Citrus Rootstock Acquisition and Evaluation — 2023[1]

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Introduction

Citrus macrophylla (Mac) and *C. volkameriana* (Volk) are the standard, vigorous rootstocks used widely across the Arizona and California desert lemon industry. They are both vigorous and produce high-yielding trees with fruit of excellent size. Lemon trees on both rootstocks are relatively cold-sensitive, with trees on Mac being more sensitive than Volk. Both are susceptible to the brown wood rot fungi (*Fomitopsis meliae)* that plague desert lemons. Also, Volk is susceptible to "winter yellows," and tends to produce excessive numbers of trunk suckers.

We have also been looking for alternatives to Mac and Volk. Ideally, these alternatives might have some greater resistance to the wood rot disease than Mac and Volk and be smaller trees with similar or better yield efficiency (fruit yield per volume of canopy), so that trees might be planted at higher density without overall loss of yield per acre.

In January 2016, we initiated a new lemon rootstock trial, the first to be planted at the University of Arizona's Yuma Mesa farm since 1993. The purpose of the trial was to evaluate the effect of several rootstocks on yield, fruit size, precocity, yield efficiency, tree size, and disease tolerance (especially tolerance to brown wood rot – *Fomitopsis meliae*). A secondary purpose was to compare the effects of traditional flood irrigation with pressurized drip irrigation on the above attributes, and to measure water savings using the pressurized system. Rootstocks used in this trial include Mac, Volk, sour orange (*Citrus aurantium* L.-Sour), Carrizo citrange (*Citrus sinensis* 'Washington' sweet orange X Poncirus trifoliata). Attributes of all these rootstocks are well-known. Also included is Rangpur lime (*Citrus limonia*) – (Rang) a hybrid of citron and mandarin, seldom used in the United States, but often used in Brazil because of its drought resistance and vigor (Wutscher, 1979). Additionally, we included Bitters (C-22), Carpenter (C-54) and Furr (C-57) citrandarin (*Citrus sunki* x Swingle citrumelo [*Citrus paradisi* x *Poncirus trifoliata*]) all hybrids of 'Sunki' mandarin and Swingle citrumelo. All three citrandarins were developed at the USDA citrus breeding program in Indio, CA and were released by the University of California in 2009. Information on these rootstocks can be found in Siebert *et al.*, (2010).

The experiment is located in block 6E (flood irrigated trees) and 6W (microsprinkler irrigated trees) at the Yuma Mesa Agriculture Center, near Somerton, AZ. The 2016 through 2021 reports for this experiment can be found as PDF files at: https://agriculture.az.gov/arizona-citrus-research-council-previously-funded-research-projects. The scion in this study is 'Corona Foothills,' and the rootstocks are those mentioned above. Tree spacing is 21 ft. square (99 trees per acre.

Materials and Methods

Trees in field 6W are irrigated with the Netafim microsprinklers and irrigation line. There are two 4 gph sprinklers per tree. Generally, the 6W trees were irrigated with microsprinklers every day in the summer, and every third day in the fall, and with occasional "supplemental" flood irrigation during the hottest part of the summer. Microsprinkler irrigated trees are irrigated according to a schedule developed from Wright (2021).

However, we were the victim of two burglaries in Spring and Summer 2023, when the copper wire connecting the pumphouse to the power pole was stolen. Before and during repair, the trees were switched to flood irrigation until the wire could be replaced. Since the trees had developed limited root systems at shallower soil depths in response to

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the sprinkler irrigation pattern and daily irrigation timing, the trees experienced longer times between irrigation and became intermittently drought stressed which affected fruit growth.

Flood irrigated trees in field 6E are watered according to normal citrus cultural practices employed by the Yuma Agriculture Center.

For 2023, tree growth data was collected on June 27 and 28, including tree height, canopy volume (spherical), Also, a subjective tree health rating was taken, where 0 = dead, 1 = almost dead, 2 = poor vigor, 3 = adequate vigor, 4 = good vigor and 5 = excellent vigor. We also counted the trees lost to and/or damaged by *Fomitopsis meliae* on April 6 (both fields), June 30 (Field 6E), July 26 (Field 6W), November 30 (Field 6W) and December 5 (Field 6E). Trees were pruned to remove wood rot after each measuring date.

For the 2023-24 season, fruit was collected to determine packout data from November 6 to 9. Approximately 150 to 350 fruit were collected from each rootstock, each block, and each field (8 rootstocks x 9 blocks x 2 fields = 144 total samples) and passed through our automated fruit sizer to collect packout data (fruit size, grade, and color)

Because of persistent rain, harvest crew issues, the holidays and the need for irrigation, yields were collected on December 4 and 5 for field 6W and on December 6 and 7 for field 6E. All fruit was stripped from the trees by commercial pickers. We determined yield by weighing the fruit harvested from each tree in individual picking sacks and subtracting the weight of the individual's sack.

Results and Discussion

Tree Size and Health

Results from 2022 (for comparison) and 2023 tree size and health measurements are shown in Table 1. There was no significant difference between flood- and microsprinkler-irrigated trees, so these data were pooled.

Table 1. 2022 and 2023 Lemon tree height, canopy volume and health rating.

Rootstock Variety	Tree Height		Canopy Volume		Tree Health Rating	
	(m)		(m^3)		(0 to 5)	
	2022	**2023**	**2022**	**2023**	**2022**	**2023**
Macrophylla	3.27 a	4.01 a	22.41 a	40.43 a	4.68 a	3.98 a
Volkameriana	2.89 b	3.95 a	15.62 b	32.48 b	4.53 ab	3.90 ab
Rangpur Lime	2.66 c	3.60 b	11.93 c	23.01 c	4.43 b	3.63 bc
C-57 'Furr'	2.50 d	3.24 cd	8.90 d	16.65 de	4.32 bc	3.25 de
C-54 'Carpenter'	2.46 d	3.24 cd	8.95 d	17.39 de	4.18cd	3.31 de
Carrizo Citrange	2.50 d	3.33 c	8.69 d	18.48 d	4.34 bc	3.45 cd
Sour Orange	2.38 e	3.04 d	7.80 de	14.48 e	4.02 d	3.24 de
C-22 'Bitters'	2.32 e	3.24 de	7.38 e	14.84 e	4.12 cd	3.14 e

For data within columns with different letter designations there is at least a 95% chance that the values are significantly different. Data in different columns cannot be statistically compared.

Not surprisingly, trees on *C. macrophylla* and *C. volkameriana* rootstock were again the largest, as shown by height and canopy volume. Rangpur lime produced intermediate sized trees, while the other rootstocks produced smaller sized trees. The citrandarins (C-22, C-54, and C-57) have produced smaller trees in studies conducted in three locations in California, and so their relatively small stature in relation to the others is not surprising. All the tree health ratings are adequate to good, there is no detrimental effect of rootstock upon overall tree health currently.

Yield

Yields for 2023 were significantly affected by the burglary of the power lines. As a result, yields on the pressurized irrigated field 6W were significantly less than those for flood irrigated field 6E. This is likely because the trees were drought-stressed as noted above. Yields across all rootstocks in field 6E averaged 159 lbs. per tree, while in field 6W, yields were only 136 lbs. per tree. This compares with the 2022 yields, where there was a slight increase in yield for the pressurized irrigation field (6W) compared with the flood irrigated field (6E). Trees in field 6W averaged 132 lbs. of fruit, while those in field 6E averaged 121 lbs. of fruit.

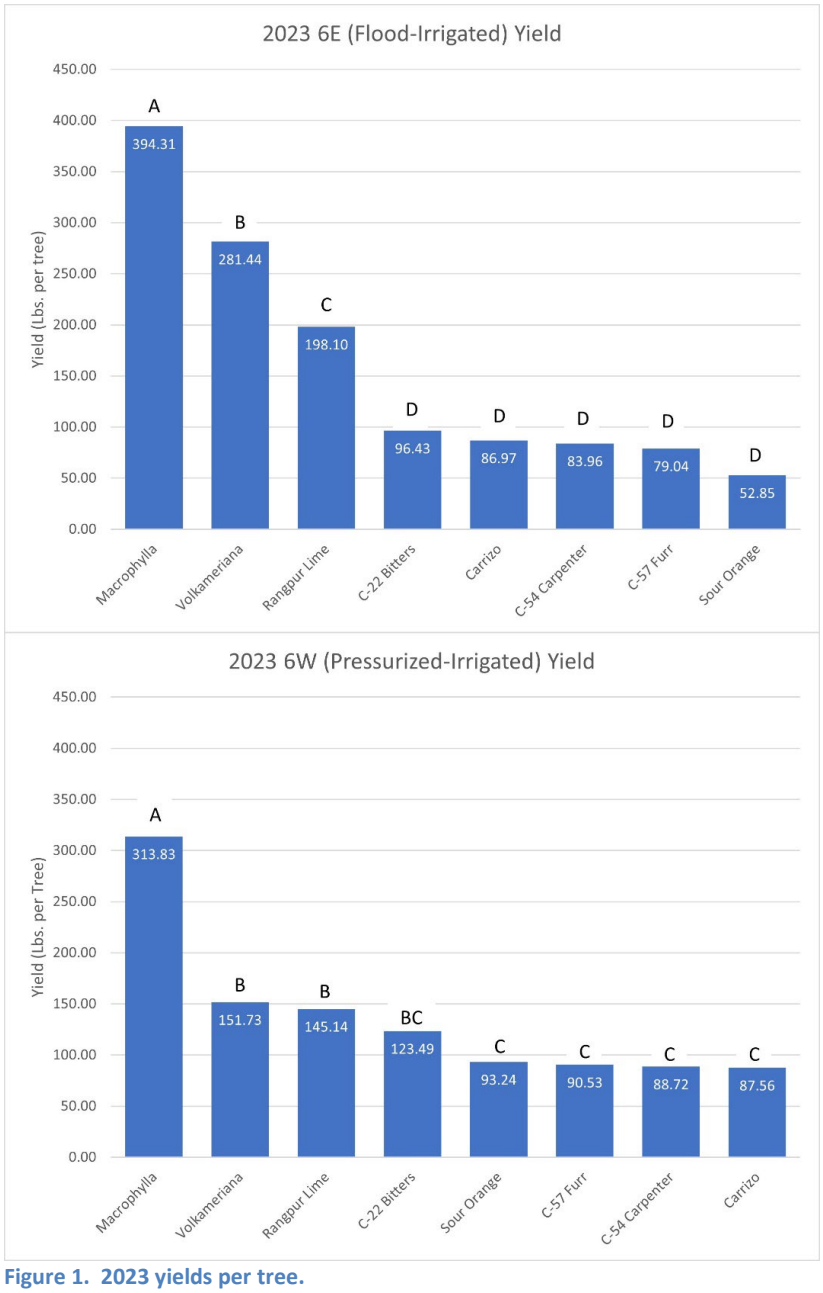


Figure 1. 2023 yields per tree.

Yields for 2023 are shown in Figure 1. For the flood irrigated field 6E, trees on Mac had the greatest yield and significantly more than the yields on any other rootstock. Yields on Volk and Rangpur were about 70% and 50% of the yields of trees on Mac, respectively. The yields of trees on the other rootstocks were 13 to 25% of the yields of the Mac trees.

Similar results were found in field 6W. Trees on Mac had the greatest yields, while yields on Volk and Rangpur were about 48 and 46% of the yields of Mac trees, respectively. Yields for the trees on the other rootstocks ranged from 27% to 39% of the Mac tree yields.

Yield Efficiency

Additionally, we calculated yield efficiency for each of the rootstocks and irrigation systems (Table 2). Yield efficiency is the yield divided by the canopy volume. We would like to see a rootstock that produces a large amount of fruit on a fairly small volume of canopy. Trees on Mac had the greatest yield efficiency under both flooded and pressurized irrigation. Rangpur and Volk, also rootstocks that produce larger trees also had good yield efficiency. Only C-22, which makes a small tree, had yield efficiencies approaching those of Mac, Volk, and Rangpur. If trees on C-22 were planted at about 200 trees per acre, yields per acre on C-22 might approach yields per acre of trees on Mac, since trees on C-22 are about 1/3 the size of trees on Mac (Table 1). Labor costs might be less because the C-22 trees are smaller.

Table 2. Yield efficiency of lemon trees on eight rootstocks irrigated with flood (F) or pressurized (P) irrigation.

Rootstock	Yield Efficiency (lbs./cubic meter)
Mac. - F	9.28
Rang. - F	8.56
Volk. - F	8.19
Mac. - P	8.18
C-22 - P	7.72
C-22 - F	7.05
Rang. - P	6.35
C-54 - F	5.71
C-57 - F	5.50
Sour - P	5.46
Carr. - F	5.10
Volk. - P	4.96
C-57 - P	4.78
Sour - F	4.45
C-54 - P	4.42
Carr. - P	4.40

Size Packout

For the flood-irrigated trees (Fig. 2), those on Mac rootstock led to the largest fruit size, followed by Carrizo and Volk. These rootstocks had fruit size that peaked on size 95, followed by size 115. For C-22, Rangpur, C-54 and C-57, the percentage for fruit in size 95 and 115 were about the same. Fruit of trees on Sour was the smallest, peaking on size 115. Generally, trees on Mac, Volk and Carrizo had significantly more fruit of sizes 63, 75 and 95 than did trees on the other rootstocks.

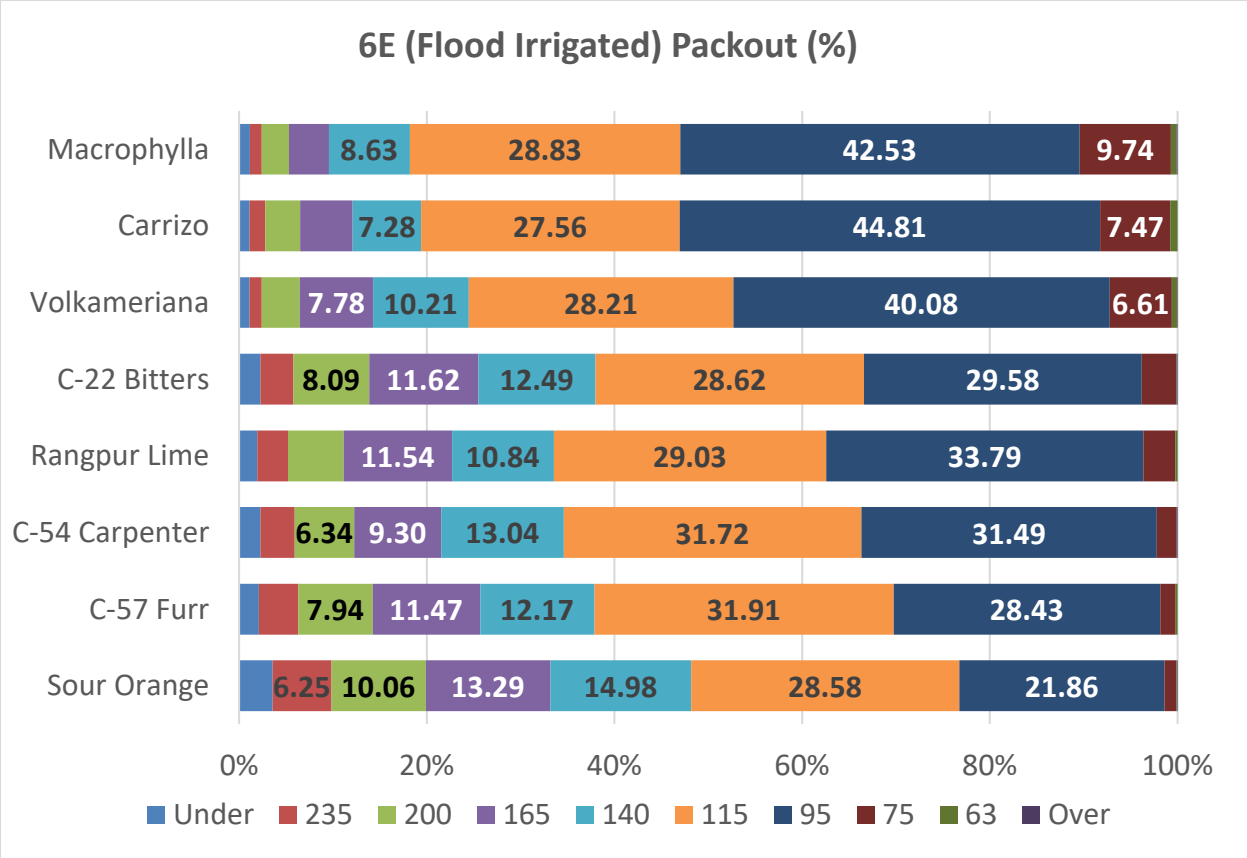


Figure 2. Packout (%) of lemons irrigated with flood irrigation. For ease of reading, values less than 6% are not shown.

Conversely, trees on Mac, Carrizo and Volk had fewer fruit of size 140 and smaller, than trees on the other rootstocks.

For the trees on pressurized irrigation, there was no effect of the rootstocks on fruit size. This may be because the fruits were smaller than expected due to the drought stress caused by the switch from pressurized to flood irrigation while the pressurized system was being repaired following the robberies.

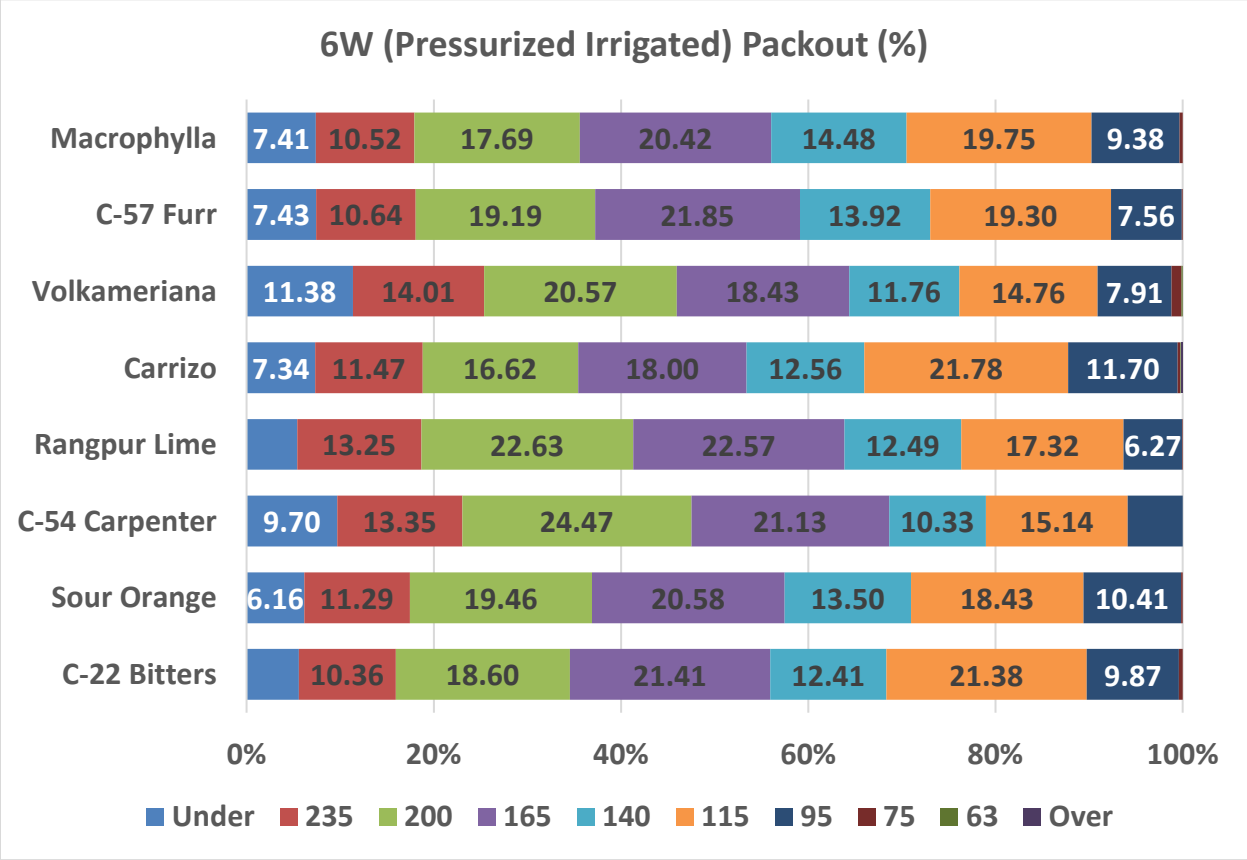
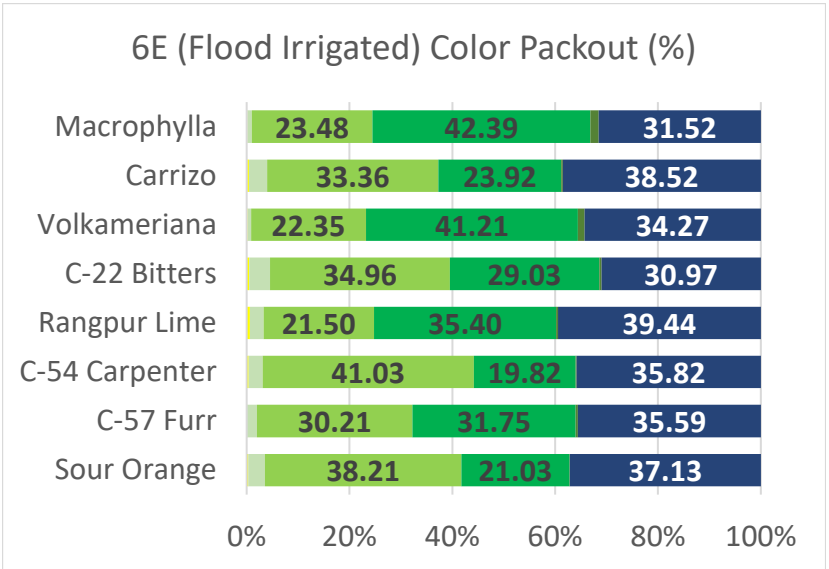


Figure 3. Packout (%) of lemons irrigated with pressurized irrigation. For ease of reading, values less than 6% are not shown.

Grade and Color Packout



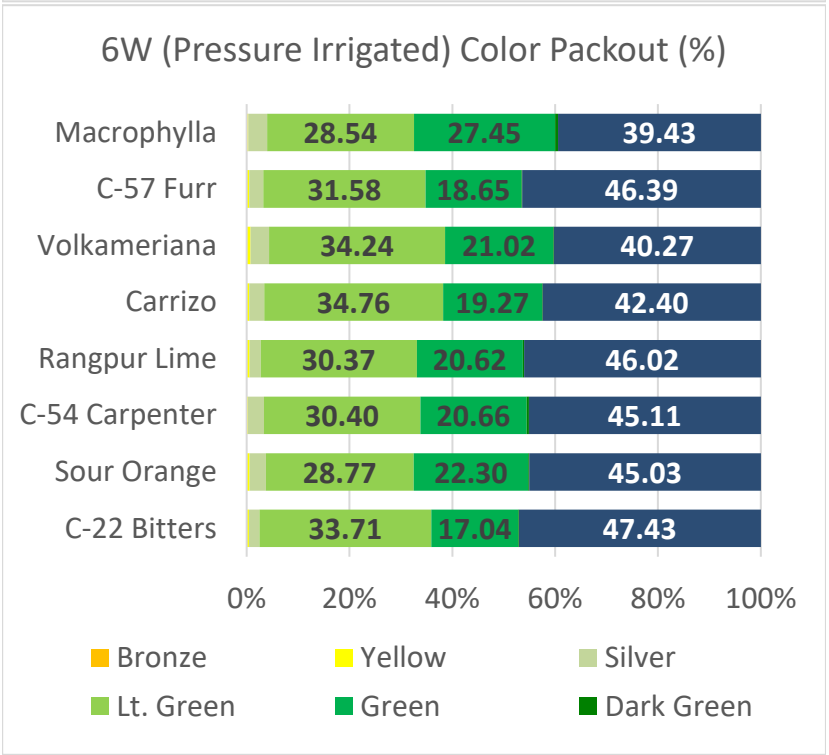


Figure 4. Color packout for lemons on eight rootstocks. For ease of reading, values less than 6% are not shown.

There was no effect of rootstock on fruit grade in either the flood- or pressurized-irrigation portion of the field, although the grade was better on the flood-irrigated trees (data not shown). For the flood-irrigated trees, fancy fruit ranged from 18 to 24% depending on rootstock, while choice fruit ranged from 41 to 45%, and juice fruit ranged from 32 to 38%. For the pressure-irrigated trees, fancy fruit ranged from 11 to 18%, choice fruit from 40 to 44% and juice fruit from 40 to 48%.

There was an effect of rootstock on fruit color in the flood-irrigated trees, but not in the pressure-irrigated trees (Fig 4). Generally, trees on Mac, Volk and Rangpur under flood irrigation had significantly more fruit of the green color, and significantly less fruit of the light green color than did trees on sour, C-54, and Carrizo. There was very little dark green, silver, yellow or bronze fruit.

Tree Losses and Incidence of Disease

As of 12/31/18, three trees had been lost to brown wood rot (*Fomitopsis meliae*), and one to *Fusarium solani.* Further progression of Brown Wood Rot and other diseases through 12/31/23 is shown in Tables 3 and 4.

Table 3. Dead trees as of 12/31/21 and 12/31/23.

Rootstock	Number of Dead trees as of 12/31/21 (%)	Additional Number of Dead trees as of 12/31/23 (%)
Brazil Sour Orange	6 (1.00%)	2 (0.33%)
C. macrophylla	3 (0.50%)	0
C. volkameriana	2 (0.33%)	0
C-22 Bitters	1 (0.17%)	0
C-54 Carpenter	1 (0.17%)	2 (0.33%)
C-57 Furr	1 (0.17%)	2 (0.33%)
Carrizo	0	1 (0.17%)
Rangpur Lime	0	0
TOTAL	14 (2.33%)	7 (1.17%)

All told, about 3.5% of the trees have been killed since 1/1/19. It is likely that the majority of those trees have died due to *Fusarium* (Quick Decline) or *Phytophthora* root rot. Trees on sour orange have been the most likely to die, followed by trees on Mac, C-54, C-57, Volk, Carrizo, and C-22. None of the trees on Rangpur have died.

Table 4. Disease infested trees as of 12/31/23.

Evaluation Date										
	9/30/22	4/6/23		6/23 to 7/23			11/23 and 12/23		TOTAL	
Rootstock	Wood Rot	Wood Rot	Gumming	Wood Rot	Gumming	Phyto-phthora	Wood Rot	Gumming	Wood Rot	Gumming
Sour	1	0	3	4	3	0	3	4	8	10
Mac	5	0	6	12	9	0	2	7	19	22
Volk	3	1	2	7	5	0	5	7	16	14
C-22	5	0	4	9	6	0	3	7	17	17
C-54	4	0	3	6	5	0	3	10	13	18
C-57	3	0	7	4	7	0	6	10	13	24
Carrizo	2	0	3	3	4	0	3	7	8	14
Rangpur	2	0	3	7	2	2	3	12	12	17
TOTAL	20	1	31	52	41	2	28	64		

Beginning in 2023, we distinguished between incidences of wood rot, (where branches were dying), and gumming, (where oozing of sap was noticed but branches were not dead). There was no significant difference between the level of either in flood or pressurized-irrigation fields. Wood rot was found in 20 trees in September 2022, and after pruning, that level was reduced to one tree by April 2023. However, despite pruning, wood rot was much higher by summer 2023, with 52 of the 579 trees showing some evidence of wood rot. Following another pruning, incidence of wood rot dropped to 28 of 579 trees by winter 2023. Trees on Mac had the most wood rot, followed by Volk, C-22C-54, C-57, Rangpur and finally Carrizo and Sour.

Thirty-one of 579 trees exhibited gumming in April 2023. This number rose to 41 in summer 2023, and 64 in winter of 2023. C-57 and Mac had the most gumming, followed by C-54, C-22, Rangpur, Carrizo, Volk and finally Sour.

Conclusions

Late in 2023, I decided to terminate the project. Certainly, the continual struggle with irrigation on the pressurized field due to the robberies and the compromising of the data played a major role. The fields are not within a fenced perimeter of University of Arizona property, and we cannot guarantee that robbery, vandalism, or other damage will not happen again. Also, we have not truly met our objectives with the project. Mac and Volk have been the best performing rootstocks – something that was not surprising. The yield and fruit size of these two rootstocks weas superior to the others tested. Unfortunately, none of the other rootstocks had a yield efficiency that would suggest that they could be substituted for Mac or Volk at a higher planting density to achieve greater yields per acre. Also, none of the other rootstocks showed any enhanced resistance to brown wood rot or gumming, and some of them were less resistant than Mac or Volk. Until other rootstocks are developed that are superior to Mac (and possibly Volk), these rootstocks should be the standards for lemons in the desert.

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