in Fort Collins in 2013 to identify grape cultivars that can be grown successfully along the Front Range. And in 2014, a fourth trial focused on cold-hardy, resistant cultivars was established with a grower-cooperator in the Grand Valley. A new cultivar trial block was started at WCRC-OM in April 2022 with the planting of Cabernet Volos, Fleurtai, and Soreli.

Yields in our cultivar trials were down compared to the very high yields of 2022. The average yield of *Vitis vinifera* cultivars in 2023 at Orchard Mesa was 3.3 ton/acre compared to 5.5 ton/acre in 2022. Yields of cold-hardy, interspecific cultivars were 3.9 ton/acre, down 1.4 ton/acre on 2022.

- 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 Rogers Mesa, and 25 cultivars at Orchard Mesa between 2008 and 2012. At Orchard Mesa, we have continued to remove poor performing cultivars and replant with new entries. For example, in 2016 we added MN 1285, a white cultivar from the breeding program at the University of Minnesota. MN

1285 was released in 2017 under the cultivar name 'Itasca'. Following the extreme low temperature event in late October 2020 another five cultivars were removed that had sustained near 100 % bud damage and had shown poor performance in the long term. In late April 2021, five new entries were planted (Agria, Arinto, Corvina Veronese, Sagrantino, Teroldego).

At Rogers Mesa, six cultivars produced a crop although fruit of Aromella was lost to shatter (Table 1). None of the *Vitis vinifera* cultivars produced a crop. Table 2 shows fruit composition at harvest. No wines were produced.

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 5 (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)	25 October	1.08
Chambourcin	25 October	1.26
Marquette	26 September	2.57
MN 1200	26 September	1.67
Vidal	25 October	1.07

Table 2: Fruit composition at harvest in 2023 for 5 mature grape cultivars planted at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Cultivar	Soluble solids (Brix)	pH	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
Aravelle[1]	22.3	3.24	8.6	7.9	3.5	205	89
Chambourcin	16.7	3.15	12.9	7.3	7.6	126	65
Marquette	27.9	3.33	9.5	5.6	5.8	202	97
MN 1200	25.8	3.34	7.0	7.7	2.2	130	103
Vidal	19.1	3.32	8.7	6.7	4.6	103	42

[1]Tested from 2008 to 2022 as NY 81.0315.17 (Cayuga White x Riesling)

At Orchard Mesa, all mature cultivars produced a crop. Harvest started with Itasca on 3 August 2023 and ended with Cinsaut, Durif, and Mourvedre on 5 October 2023 (Table 3). Although growing degree accumulations were down compared to the previous three years, the average harvest date in 2023 was only one day later than in 2022. This minor delay in crop ripening despite a late bud break and lower growing degree accumulation is most likely the result of the lower crop load in 2023 compared to the previous year. Averaged across all cultivars, yields were down 35 % compared to the 2022 season. Only Cabernet Sauvignon (+ 4 %) had a higher yield in 2023 compared to 2022; all other cultivars had lower yields. A summary of fruit composition is presented in Table 4. When looking at longer trends it is worth noting that Zweigelt has had the lowest (6 times) or second lowest (3 times) malic acid concentration in all of the last nine vintages while having the highest concentration of tartaric acid in seven vintages. Eight varietal wines were produced in 2023 using micro-vinification techniques.

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

Cultivar	Harvest date 2023	Yield per vine (lb)	Yield (ton/acre)[1]
Albarino	11 September	9.42	4.92
Barbera	28 September	10.79	3.53
Cabernet Dorsa[2]	11 September	8.79	3.39
Cabernet Sauvignon	28 September	9.67	5.05
Chambourcin[2]	27 September	10.78	4.40
Cinsault	5 October	15.11	5.14
Durif	5 October	9.06	4.69
Itasca[3]	3 August	2.93	1.11
Malvasia bianca	12 September	8.07	3.30
Marquette[2]	21 August	9.66	3.51
Marsanne	27 September	7.34	2.40
Merlot	15 September	5.58	2.41
Mourvedre	5 October	5.30	2.60
Roussanne	22 September	11.88	3.50
Souzao	29 September	5.28	2.30
Touriga national	29 September	7.49	2.24
Verdelho	11 September	8.86	3.38
Zweigelt[2]	22 September	6.54	3.41

[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 2023 for 18 mature grape cultivars planted at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	Soluble solids (Brix)	pH	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
Albarino	24.8	3.34	7.8	7.8	3.3	137	108
Barbera	26.5	3.34	8.0	8.2	3.7	186	138
Cab. Dorsa[1]	25.2	3.66	6.7	7.0	3.9	160	103
Cab. Sauvignon	24.5	3.33	7.1	7.6	2.5	91	105
Chambourcin[1]	26.2	3.15	9.2	6.6	3.5	186	111
Cinsault	23.0	3.53	5.5	5.4	1.4	165	128
Durif	23.1	3.34	6.9	6.4	2.3	142	93
Itasca[2]	23.1	3.33	11.2	8.1	8.3	145	69
Malvasia bianca	20.9	3.39	7.2	6.4	2.7	124	93
Marquette[1]	27.6	3.21	11.0	4.7	7.0	270	105

Table 4 continued

Cultivar	Soluble solids (Brix)	pH	Titratable acidity (g l^{-1})	Tartaric acid (g l^{-1})	Malic acid (g l^{-1})	Alpha amino nitrogen (mg l^{-1})	Ammonia (mg l^{-1})
Marsanne	22.3	3.60	6.4	6.4	3.0	111	73
Merlot	24.1	3.60	5.7	6.7	1.8	121	94
Mourvedre	23.8	3.49	6.5	6.3	2.2	180	117
Roussanne	22.9	3.41	7.7	6.7	3.0	148	96
Souzao	26.9	3.33	6.7	7.2	1.6	141	125
Touriga national	24.9	3.44	6.7	6.6	2.3	147	115
Verdelho	27.0	3.36	7.4	6.6	2.6	211	146
Zweigelt[1]	23.8	3.24	7.1	9.0	0.6	142	131

[1]Planted in 2011 and 2012.

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

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

A new vineyard was established on a grower cooperator site in Fort Collins in 2013 to identify grape cultivars best suited along the Front Range. Repeated cold events have led to a slow vine establishment. Two extreme cold temperature events during dormancy (-9 F on 12 November, and -22 F on 30 December 2014) caused near 100 % bud and trunk damage to Chambourcin, Noiret, and Traminette. In contrast, Aromella, Frontenac, and Marquette had about 90 % live fruitful buds (primary and secondary). However, a severe freeze event on 11 May 2015, when most cultivars were near or already past bud break, caused significant cold damage to emerging shoots and near 100 % crop loss. Consequently, many vines needed re-training during 2015. Milder minimum temperatures during the 2015/16 dormant season resulted in no bud or trunk damage, and there were no late spring freezes. However, yields again were low. In 2018, vines were again damaged by late spring frosts as well as hail. Low vine vigor in 2018, bud damage from cold temperatures during the dormant season, some damage from a late spring frost, and some hail damage all contributed to very low yields in 2019. In 2020, there was no yield and many vines required retraining from the ground. Vines were again damaged by an extreme cold temperature event in late October 2020, once again resulting in many vines dying back to the ground and no crop in 2021. Vine growth was better in 2022 compared to previous years, however fruit was removed on most vines to encourage vegetative growth. There was minimal cold damage during the 2022/23 dormant season and vines grew better than in the previous years. However, vine vigor at this site continues to be too weak.

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

A new replicated cultivar trial was established in 2014 on a grower cooperator site near Clifton to identify grape cultivars that can be grown successfully in cold Grand Valley sites.

There was minimal to no bud damage from the extreme low temperature event in October 2020. However, many vines needed retraining from the ground during 2021 indicating that while bud damage was minimal the event caused substantial damage to the trunks. The percentage of vines needed retraining from ground ranged from zero for Brianna and Marquette to 80 % for Chambourcin. Vines recovered well in 2021 and produced good to very good crops in 2022.

There was again no cold temperature damage during the 2022/23 dormant season. The average yield of 3.25 ton/acre in 2023 was only slightly down on 2022. However, there were very large year-to-year fluctuations depending on cultivar (Table 5). Year-over-year changes in yield ranged from -89 % for Arandell to +159 % for Aromella. Once again there was >90 % bird damage to Brianna, despite netting. On average, harvest was later by 1 day. A summary of fruit composition is presented in Table 6. No wines were produced from this trial.

One unexpected observation at this site are continuing vine losses with St Vincent. St Vincent was the cultivar with the best establishment in years 1 and 2. However, we continue to see vines die that grew well in the previous season. At the end of the 2017 season there were 19 live vines of St Vincent. In spring of 2018 seven vines failed to break bud. Even worse, there was no sucker growth coming up from the lower trunks or roots. Another vine died between harvest 2018 and spring 2019 and three more between harvest 2019 and spring 2020. After eight growing seasons only 29 % of the vines are still alive. Another cultivar with low vine survival is Traminette with 50 % vine losses over the past three seasons. However, there are also some unexplained vine losses with Traminette. It appears that sometime between harvest 2019 and the start of dormant pruning in February 2020 four vines were cut down without the knowledge of our grower collaborator. The reason behind this remains a mystery.

Table 5: Harvest dates in 2023 and yield information for 12 grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	Harvest date 2023	Yield (ton/acre)[1]
Arandell	27 September	0.51
Aromella	8 September	7.00
Brianna	22 August	0.46
Cayuga White	20 September	4.19
Chambourcin	10 October	3.82
Corot noir	10 October	6.14
La Crescent	11 September	3.85
Marquette	28 August	3.61
Noiret	27 September	5.35
St Vincent	23 October	1.51
Traminette	27 September	1.75
Vignoles	20 September	0.79

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

Table 6: Fruit composition at harvest in 2023 for 12 grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	Soluble solids (Brix)	pH	Titratable acidity (g l^{-1})	Tartaric acid (g l^{-1})	Malic acid (g l^{-1})	Alpha amino nitrogen (mg l^{-1})	Ammonia (mg l^{-1})
Arandell	23.5	3.90	5.3	5.6	3.2	302	103
Aromella	23.3	3.20	8.4	6.4	2.7	165	104
Brianna	20.5	3.45	7.9	4.9	3.9	258	80
Cayuga White	23.1	3.44	6.0	6.1	0.4	226	102
Chambourcin	25.8	3.24	8.3	7.3	2.1	203	116
Corot noir	23.5	3.76	4.6	5.1	0.4	244	108
La Crescent	28.5	3.37	10.2	6.5	7.6	208	83
Marquette	27.0	3.27	9.7	4.7	4.7	389	144
Noiret	21.4	3.42	6.9	7.4	1.9	158	92
St Vincent	24.5	3.19	8.4	6.8	2.6	177	114
Traminette	26.5	3.35	7.1	8.5	1.0	168	127
Vignoles	28.1	3.22	10.6	4.4	6.1	215	104

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 perios 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. About 75 % of these vineyards are planted with own-rooted vines of European cultivars, making them susceptible to phylloxera damage. Initially, feeding of phylloxera on roots of susceptible grape vines leads to reduced vine vigor and lower yields. However, phylloxera feeding, in combination with fungal and bacterial infections of the damaged root system, will eventually kill the vines. While phyto-sanitary practices and insecticide applications can slow the spread of phylloxera, the long-term solution is the removal of own-rooted vines of cultivars that are not phylloxera tolerant (all *Vitis vinifera* and some 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 the Western Colorado Research Center – Orchard Mesa (WCRC-OM) in 1992/93. The second, planted in 2009 also at WCRC-OM, uses Viognier grafted to five different rootstocks. Rootstock research is now a high priority area and three further trials, all located on commercial vineyards in the Grand Valley, have been initiated since 2017.

Two other phylloxera-related questions are also being addressed: how to best manage the graft union; and what is the best method for replanting.

- 2009 Rootstock trial with Viognier (Caspari, Bertin, Gardner, and Gautam)

A rootstock trial with Viognier (clone FPS 01) grafted to 5 different rootstocks as well as own-rooted Viognier was planted at WCRC-OM in late April 2009. Some replanting took place in the spring of 2010. The trial is set up as a randomized block design with seven replications, and four vines per replication. Vine x row spacing is 5 feet x 8 feet. Vines were originally irrigated by drip but the irrigation system was changed to micro sprinkler in the fall of 2018 as this vineyard block is now used for a new cover crop study (see below). The following rootstocks are included: 110 Richter (110R), 140 Ruggeri (140Ru), 1103 Paulsen (1103P), Kober 5BB (5BB), and Teleki 5C (5C).

Average yield per cropping vine in 2023 was 10.4 lb, down 45 % on 2022. Yield per cropping vine was highest on 140Ru (14.0 lb) and lowest on 110R (6.0 lb). However, vine survival is very low for 140Ru, resulting in very low yields per acre (Table 7). Viognier grafted to 5C had the third highest yield per cropping vine (9.8 lb) but due to the highest survival rate and highest number of vines with crop of any rootstock included in this trial, it had the highest yield for grafted vines per acre. However, own-rooted vines have had the highest survival rate throughout this study to date, and had a 1.2 ton/acre higher yield than 5C in 2022.

Table 7: Effect of rootstock on vine survival after 15 years and yield in 2023 of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield per vine (lb)	Yield (ton/acre)[1]
110R	57	6.0	1.87
140Ru	18	14.0	1.36
1103P	50	11.1	3.03
5BB	61	9.7	3.21
5C	79	9.8	3.82
Own-rooted	96	9.6	5.05

[1]Yield calculation based on number of vines initially planted.

Own-rooted vines produced fruit with the lowest concentration of soluble solids, lowest pH, highest titratable acidity, and highest concentration of tartaric acid (Table 8).

Fruit from vines grafted to 1103P had the highest soluble solids concentration which was 3.3 Brix higher than with own-rooted vines, and the lowest titratable acidity. Malic acid concentration was lowest with 5BB.

Table 8: Effect of rootstock on fruit composition at harvest in 2023 of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Soluble solids (Brix)	pH	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
110R	23.8	3.37	6.6	7.1	2.2	131	98
140Ru	23.7	3.41	6.7	6.9	2.3	191	127
1103P	25.1	3.55	6.2	6.6	2.9	128	87
5BB	24.1	3.37	6.5	7.3	1.9	151	115
5C	23.5	3.41	6.4	7.2	2.1	165	105
Own-rooted	21.8	3.29	7.1	7.5	2.0	167	120

This Viognier rootstock study was initiated in 2009 with some vine plantings taking place over the following three years to replace missing vines. Monitoring of yield and fruit quality started in 2015 when vines were mature (4 to 7 years old, depending on planting year) and continued until 2023. Vines were removed at the end of the 2023 growing season.

Survival of grafted vines was very low with rootstock 140Ru and highest with rootstock 5C (Table 9). Vine survival was much higher for own-rooted vines at 96 %. Interestingly, mortality of grafted vines was high in the early years of the vineyard whereas only four vines were lost between 2015 and 2023. Still, 79 % vine survival with 5C after 15 years is less than expected. In the 1992 rootstock study with Chardonnay vine survival averages 92.5 % after 32 years, ranging from 82 % with 3309C to 100 % with 5C. The reasons for the high vine mortality rate in the early years are unknown, however the data from this and three other subsequent rootstock trials (see below) suggests that more attention needs to be paid in the early years to reduce vine mortality.

Table 9: Effect of rootstock on vine survival after 15 years, cumulative and average annual yield (2015 – 2023) of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	9-year cumulative yield (ton/acre)	Average annual yield (ton/acre)
110R	57	22.4	2.49
140Ru	18	10.3	1.15
1103P	50	25.4	2.83
5BB	61	25.3	2.81
5C	79	33.1	3.67
Own-rooted	96	32.2	3.58

Own-rooted vines had the highest yield in six out of the past nine years with 5C having had the highest yield in three years. Conversely, 140Ru had the lowest yield in all nine years due to the very low rate of vine survival (Table 9). Rootstocks 1103P and 5BB had nearly identical yields due to higher yields per vine with 1103P as vine survival was 20 % less than with 5BB. Cumulatively (2015 to 2023), vines grafted to 5C produced the largest yield which was 0.9 ton/acre more than own-rooted vines (Table 9).

In general, rootstock effects on fruit composition were minor and inconsistent between years. For grafted vines, fruit from 110R tended to have the lowest total soluble solids and pH values, and the highest titratable acidity and tartaric acid concentration (Table 10). Compared to grafted vines, fruit from own-rooted vines had lower pH and soluble solids (except 110R) and higher titratable acidity and tartaric acid concentration. In six out of seven years (there was no crop in 2021 on 140Ru), grape berries from rootstock 140Ru had the highest concentration of yeast assimable nitrogen.

Table 10: Effect of rootstock on long-term (2015 to 2023, except 2019) average fruit composition of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Soluble solids (Brix)	pH	Titratable acidity (g l^{-1})	Tartaric acid (g l^{-1})	Malic acid (g l^{-1})	Alpha amino nitrogen (mg l^{-1})	Ammonia (mg l^{-1})
110R	27.3	3.33	6.2	7.0	1.6	152	109
140Ru	28.1	3.41	6.0	6.6	1.9	193	130
1103P	28.4	3.41	5.9	6.7	1.9	146	99
5BB	28.7	3.33	6.0	6.7	1.6	156	117
5C	28.2	3.36	5.9	6.6	1.5	165	123
Own-rooted	27.5	3.32	6.4	7.1	1.7	182	130

In summary, the results confirm the conclusion from the initial rootstock study with Chardonnay that Teleki 5C is well suited to the growing conditions at our site. With Chardonnay, the long-term performance of 5C has been superior to rootstocks 3309 Couderc, 101-14 Mgt, and 420 A.

- 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. Vine establishment in year 1 was very good (255 out of 258 vines planted). In late spring of 2018, vines were pruned back to no more than two spurs per vine, and two buds per spur. On 20 April 2018, two missing entries were replanted using leftover vines from the original planting that had been grown in pots at WCRC-OM.

Shoot growth during 2018 was very vigorous. Five vines were lost during 2018. Graft unions were protected by hilling up soil in late fall 2018. Graft union were uncovered again in spring of 2019. Vine assessment showed 250 out of 258 vines originally planted were still alive. There was 100 % vine survival with eight rootstocks but some vine mortality with rootstocks 5C (2), 1616C (1), and 140Ru (5).

Although most vines carried a crop in 2019 no harvest data is available as the vines mere mistakenly harvested by a picking crew after the early freeze event on 10 October 2019.

Graft unions were again hilled over in the fall of 2019 and uncovered in the spring of 2020. Seven more vines were lost during the 2019/20 dormant season. Hilling and uncovering was again repeated during the 2020/21 dormant season. Some missing vines were replaced in late June 2021. At the end of the 2021 growing season only three out of eleven rootstocks 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. Graft unions were protected by hilling up with a wood chip mulch in November 2021.

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

Table 11: Effect of rootstock on vine survival after four years and yield in 2023 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	100	5.75	2.14
140Ru	65	5.27	1.44
1103P	96	5.86	2.32
1616C	96	7.64	3.20
101-14	96	5.71	2.30
3309	100	4.15	1.79
5C	91	6.34	2.60
Riparia Gloire	91	4.12	1.75
Salt Creek	100	4.40	1.85
Schwarzmann	96	3.54	1.49
SO4	87	7.29	2.90

[1]Yield calculation based on number of vines initially planted.

Vines were dormant pruned in March/April 2023. Except for some shoot and fruit thinning most of the seasonal vineyard work was performed by the cooperating grower. Fruit was harvested on 4 Oct 2023. Vines grafted to 1616C, SO4 and 5C had both the highest yield per cropping vine and yield per acre. (Table 11). Vines on Schwarzmann had the lowest yield per cropping vine followed by vines grafted to Riparia Gloire and

3309. However, the lowest yield per acre was recorded with rootstock 140 Ru due to the lowest survival rate of 65 %. All other rootstocks have survival rates above 85 %.

Fruit composition of Cabernet Sauvignon at harvest was very similar irrespective of the rootstock used (Table 12).

Table 12: Effect of rootstock on fruit composition at harvest in 2023 of Cabernet Sauvignon growing in a commercial vineyard in the western part of Orchard Mesa near Grand Junction, CO.

Rootstock	Soluble solids (Brix)	pH	Titratable acidity (g l^{-1})	Tartaric acid (g l^{-1})	Malic acid (g l^{-1})	Alpha amino nitrogen (mg l^{-1})	Ammonia (mg l^{-1})
110R	29.2	3.80	5.5	7.4	2.8	220	154
140Ru	28.0	3.74	5.8	7.3	3.0	273	202
1103P	29.0	3.82	5.3	7.3	2.9	217	167
1616C	28.3	3.84	6.0	7.3	3.7	292	209
101-14	28.4	3.94	5.3	7.2	3.1	305	198
3309	28.7	3.87	5.6	7.3	3.3	274	190
5C	28.0	3.84	5.6	7.3	3.2	259	192
Riparia Gloire	30.2	3.88	5.5	7.2	3.0	218	158
Salt Creek	28.6	3.84	5.2	7.4	2.4	230	172
Schwarzmann	29.8	3.86	5.4	7.4	2.9	220	158
SO4	27.9	3.87	5.6	7.1	3.4	260	185

- 2018 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 May/June 2018 on a grower cooperator's vineyard in the central part of Orchard Mesa. The following rootstocks were planted on 24 May 2018 using dormant potted vines: 110 Richter, 140 Ruggeri, 1103 Paulsen, 1616C, 101-14 Mgt, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, and SO4. Green potted vines on rootstock Teleki 5C were planted on 14 June 2018. There was a shortage of vines grafted to 5C, 1616C, and 1103 Paulsen. Missing vines were planted in June of 2019. The site is located about 3.5 miles East of WCRC-OM. The trial is set up as a randomized complete block design with 6 replications, and 4 vines per replication. 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 cooperator.

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 ranges from 58 % with rootstocks Riparia Gloire and 101-14 to 100 % for 1616C (Table 13).

Only 39 out of 66 entries (6 replications of 11 rootstocks) produced a crop in 2023. Yields ranged from 0.46 ton/acre with rootstock 3309 to 2.36 ton/acre with rootstock Schwarzmann. Less than 40 % of the surviving vines grafted to 1103P produced a crop in 2023; hence the low yield per acre despite a yield of >5 lb per cropping vine. The percentage of surviving vines carrying a crop varied from a low of 39 % with 1103P to a high of 85 % with Saltcreek. The average yield across all rootstocks in 2023 was 1.73 ton/acre.

Table 13: Effect of rootstock on vine survival after four years and yield in 2023 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	83	4.42	1.20
140Ru	88	4.90	1.23
1103P	75	5.36	0.85
1616C	100	4.83	1.65
101-14	58	5.85	1.06
3309	75	1.46	0.46
5C	88	4.83	1.53
Riparia Gloire	58	6.12	1.53
Salt Creek	83	2.93	1.13
Schwarzmann	79	6.93	2.36
SO4	96	5.42	2.09

[1]Yield calculation based on number of vines initially planted.

Unlike the other rootstock study with Cabernet Sauvignon (see above) there were some pronounced differences in fruit composition between rootstocks. Cabernet Sauvignon grafted to 1103P had the second lowest pH and lowest soluble solids concentration but the highest concentration of total titratable acidity, tartaric acid, and malic acid (Table 14). Combined those data indicate that fruit from 1103P was the least mature of any of the rootstock combinations. In contrast, fruit from vines grafted to Schwarzmann had the highest pH and second highest concentration of soluble solids but the lowest concentration of total titratable acidity and tartaric acid, and second lowest malic acid values. This indicates an advancement in fruit maturity even as vines on Schwarzmann had the highest yield (Table 13).

Table 14: Effect of rootstock on fruit composition at harvest in 2023 of Cabernet Sauvignon growing in a commercial vineyard in the central part of Orchard Mesa near Palisade, CO.

Rootstock	Soluble solids (Brix)	pH	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
110R	27.7	3.42	6.2	6.4	2.0	148	119
140Ru	27.4	3.60	6.6	6.6	3.5	226	193
1103P	25.8	3.35	8.1	6.9	4.1	185	184
1616C	27.7	3.58	5.4	6.2	1.5	150	132
101-14	27.4	3.54	6.0	6.1	2.4	174	152
3309	27.3	3.52	6.1	6.0	2.4	175	168
5C	28.1	3.60	5.8	6.2	2.3	162	144
Riparia Gloire	26.9	3.61	6.5	6.1	3.1	212	190
Salt Creek	26.3	3.34	7.2	6.7	3.0	175	183
Schwarzmann	27.9	3.67	5.2	5.7	1.7	183	159
SO4	26.7	3.46	6.6	6.5	2.8	171	160

- 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. Replacement vines for all the other rootstocks have been ordered for planting in 2024. Overall vine survival of the original 2019 planting is 80 %, ranging from 50 % with 1103P to 96 % with 101-14 (Table 15).

Yield per cropping vine was highest with rootstock 1616C while vines on SO4 produced the highest yield per acre (Table 15). 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 %. Also, only 75 % of the mature surviving vines on 1103P produced a crop compared to 100 % of all other rootstocks. All rootstocks except 1103P produced 4.5 to 5.5 ton/acre. Averaged across all rootstocks the yield in 2023 was 4.58 ton/acre, more than twice that of 2022.

Table 15: Effect of rootstock on vine survival after 5 years and yield in 2023 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	7.67	4.56
1103P	50	9.09	2.32
1616C	71	10.11	5.30
101-14	96	7.05	4.68
3309	92	7.30	4.53
5C	83	8.85	5.18
SO4	88	8.39	5.49

[1]Yield calculation based on number of vines initially planted.

Rootstock effects on fruit composition at harvest were small (Table 16). Similar to the results from the 2018 Cabernet Sauvignon rootstock study (Table 14), Souzao grafted to 1103P produced fruit with the lowest pH and highest titratable acidity (equal to SO4) and highest tartaric acid concentration. Yeast assimable nitrogen (YAN) concentrations were down slightly compared to the 2022 harvest but still relatively high with an average value >300 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	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
110R	24.3	3.46	6.9	6.6	2.9	184	128
1103P	24.1	3.35	7.4	7.0	2.6	190	131
1616C	24.0	3.47	7.1	6.4	3.1	209	134
101-14	23.8	3.48	6.8	6.9	2.6	228	131
3309	23.8	3.51	6.8	6.5	2.8	239	134
5C	23.7	3.46	7.1	6.6	3.0	213	135
SO4	23.8	3.42	7.4	6.4	3.0	213	126

- 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 infestation before vine productivity has declined to such a low level that it requires replanting. Generally at this point, vines are pulled in fall shortly after harvest, then the vineyard is prepared for replanting with grafted or phylloxera-tolerant cultivars the next spring. With this approach, similar to a newly planted vineyard, the first crop is expected in year 3. Another option, however, is to interplant with vines of the new cultivar 2 to 3 years before the anticipated removal. While at that time the vineyard productivity is already declining, vines are still productive enough to not yet warrant removal. With good management, the inter-planted vines can be grown so that at the end of the second or third season, when own-rooted vines need to be removed, canes can be tied to the cordon wire, and a crop can be produced the following season. The advantage of the interplant approach is that there is no 2-year break in crop production. However, it requires good management of the inter-planted vines.

A new trial to evaluate the inter-planting approach was established in early May 2017 at WCRC-OM. A total of 120 dormant Chardonnay (clone 99) vines grafted to SO4 rootstock were inter-planted in a block of Chardonnay planted with own-rooted vines in 1991. Phylloxera was discovered in this block in December 2016. For several years prior to the discovery of phylloxera, vine vigor and yield had been severely depressed at the northern end of the block while the southern part was not affected. Original vine spacing is 5 feet, and interplants were planted midway between the existing vines. As this block is also used for the cover crop / irrigation study (see below), some areas of the block are drip irrigated while other areas are irrigated by micro-sprinklers.

Vine establishment in year 1 was very good. All vines established, and many vines had >0.5 m shoot growth. Graft unions were covered with soil in late fall, and uncovered again in May 2018. Vines were pruned in late spring 2018, leaving no more than two spurs per vine, and two nodes per spur. No more than two shoots per vine were trained up during the 2018 growing season. Graft unions were protected again with soil in late fall 2018.

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

Inter-planted vines produced the equivalent of 0.16 ton per acre in 2019 compared to 1.6 ton per acre from the mature vines. Both yields are way too low to meet annual operating costs. It is reasonable to expect a yield of 1 to 2 ton per acre in year 3 so inter-planted vines produced less than 10 % of what is expected.

Combined yields of inter-planted and mature own-rooted vines in 2020 were again much below expectations at 1.16 ton/acre. Mature grafted vines 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.

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.

The cumulative yield after seven years from the combination of grafted inter-planted and mature own-rooted vines (removed at the end of year four) is 11.3 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 14.6 ton/acre. Cumulative yields were similar up until the third harvest but vines growing without competition from mature vines produced higher yields from year six onwards. However, there is a substantial impact of irrigation method on the yield in the study on graft union management. Drip irrigated vines in this study produced 3.73 ton/acre in 2023, i.e. a nearly identical yield to that of the inter-planted vines, while vines irrigated by micro-sprinklers yielded 5.39 ton/acre.

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.

Initially, for treatments with the graft union below the soil surface, the planting holes were only partially filled so that the graft unions did not get covered by soil. In late fall, more soil was added to those holes right up to the level of the soil surface. Graft unions will remain covered for the remainder of the experiment. Graft unions of Control vines with graft unions placed 2" above the soil 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, and 2023 the CC vines were again checked for scion rooting, and the graft union covered up again right after the observations. Again, no scion roots were found.

So far the results from this second part of the study are promising. No scion rooting has been observed after four years of continuous cover with a wood chip mulch. If no scion rooting can be confirmed in future years then this practice could replace the annual hilling up in fall and uncovering in spring. From a practical perspective it should be noted that the wood chip mound stayed intact around the graft union of drip irrigated vines but there was a need to touch up the mound of micro-sprinkler irrigated vines. A few more years of observations are required before a final conclusion about the feasibility of this practice can be made.

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

Based on the promising results with wood chips to protect the graft union 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. Unlike the 2017 study, the planting holes for the treatment 2” below soil surface were not filled up entirely, leaving the graft union exposed. In fall of 2021 those holes were filled up to the soil surface. Half the holes in this treatment were filled with soil, the other half with wood chip mulch. Graft unions will remain covered throughout the experiment. Graft unions of half the Control vines were covered in fall 2021 with soil while graft unions of the other half of the Control vines were covered with wood chip mulch. In early May 2022, for each covering treatment of the Control (soil or wood chip mulch), half the graft unions were uncovered while the other half remained covered (treatment CC). Uncovered graft unions were covered up again in the fall of 2022, uncovered in spring 2023, and covered again in fall 2023. These annual covering / uncovering treatments will be applied to the same Control vines for the remainder of the experiment. The graft unions of the CC treatment as well as the graft unions placed 2” below ground will remain covered throughout the experiment, 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 continously covered with wood chips. However, 3 out of 10 vines with the graft union above ground and continously 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.

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 initiated in mid October 2023, prior to a killing frost on 30 October. Tests with cultivars Chardonnay and Syrah were conducted on a weekly basis with other cultivars tested every other week. For further information and updates visit:

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

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

Previous CWIDB-funded work has revealed that while Colorado is warming, and this warming trend is expected to continue, trends in killing freezes, described herein as Low Temperature Injury Events (LTIEs) for both European wine grapes *Vitis vinifera* and interspecific cultivars are less clear. Understanding how risks may change is important for Colorado grape producers, marketers, and investors in projecting and planning for the Colorado wine industry's future. Global climate models designed to simulate future weather conditions under various carbon emission scenarios offer clues into how LTIE frequency may change in the future. We examined changes in LTIE frequency across Colorado in 18 global climate change models.

Methods: An ensemble of Climate Model Intercomparison Project 6 global climate models was used to estimate changes in LTIE risk by the middle and end portions of the 21st century. All model data were downloaded at daily temporal resolution, and have been locally downscaled to 6 km resolution. Climate model data was obtained from https://cirrus.ucsd.edu/~pierce/LOCA2/. For more information on the Climate Model Intercomparison Project see Pierce et al. 2023. For additional information on how these models were downscaled to 6 km visit Pierce et al. 2014.

Previous CWIDB-funded projects used Parameter-elevation Regressions on Independent Slopes (PRISM) Model daily minimum temperature data to map the frequency of LTIEs across Colorado. LTIEs were determined using the methodology outlined in Goble et al. 2023. This table is provided here for the reader's convenience. It should be noted that these temperature thresholds are conservative, i.e. we are taking a cautious approach. Grapevine cold hardiness varies throughout the dormant season, even responding to temperature fluctuations when tissues are at their most hardy. There is a high level of uncertainty especially late in the growing season / early in the dormant season. This can be illustrated by very large differences in bud cold hardiness that were observed in late October 2019 and 2020. In 2020, an overnight low of 14 °F on October 26th followed by 9 °F on the 27th caused 100 % bud mortality to most *Vitis vinifera* cultivars in the Grand Valley. In fact, most vines of *Vitis vinifera* cultivars were killed to soil line and required retraining. We observed some bud and even trunk damage on cold-hardy interspecific cultivars. In contrast, minimum temperatures of 8 ºF and 9 °F on October 30th and 31st in 2019 caused only minor bud damage to the majority of *Vitis vinifera* cultivars and no damage to interspecific cultivars. Controlled freezing tests showed lethal temperatures to kill 50 % (LT_{50}) of Chardonnay buds of 4.5 °F just prior to the cold event in 2019. In 2020, LT_{50} of Chardonnay buds just prior to the cold event was only 11 °F, thus explaining the very large difference in cold injury in late October between the two years.

Table 17: Low temperature injury events thresholds for *Vitis vinifera* and medium cold-hardy interspecific cultivars. Based on data from Goble et al. 2023.

Vitis vinifera cultivars	Interspecific cultivars
T_{min} < 10 ˚F before October 31st	T_{min} < 8 ˚F before October 31st
T_{min} < 5 ˚F before November 15th	T_{min} < 0 ˚F before November 15th
T_{min} < 0 ˚F before December 1st	T_{min} < -8 ˚F before December 1st
T_{min} < -8 ˚F at any point	T_{min} < -13 ˚F at any point
T_{min} < 28 ˚F between May 15th and September 30th	T_{min} < 28 ˚F between May 15th and September 30th

We first compared historical CMIP6 historical data to PRISM historical data for 1985-2014, ensuring that CMIP6 is downscaling produces reasonable results. We then looked at how LTIE frequency may change by computing the number of years with at least one LTIE occurring in mid-century (2036-2065) and late-century (2071-2100) under a moderate, high, and very high carbon emission scenario.

The moderate, high, and very high carbon emissions scenarios come from three different "shared socioeconomic pathways" (ssps) (Riahi et al. 2017). Shared socioeconomic pathways are designed to approximate how carbon emissions may change under various future geopolitical scenarios. There are five commonly used ssps: 1. The "green" pathway, 2. Middle of the road emissions, 3. Regional rivalry, 4. Inequality, and 5. "Taking the highway." Ssps 1-5 are labeled sequentially in order of how high carbon emissions throughout the remainder of the century are projected to be.

In this study we used data from ssps 2, 3, and 5. Each ssp includes an estimate for how many additional W m^{-2} of thermal energy the earth's surface will emit by the end of the 21st century. These estimates are 4.5, 7.0, and 8.5 respectively for the pathways used in this study, so the three emissions scenarios are labeled ssp 245, ssp 370, and ssp 585 from here on out.

Previous statements of work have used the PRISM to estimate LTIE frequency historically (Daly et al. 2008). The historical dataset used to calibrate the CMIP6 ensemble used here generates significantly colder daily minimum temperatures, especially in winter (Lukas et al. 2020). Differences in some parts of western Colorado average greater than 5 ˚F/month (Fig. 1.1). For consistency's sake the CMIP6 data, both past and present, were bias corrected to more closely match PRISM. All CMIP6 temperature data were adjusted up-or-down by the average difference between CMIP6 and the nearest PRISM gridpoint for the current month. This was done using the final 30 years in the "historical" CMIP6 dataset (1985-2014). "Historical" is put in quotations here since CMIP6 data for past years are not observations, but climate model simulations based on global greenhouse gas concentrations, and bias corrected using observations.

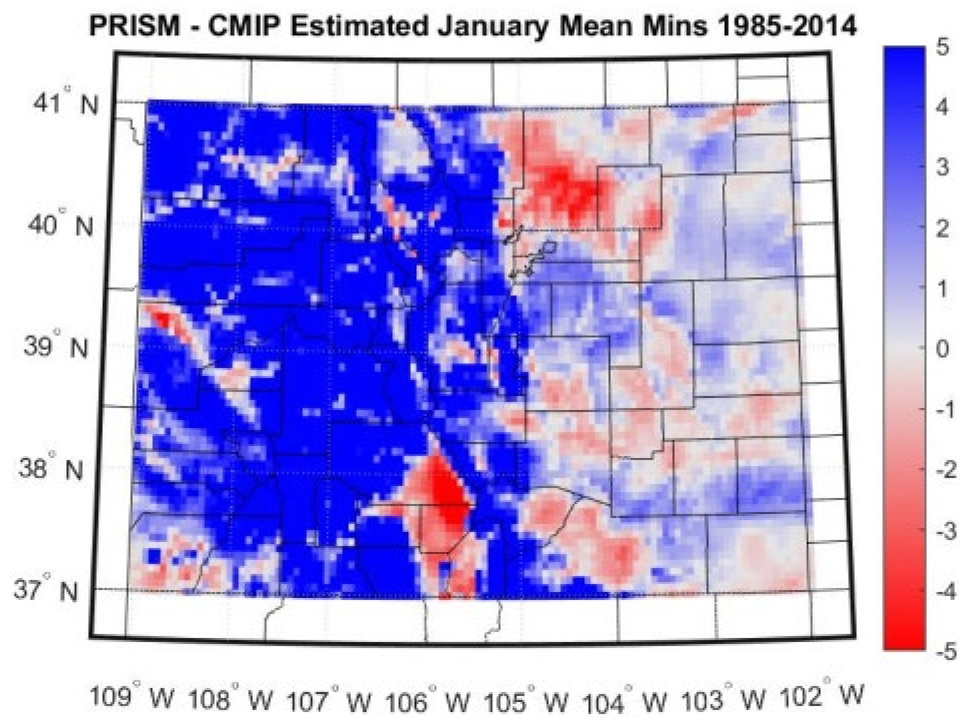


Fig. 1: Average minimum daily temperature difference between PRISM and CMIP6 data for January. Based on years 1985-2014.

Daily minimum temperature data were used from all 18 CMIP6 models using ssps 245, 370, and 585 to map 1). Fraction of LTIE years across Colorado for 2036-2065 and 2071-2100; 2). Change in fraction of LTIE years across Colorado from 1981-2010 to 2036-2065 and from 1981-2010 to 2071-2100; 3). Model spread, specifically the inner quartile ranges of model estimated fraction of LTIE years for 2036-2065 and 2071-2100; and 4.) Potential "viticultural exploration opportunities" for 2036-2065 and 2071-2100. "Exploration opportunity" areas are where LTIEs occur in fewer than 20 % of years.

This was done for both *Vitis vinifera* and interspecific cultivars using LTIE thresholds from the table above. Finally, timeseries were plotted depicting LTIE frequency from 2031-2100 for cities with either current or prospective vineyard activity (e.g. Grand Junction, Cortez, Cañon City), and for some cities where trends suggest more activity may be possible in the future (e.g. Boulder, Rangely) using data from ssp370 and thresholds for both *Vitis vinifera* and interspecific cultivars (Fig. 2).

Results: The average fraction of Colorado experiencing a LTIE in a given year between 1981 and 2010 for the CMIP6 ensemble was 91 %. The average fraction in the PRISM dataset was 82 %. Figure 3 shows the statewide fraction of LTIE years 1985-2014 for both PRISM and the CMIP6 ensemble. Both show low LTIE frequency in the Grand Junction/Palisade area and the Four Corners, but CMIP6 shows a greater frequency of LTIEs in other portions of western Colorado such as western Mesa, Montrose, San Miguel, and Dolores Counties. CMIP6 generally shows greater LTIE frequency for the Arkansas River Basin in southeastern Colorado. The PRISM data should be regarded as the more accurate data source since it is based on real-world observations, and fit to a grid using carefully constructed interpolation schemes. CMIP data come from climate model weather simulations based on measured global greenhouse gas concentrations over the years. Given the overestimation of LTIEs in CMIP6 model runs, this data source may be prone to generating conservative estimates, or underestimates, of how much land will become suitable for wine grape growth in the future. Data resolution is a concern. Locally downscaled CMIP6 data is run at 6 km grid resolution. PRISM is run at 4 km resolution. Even 4 km is a coarser-than-ideal scale given the complex topography of western Colorado, sprinkled with canyons, mesas, and valleys.

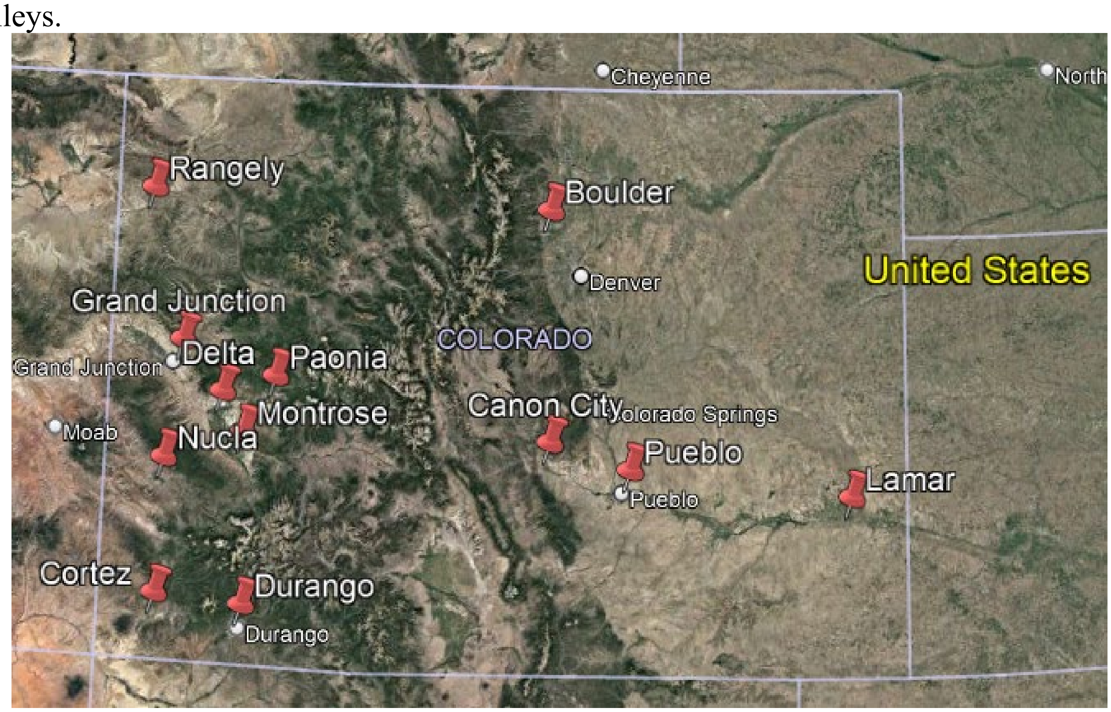
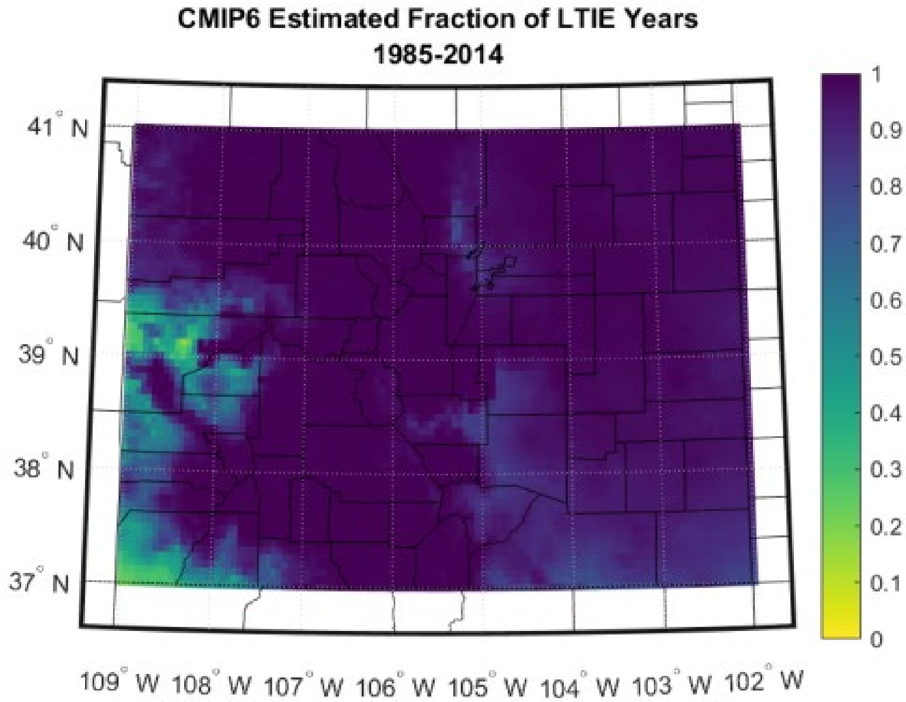


Fig. 2: Locations of Low Temperatute Injury Events projections plotted in Fig. 8.



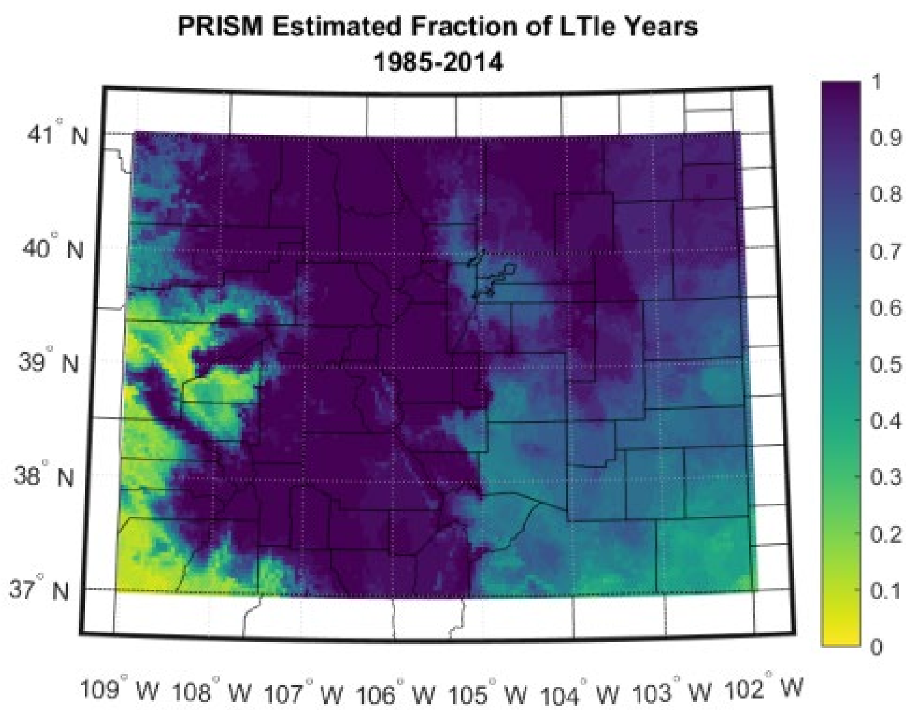


Fig. 3: Fraction of years experiencing a low temperature injury event for water years 1985-2014 from the Climate Model Intercomparison Project (top), and PRISM (bottom).

Projected changes in statewide climatological suitability for growing *Vitis vinifera* are generally small between the mid-21st century and the historical baseline (1985-2014). The annual average fraction of Colorado experiencing a LTIE for *Vitis vinifera* during the historical baseline years was 91 %. This drops to 82 % for ssp245, 80 % for ssp370, and 78 % for ssp585 by mid-century (2036-2065). The average fraction of Colorado experiencing a LTIE was reduced to 72 % for ssp245, 62 % for ssp370, and 53 % for ssp585 by late century (2071-2100). These fractions shrink to 68, 65, and 64 % by mid-century and 55, 45, and 34 % by late century when using the thresholds from Table 1 for interspecific cultivars.

Climate models indicate a potential broadening of the suitable range for *Vitis vinifera* around the currently cultivated areas (Figs. 4, 5). The Grand Junction and Palisade area, and the Four Corners area are shown as suitable with the historical baseline years, but only over a narrow area range. This range broadens considerably by mid-century under a very high emissions scenario and by the end of the century under all emissions scenarios investigated here. The largest changes are projected to occur in Mesa, Montrose, San Miguel, Dolores, Montezuma, and La Plata Counties. The frequency of LTIEs does decrease for eastern Colorado in all scenarios as well, but not by as much, and arguably not to the point of being suitable for *Vitis vinifera* (Figs. 4, 5, 6). One of the most notable results for eastern Colorado was the spread among climate models, especially by the end of the century (Fig. 6). The difference between 75th and 25th percentile climate models in ssp245 and ssp370 is between 0.30-0.50, meaning LTIEs may either be frequent or very infrequent by the end of the century in eastern Colorado. The one scenario where most climate models agree in a large change in suitability for *Vitis vinifera* for eastern Colorado is the ssp585 scenario by the end of the century.

If experiencing LTIEs in fewer than 20 % of years is used as a threshold of "suitability," or an "exploration opportunity," then Figure 7 shows the projected changes in area of Colorado suitable for growing *Vitis vinifera* and interspecific cultivars. As discussed above, by mid-century (2036-2065) the area suitable for *Vitis vinifera* and interspecific cultivars generally broadens around currently suitable areas in Mesa and Montezuma Counties as well as expanding in Delta, Montrose, San Miguel and Dolores Counties. Eastern Colorado remains too cold by mid-century for all ssps. Projections diverge considerably as a function of emissions pathway by the late 21st century (2071-2100). All pathways continue to show broader swaths of western Colorado as suitable for *Vitis vinifera* and interspecific cultivars. Ssp585 shows much of eastern Colorado becoming suitable for interspecific cultivars. The range of eastern Colorado recommended for interspecific cultivars is much more confined for ssps245 and 370, and include the Cañon City area, portions of the urban corridor around Denver, Boulder, and Colorado Springs, and the far southeastern portion of the state.

Most current or prospective locations of grape growth around the state do show downward trends in LTIEs over time for all ssps (trends shown for ssp370 in Fig. 8). Portions of Colorado such as Grand Junction, Delta, Montrose, Paonia, Cañon City, and Nucla that see few LTIEs relative to the rest of the state will continue to see decreasing LTIE risk in the future. Other areas like Durango and Boulder that are too cold to be suitable for production now may become viable over time, especially for interspecific cultivars. The northwestern and southeastern corners of the state (e.g. Lamar, Rangely) see large decreases in the frequency of LTIEs, but not to the point where an overwhelming majority of years are LTIE-free. What Fig. 8 does not show is the spread among climate models. This is important for a couple reasons: The observed interdecadal variability will not be as smooth as shown by an 18-model average. Observed temperature patterns and individual model output suggest that even as temperatures warm the decrease in LTIEs with time will be nonlinear and highly stochastic. In other words, a decade with four or five LTIE years in places like Grand Junction and Palisade that see few LTIEs on average, should not be considered impossible.

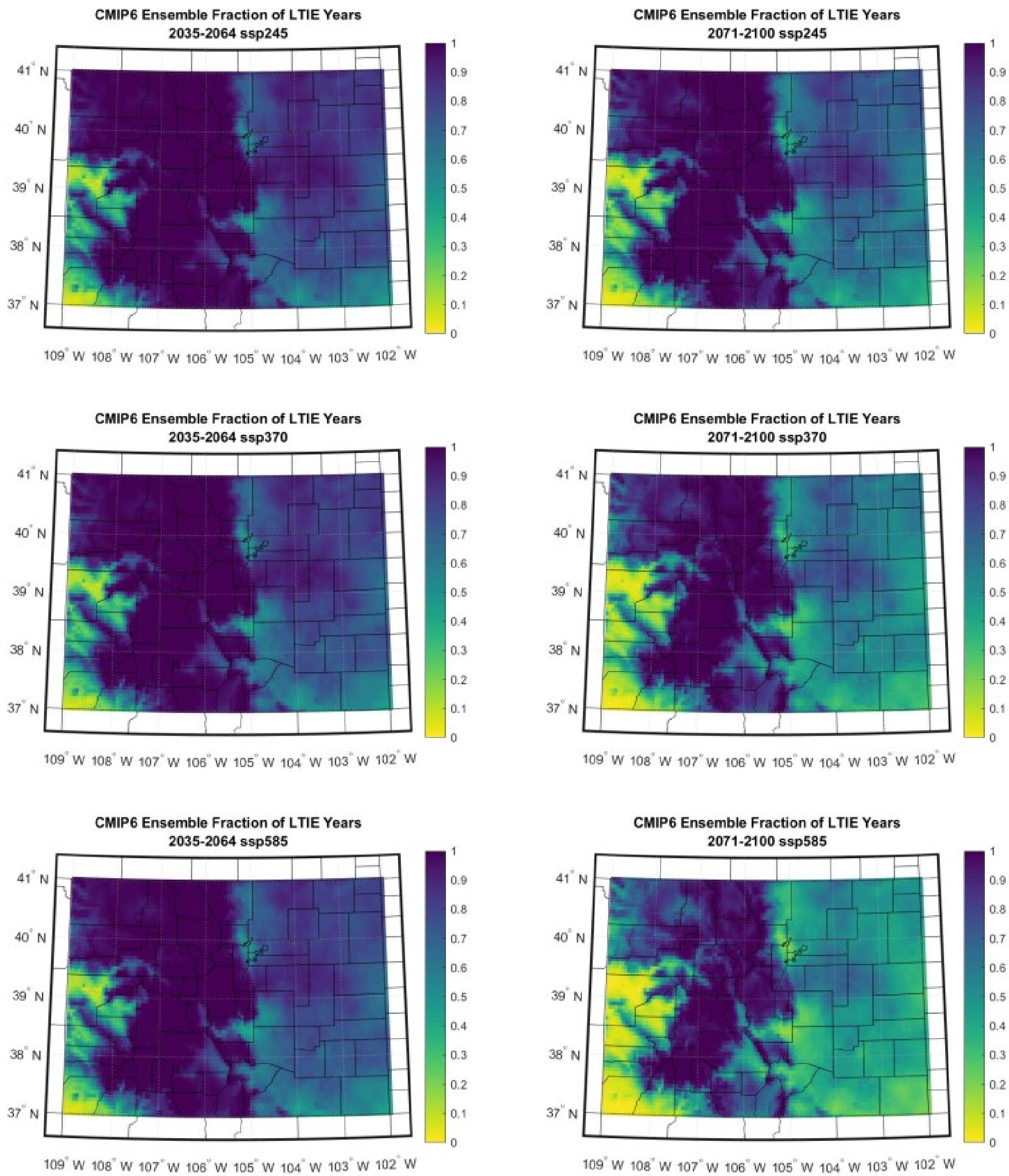


Fig. 4: Colorado maps of fraction of years receiving at least one LTIE (0-1) in years 2035-2064 (left) and 2071-2100 (right) for emission scenarios ssp245 (top), ssp370 (middle), and ssp585 (bottom).

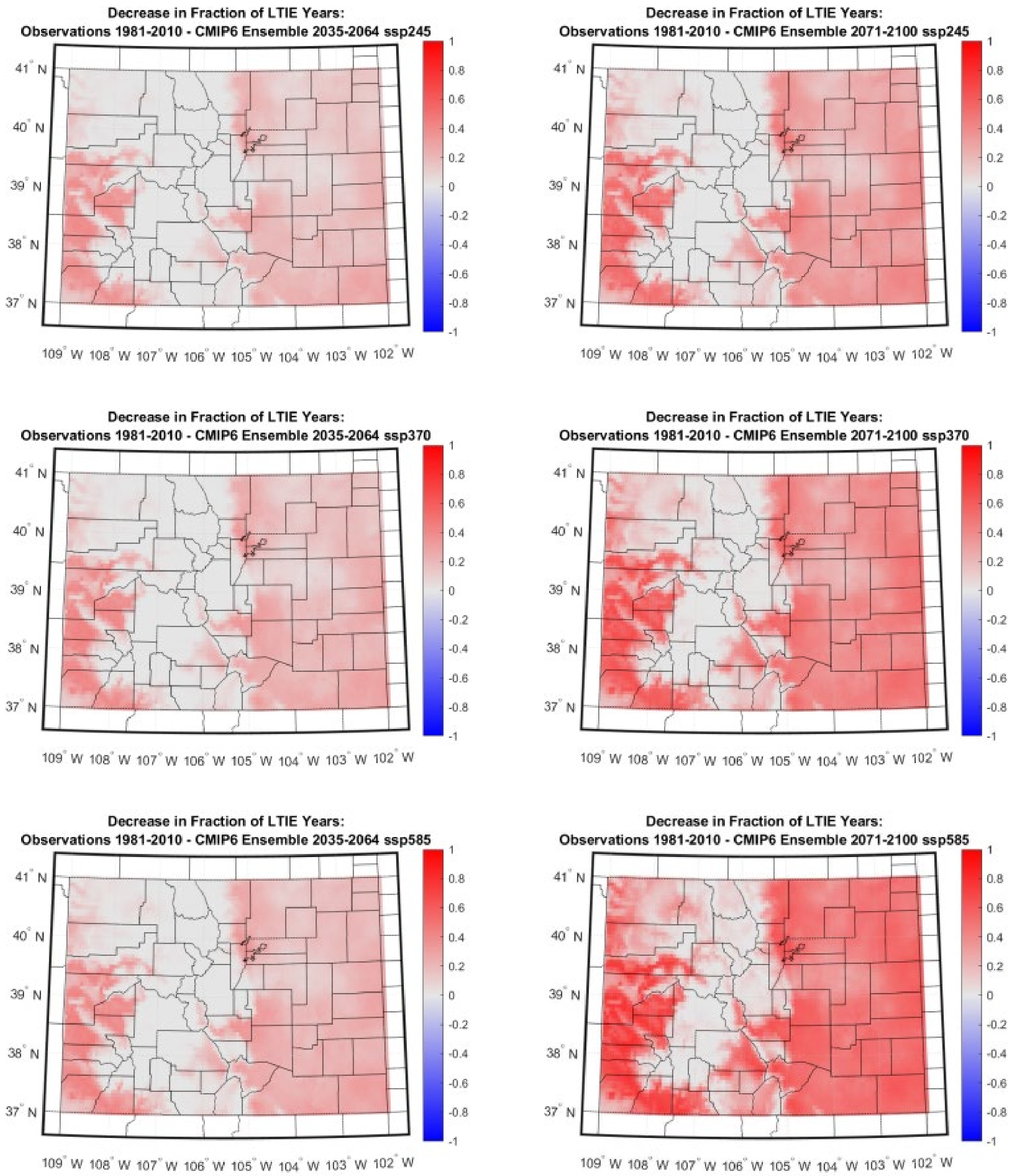


Fig. 5: Colorado maps of fraction of years receiving at least one LTIE (0-1) in years 2035-2064 (left) and 2071-2100 (right) for emission scenarios ssp245 (top), ssp370 (middle), and ssp585 (bottom) subtracting baseline period 1981-2010.

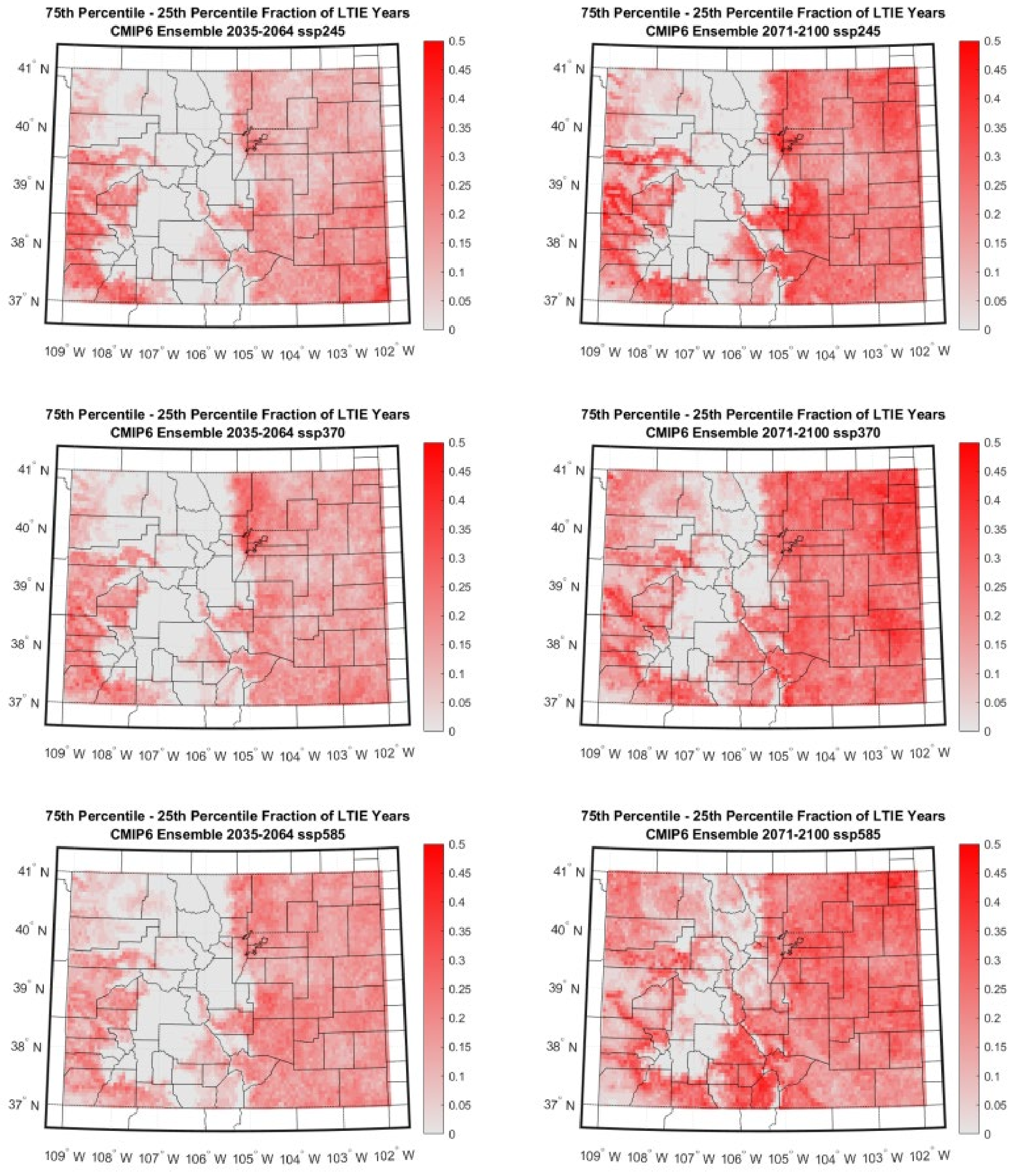


Fig. 6: Colorado maps of CMIP6 model inner quartile range in fraction receiving at least one LTIE (0-1) in years 2035-2064 (left) and 2071-2100 (right) for emission scenarios ssp245 (top), ssp370 (middle), and ssp585 (bottom). Higher numbers mean higher future uncertainty.

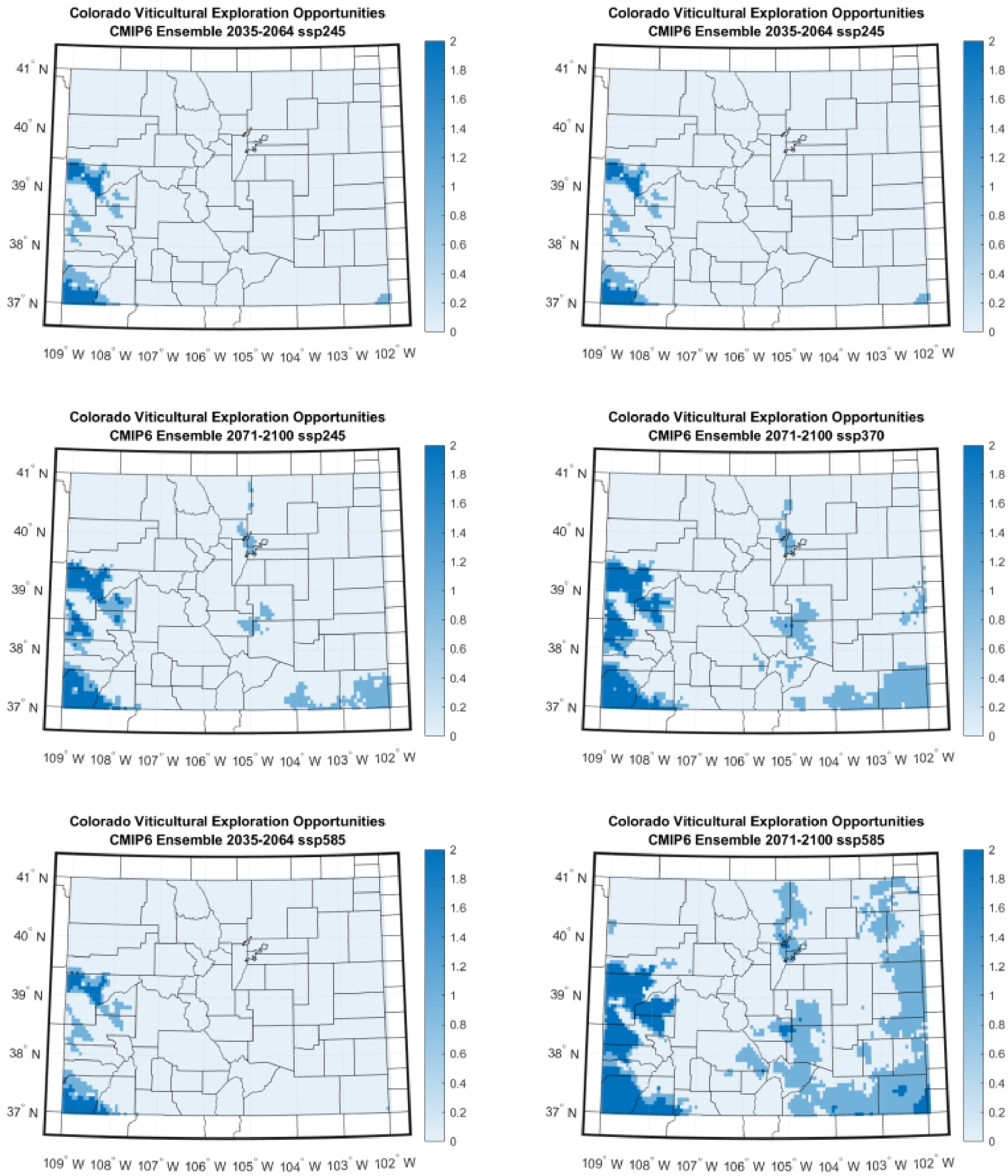


Fig. 7: Colorado maps of CMIP6 ensemble-estimated viticultural “exploration opportunities” for *Vitis vinifera* (dark blue) and interspecific cultivars (light blue) in years 2035-2064 (left) and 2071-2100 (right) for emission scenarios ssp245 (top), ssp370 (middle), and ssp585 (bottom).

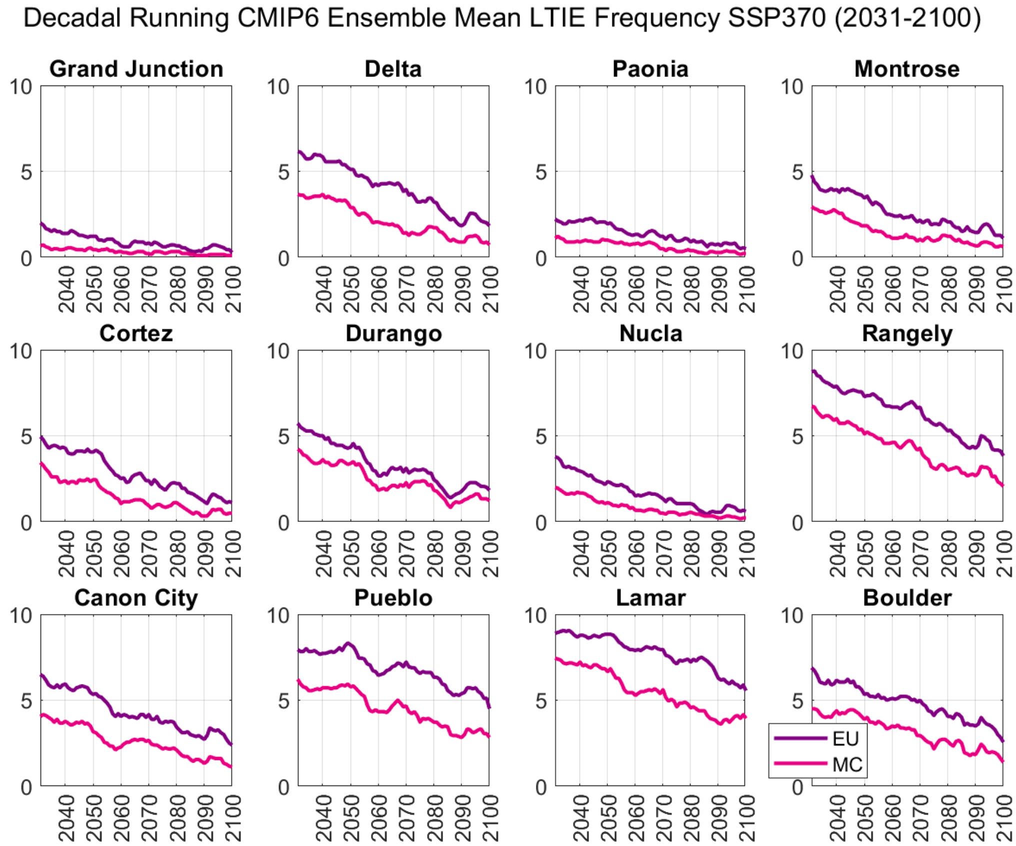


Fig. 8: Running 10-year sum of number of years with at least one LTIE for *Vitis vinifera* (or European varieties EU, purple) and interspecific cultivars (MC, pink)

Discussion: All future carbon emission scenarios presented here lead to decreases in LTIEs in Colorado for both *Vitis vinifera* and interspecific cultivars. It is likely that the area of suitable land for viticulture, from a temperature standpoint, will widen around the currently viable areas. All scenarios suggest an increased area of western and southwestern Colorado may be suitable for cultivating grapes by mid-century, with an even wider range possible by late century. This range is similar for moderate, high, and very high carbon emission scenarios (ssp245, ssp370, and ssp585) by mid-century, but these scenarios diverge greatly by the late century. However, all scenarios point to increased area of suitability for *Vitis vinifera* and interspecific cultivars in Mesa, Montrose, San Miguel, Dolores, Montezuma, and La Plata Counties.

Eastern Colorado results varied widely based on the climate model and carbon emission pathway used. Higher emission scenarios show wide swaths of eastern Colorado becoming exploration opportunities for interspecific cultivars based on LTIE occurrence in fewer than 20 % of years by the late century. This includes the urban corridor of Colorado with the Boulder area showing the best suitability along the Front Range. However, due to the risks of severe weather in eastern Colorado (Childs and Schumacher 2019), which may increase in a warmer climate (Childs et al. 2020), and the increasing risk of extreme heat and drought by the end of the century for high and very high greenhouse gas scenarios, eastern Colorado may not be as tenable. There are important and notable exceptions (e.g. Cañon City), however our results suggest that investments in future viticultural expansion is much more likely to be met with favorable climatic conditions on the west slopes of Colorado.

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Task 1.2 (Water Year 2024 Freezes): This task will be performed at the end of the 2023-2023 cold season.

Task 2 (CoAgMET Station Installations): We have ordered the equipment for one new CoAgMET-lite station, and one new full CoAgMET station from Campbell Scientific. Weather permitting, these stations will be installed early in 2024. The Lebanon station will be upgraded to a full CoAgMET station, and the lite equipment will be moved to Fox Fire Farms in La Plata County. The new CoAgMET-lite station will be installed in Nucla.

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, and Gardner)

Approximately 40% of the vineyards in Colorado are drip irrigated. While drip and sub-surface drip irrigation are the most water efficient methods of irrigation, the question arises how to manage the inter-row area. Precipitation in Colorado's semi-arid climate is generally insufficient to maintain a green cover crop. Many older vineyards were set up with drought tolerant grasses sown in the inter-row area, but over the years those grasses have died out and been replaced by weeds. Some growers opt to clean-cultivate the inter-row, others maintain bare soil using herbicides or mow the resident vegetation. Bare soil or minimal vegetation cover in the inter-row is likely to degrade soil quality that potentially has negative impacts on vine performance. Results from the cultivar trial at Rogers Mesa (see Viticulture Webpage) show a very strong effect of soil condition and irrigation system on yield and fruit quality[2].

To further investigate the effects of different soil and irrigation management on long-term vineyard productivity and vine and soil fertility, an experiment was initiated in the fall of 2013 in the Chardonnay block at the Orchard Mesa site that was planted in 1992. These vines have been drip irrigated since planting, with an initial crested wheatgrass cover crop planted in the inter-row area. Over time the grass has been replaced by weeds and/or bare soil. Vine vigor is low in many areas of the block - a situation not uncommon in older commercial vineyards. After the 2013 harvest, the irrigation system was changed from drip to sprinkler, and four replicated cover crop treatments established: two different grass-only cover crops; one grass-legume mix; and one legume mix. During the 2014 growing season the vineyard was sprinkler irrigated to optimize the establishment of the cover crops. In spring 2015 one of the grass-only treatments ("Hycrest" crested wheatgrass) was returned to drip irrigation (the "standard" situation since planting in 1992).

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 were no vine losses during the

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[2] Sprinkler-irrigated vines with a grass cover crop growing in the inter-row area have produced on average 2.8 times more yield than drip irrigated vines with a bare soil inter-row area. Fruit maturity was almost always enhanced (berries higher in soluble solids and pH, and lower in titratable acidity) under drip irrigation and bare soil. An analysis of data from the 2012 grape grower survey also suggests higher yields with furrow or sprinkler irrigation versus drip irrigation.

2021, 2022, and 2023 growing seasons. The majority of 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 two times during the remainder of the 2023 season.

Vine vigor in this replant situation has been low and vines produced only a small crop of 0.5 ton/acre in this third growing season compared to 3.76 ton/acre for mature vines growing in adjacent rows.

In November 2023, soil samples were taken from the center of the cover crop plots as well as underneath the vines. Soil samples have been prepared for submission to a laboratory to analyze soil nutrients, pH, and organic matter.

Cover crop plots will be maintained and the establishment and performance of the new vines will be monitored in future years.

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

Results from the 2004 cultivar trial at WCRC-RM show a very strong effect of soil management and irrigation system on yield and fruit quality. Briefly, sprinkler-irrigated vines with a permanent grass cover crop growing in the inter-row area have produced on average 2.8 times more yield than drip irrigated vines with a bare soil inter-row area. The hard fescue cultivar used in the study at WCRC-RM was Aurora Gold, a cool-season turf with a natural tolerance to Roundup. It is a low maintenance grass with good drought and shade tolerance. In the study at WCRC-RM, as well as the more recent study at WCRC-OM, Aurora Gold has produced a very dense, low growing turf with minimum weed presence, even in the absence of Roundup applications. Due to its low growing nature and the oppression of weed species it is very easy to manage. Over the years we have received many grower enquiries about this grass cover crop, and where to buy seeds. Unfortunately, seeds of Aurora Gold are scarce.

In late summer of 2018, a new study to evaluate different grass species / cultivars with similar characteristics to Aurora Gold was established in a mature vineyard block at WCRC-OM. Irrigation in this block was changed from dip to micro-sprinkler. In early September 2018, five different turf cultivars and one blend were sown: 'Shademaster III' and 'Xeric' creeping red fescue (*Festuca rubra ssp arenaria*); 'Ambrose' and 'Enchantment' Chewing's fescue (*Festuca rubra ssp fallax*); 'Eureka' hard fescue (*Festuca brevipila*); and 'Earth Carpet Care Free', a commercial blend of Chewing's fescue (40 %), creeping red fescue (35 %), hard fescue (20 %), and blue fescue (*Festuca glauca,* 5 %). Turf cultivars were selected with assistance from Dr. Tony Koski, Professor and Extension Turfgrass Specialist at Colorado State University. All grass cultivars have growth characteristics similar to Aurora Gold, i.e. low growth habit forming a dense turf, with good drought and shade tolerance. The experimental design is a randomized block with six replications per treatment. Each replication is ~210' long (half a row). The focus of this study is on turf establishment, persistence, weed suppression, and drought and traffic tolerance.

All treatments have overwintered well. Turf density is continuing to increase and slowly suppressing native grasses and other, non-grass species. As all the entries in this cover crop trial are low growing grass species the entire block can be mowed quickly with an electric ride-on mower which eliminates the needs 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. Eight varietal wines were produced from the NE-2220 cultivar trial at the Orchard Mesa site using micro-vinification techniques. An additional 8 wines were produced from a Chambourcin crop load trial that was replicated in two blocks. At the end of 2023, all wines were still in carboys.

Engagement / Outreach / Communications

The ever-increasing number of growers and wineries in the state means that individual consultations are a very inefficient, and costly way of providing information. We therefore try to conduct our engagement / outreach primarily through industry workshops / seminars, formal presentations (e.g. at VinCO), and field days. However, on an annual basis we respond to 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 four vineyard sites in the Grand Valley is accessible to grape growers and the public via the internet. We will continue to service both the software and hardware for this weather station network.

- Field demonstrations/workshops/tours

The CSU Western Campus held on Open House on 19 October 2023. Together with Dr. Oliver we spoke to attendees about CSU's viticulture research and extension activities.

- Off-station research and demonstration plots

The uptake of new research results and new production techniques is fastest when growers are directly involved in their development. One way of involving growers in research is to establish research plots on grower properties. Since 2013, we have established two replicated cultivar trials in grower vineyards. At the Fort Collins site, a CSU student intern managed the vineyard during the 2022 season. 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

Media interviews in response to the publication of the results from the climate mapping study in the Journal of Applied and Service Meteorology (Goble et al., 2023) resulted in a CSU Source article (30 Aug 2023) as well as two radio interviews (9NEWS, 18 Sep 2023; NPR for Northern Colorado, 28 Nov 2023).

Jessica Zimmer, a journalist participating in the CWIDB's media tour in May 2023, conducted a follow-up interview on cold injury / hardiness with Dr. Caspari resulting in a publication in Michigan Uncorked: Fighting the cold. Michigan Uncorked Vol 5 No. 4 Winter 2023: 17-19 https://issuu.com/userg123/docs/mu_-_winter_2023

Ann Wright, a journalist with The Daily Sentinel, published a front page article about the Viticulture Program's lab services to the grape and wine industry. "Juiced – Analysis dictates grape harvest, pushes local wine industry forward." The Sunday Sentinel, 10 Sep 2023. https://www.gjsentinel.com/news/western_colorado/helpful-data-juice-analysis-dictates-grape-harvest-pushes-local-wine-industry-forward/article_2c1c3b5a-4db7-11ee-b322-eb079c77d096.html

- Colorado Wine Grower Survey

Colorado State University has conducted this annual survey since 1984. Survey forms were sent out in early December 2023. All forms were sent electronically. By early January 2024 we had received 16 responses (representing 73 vineyard sites) totaling 346 acres. The very preliminary results of the survey are:

- Average yield >4 ton/acre
- 1,448 ton production reported so far
- Expected total state production >2,500 ton
- Some surplus grapes
- Average price trending upwards compared to 2022
- Continued removal as well as replanting of vineyards