Project No.:

Project Leader: Roger Duncan, 3800 Cornucopia Way #A, Modesto, CA 95358.
raduncan@ucdavis.edu; 209-525-6800

Project Cooperators and Personnel:

Joe Connell, UCCE Butte County Emeritus.
Katherine Jarvis-Shean, Yolo/Solano/Sacramento Counties.
Mohammad Yaghmour, UCCE Kern County.

A. Summary

This is the final report of a compilation of long-term field assessments of over 25 rootstocks grown in four counties in California under various irrigation, weather, disease, and soil chemistry conditions. This project encompasses trials conducted by UC Farm Advisors in Stanislaus (Keyes established 2003; Westley established 2012), Butte (established 2010), Yolo (established 2011), and Kern (established 2019) Counties. All trial locations were embedded within commercial orchards and were farmed according to local practice. In each trial, the following data were collected: yield and kernel quality, canopy size (Photosynthetically Active Radiation, or PAR), trunk circumference, anchorage, leaf nutrient and salt concentrations, hull boron, hullsplit timing and duration, pathogenic nematodes, and stem water potential.

Although results varied, there are some clear trends across locations. In general, most peach almond hybrid rootstocks and Empyrean 1 were the most vigorous across all trials. They had the largest trunks and the largest leaf canopies (collected the most photosynthetically active radiation). Lovell, Krymsk 86, and Rootpac R tended to be the smallest. Brights 5 and Cornerstone were smaller than most other peach x almond hybrids. Rootstock had very little effect on bloom time in these trials, but made very significant changes in hullsplit start date, end date, and duration. The most vigorous rootstocks delayed harvest by two to three weeks compared to standard rootstocks Lovell, Krymsk 86, and Nemaguard. In general, the most vigorous rootstocks consistently had the highest yields and largest kernels in all locations. Comparisons of yield per PAR indicated many of the higher vigor peach x almond hybrid rootstocks may also be more yield efficient (more kernel pounds per unit of canopy).

Krymsk 86, PAC9908-02, Hansen, and Viking have shown excellent anchorage in these trials. Hansen x Monegro (HM2) has unacceptably poor anchorage. Empyrean 1, HBOK 50, and Lovell have relatively poor anchorage, while Cornerstone is leaning most in the Kern trial. Peach x almond hybrid rootstocks have shown very good salt tolerance, along with Empyrean 1. Krymsk 86 and peach rootstocks Lovell, Guardian, Nemaguard, and HBOK 50 often accumulate high, even toxic, levels of sodium and chloride in their leaf tissue. Viking and Cadaman were moderately tolerant to salt accumulation. Rootpac R appears to be tolerant of chloride but can accumulate high levels of sodium. The most significant leaf nutrient affect by rootstock was potassium. In general, peach x almond hybrid rootstocks and Cadaman had higher leaf potassium

than other rootstocks, although early Kern County results may differ. There were often statistically significant differences in nitrogen among rootstocks, but differences were usually small and not very meaningful. Peach x almond hybrid rootstocks and Viking tended to have lower hull boron while Lovell accumulated the most.

Only the Keyes location in Stanislaus County had substantial populations of pathogenic nematodes. Peach x almond hybrid rootstocks Nickels, Cornerstone, and Hansen supported very high numbers of ring nematodes. This is consistent with previous rootstock trials. Root lesion nematodes were present in the trial but there were no differences among rootstocks. Tree water status as measured by stem water potential was inconsistent among trials. In the Westley trial, Rootpac R was consistently the most water stressed while Atlas and Brights 5 were least stressed. In the very young Kern County trial, Krymsk 86, Rootpac R, and Cornerstone were the least stressed trees, while most of the peach x almond hybrid rootstocks indicated higher water stress. In Kern County, it appeared it was the largest trees (larger canopies using more water) that were the most stressed.

B. Objectives

1. Evaluate rootstock trials in Stanislaus County, including under Western San Joaquin Valley conditions, irrigated with saline water in alkaline, loamy clay soil; and in Eastern Stanislaus County in a sandy loam replant site without pre-plant fumigation. (Roger Duncan, UCCE Stanislaus County).
2. Evaluate variety compatibility with rootstocks for almond, particularly compatibility with Nonpareil, under upper Sacramento Valley growing conditions (Joe Connell, UCCE Butte County Emeritus).
3. Evaluate alternative rootstocks under high boron, West San Joaquin Valley conditions (Katherine Jarvis-Shean, UCCE Yolo County).

4. Evaluate eleven rootstocks under Kern County growing conditions, challenged with periodic high Santa Ana winds (Mohammad Yaghmour, Kern County).

Researchers have measured several standardized parameters in each field trial, along with evaluations relevant to each individual location. Many of these data have been previously reported in detail in prior Almond Board reports. Summaries are included in this final report. These parameters include:

- Complete leaf analyses of non-fruiting spur leaves (July)
- Hull analysis for boron (at harvest)
- Hullsplit timing and duration
- Yield and quality assessment
- Trunk circumference
- Trunk angle (measure of anchorage)
- Photosynthetically Active Radiation (PAR)
- Pathogenic nematodes
- Stem Water Potential

A. Almond Rootstock Evaluations in Stanislaus County

Project leader: Roger Duncan, UCCE Advisor, Stanislaus County

1. Performance of Almond Rootstocks for the West Side of the North San Joaquin Valley.

Westley, CA. Grower Cooperator: Lee Del Don

Objective:

Evaluate 16 almond rootstocks for their performance in an alkaline clay loam soil moderately high in boron and irrigated with water high in chloride.

Interpretive Summary:

- Rootstock has had no substantial effect on bloom start or end dates.
- The initiation of hull split in the most vigorous rootstocks has been delayed by up to two weeks compared to Nemaguard and Lovell. The duration of hullsplit (from 1% - 100% hullsplit) was 13 days longer in 2021 for the most vigorous rootstocks compared to Nemaguard. In all, harvest maturity of the most vigorous rootstocks has been delayed by more than three weeks compared to Nemaguard, Lovell and Krymsk 86.
- The largest trees as measured by trunk circumference at the end of the 11th leaf were peach x almond hybrid rootstocks Flordaguard x Alnem (FxA), BB 106, Hansen and Hansen x Monegro (HM2). Paramount (a.k.a. GF 677) and Brights 5 are significantly smaller than the other PxA hybrid rootstocks. Lovell and Krymsk 86 are the smallest trees in this trial.
- Hansen x Monegro (HM2) has unacceptably poor anchorage and some trees have fallen over. Empyrean 1, HBOK 50, and Lovell also have excessive leaning in this trial, indicating they may not be suitable for use in windy areas.
- July leaf analyses indicate that leaf chloride levels have increased each year in this trial in susceptible rootstocks. Some rootstocks have had chloride levels well above the critical level of 0.3% for many years. Krymsk 86 and PAC9908-02 have significantly higher leaf chloride than other rootstocks (1.2% and 1.1%, respectively, in 2021), and Nemaguard and Lovell have more than three times the critical level. Peach x almond hybrid rootstocks, with the exception of PAC9908-02, and Rootpac R have significantly lower leaf chloride and are below the critical level threshold of 0.3%.
- Lovell, Atlas, Cadaman, HBOK 50, and Nemaguard had the highest hull boron while peach x almond hybrids, Viking, Rootpac R and Empyrean 1 had low boron.
- The highest yielding rootstocks are also the largest (largest canopy and trunk circumference). However, many of the larger, highest yielding rootstocks also had higher yield efficiencies (crop per unit of canopy). Lovell, Krymsk 86. Nemaguard and HBOK 50 have the lowest cumulative yields in this trial, producing only 40-60% of the crop of the highest yielding rootstocks. Trees on Lovell had the lowest yields and the lowest yield efficiency. The highest yielding rootstocks would have grossed $11,738 per acre more than Nemaguard so far, calculated at $2.00 / lb.

Background:
Almond planting continues to expand on the west side of the North San Joaquin Valley, replacing lower value row crops. In contrast to the more traditional tree growing areas on the east side of the valley with more neutral pH, nematode infested, sandy loam soils, west side soils are typically heavier clay loams with higher salt, pH, and boron. Irrigation water is typically high in bicarbonates, boron and chloride. Historically westside growers planted on Lovell or Nemaguard due to lack of information or experience with alternative rootstocks.

Materials and Methods:
In this trial, the performance of sixteen rootstocks is being tested under "typical" west side conditions. On December 21, 2011, test trees were planted in a randomized complete block design with six replicates of all rootstocks in a commercial orchard off Highway 33 near the town of Westley. Trees were planted at a spacing of 16' x 20' (136 trees per acre). All tested rootstocks have Nonpareil as the scion. Pollinizer varieties are Carmel and Monterey. Rootstock parentage includes peach (*P. persica*), intra-species peach hybrids, hybrids of peach x almond, peach x plum, almond x plum and complex hybrids that include peach, almond, plum and apricot. Rootstocks and their parentage are shown below (Table 1).

Table 1. List of Rootstocks and Their Genetic Background

Rootstock	Genetic Background
Lovell	Domestic peach
Nemaguard	Domestic peach
Empyrean 1	Domestic peach x wild peach
Avimag (a.k.a. Cadaman)	Domestic peach x wild peach
HBOK 50	Harrow blood peach x domestic peach
Hansen	Peach x almond
Brights #5	Peach x almond
BB 106	Peach x almond
Paramount (a.k.a. GF 677)	Peach x almond
Flordaguard x Alnem (FxA)	Peach x Israeli bitter almond
PAC9908-02	(peach x almond) x peach
HM2 (Hansen x Monegro)	(almond x peach) x (almond x peach)
Viking	((plum x apricot) x almond) x peach
Atlas	((plum x apricot) x almond) x peach
Krymsk 86	Plum x peach
Rootpac R	Almond x plum

This rootstock trial is growing in a Zacharias clay loam. Preplant soil samples indicated moderately high soil pH (7.5), high magnesium (555 ppm), high boron (1.7 ppm) and moderate soluble salts (1.3 mmhos / cm). In previous years, the field was irrigated primarily with West Stanislaus Irrigation District water, which is blended with tail water from area fields and water from the San Joaquin River. The water quality can be variable through the season and sometimes high in salts, especially towards the end of summer. During the drought, this orchard was primarily irrigated with well water. The

water is treated with sulfuric acid but is still high in sodium, chloride, boron and bicarbonate (Table 2.). After three years of irrigation with well water, soil samples indicated very high total salinity (2.5 – 3.4 dS/m), high sodium (9.4-14.7 meq/l) and very high chloride (11.0 – 17.1 meq/l) (Table 3.). The most recent soil and water samples (May 2021) indicate increasing bicarbonates (5.85 meq/l) and chloride (8.21 meq/l). Prior to planting the orchard, the field had a long history of melons, tomatoes and other row crops which led to expression of Verticillium wilt disease in the early years of this trial and expression of disease varied among rootstocks (previously reported). Preplant and subsequest 8th leaf soil samples indicated no detectable rootknot or ring nematodes.

Table 2. Analysis of Irrigation Water Indicating High Sodium, Chloride, Bicarbonate, & Boron.

	EC (dS/m)	Na (meq/l)	Adj. SAR	Cl (meq/l)	CO3 +HCO3 (meq/l)	B (mg/l)	pH
2015	1.86	9.40	8.80	8.90	2.50	0.84	7.1
2017	0.96	4.13	3.07	3.64	2.16	0.31	7.9
2020	1.42	6.61	3.97	6.06	3.11	0.89	7.5
2021	2.00	6.52	2.68	8.21	5.85	0.52	7.7
Critical	< 1.10		< 3.0	< 4.0		0.50	

Table 3. Soil Analyses Indicating High pH, Sodium and Chloride.

	Sample Depth (in.)	pH	EC (dS/m)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	Cl (meq/l)	B (mg/l)	ESP (%)
At Planting (2012)	0-18”	7.3 - 7.8	3.42	7.2	14.7	14.7	17.1	0.6	5.0
	18”-36”	7.8	2.49	5.9	12.9	9.4	11.0	0.3	3.2
December 2020	0-18”	7.1 - 7.8	0.8-2.3	2.6-8.8	1.7-8.3	4.9-9.6	1.0-5.8	0.4-0.7	3.4
	18 – 36”	7.8 - 8.2	1.0-2.1	2.0-5.7	3.0-10.4	4.9-10.8	1.4-4.7	0.4-1.0	4.0
	36 - 52”	8.2 - 8.4	1.0-2.4	1.8-4.7	3.5-11.0	4.9-15.5	1.5-5.2	0.4-0.7	4.9
	Critical level		1.50				5.0	0.5	5.0

Results & Discussion:

Rootstock effect on bloom. Trees were observed approximately every three days during bloom to document the effect rootstock had on bloom date and perceived bloom density. Bloom density is a subjective rating from 1 (very few flowers) to 5 (trees very dense with flowers). Rootstock had no substantial effect on the dates of bloom start (1-5% of flowers open), full bloom (80-90% of flowers open) or end of bloom (> 95% of flowers with no petals) (Table 4). The winter of 2020 – 21 had sufficient winter chilling (1037 hours < 45 F from September 1, 2020 - February 15, 2021) and almonds in general have a low chilling requirement. Perceived bloom density was lowest on Lovell and highest on Rootpac R. There did not appear to be a clear relationship between bloom density and rootstock genetics.

Table 4. Bloom date and density comparisons for Nonpareil almond on 15 rootstocks. 2021.

Rootstock	Bloom start	Full Bloom	End of Bloom	Full bloom date +/- Nemaguard	Bloom Density Rating (1-5)
Nemaguard	2-16	2-24	3-1	--	3.5
Lovell	2-16	2-25	3-1	-1	2.7
HBOK 50	2-15	2-24	3-1	0	4.2
Atlas	2-15	2-25	3-1	-1	4.0
Empyrean 1	2-15	2-23	3-1	+1	4.3
Hansen	2-16	2-22	3-1	+2	3.5
Brights 5	2-16	2-24	3-1	0	3.7
BB106	2-16	2-24	3-1	0	3.3
HM2	2-15	2-24	3-1	0	4.2
FxA	2-16	2-24	3-1	0	4.0
Paramount	2-16	2-22	3-1	+2	4.5
Viking	2-16	2-24	3-1	0	3.7
Krymsk 86	2-16	2-24	3-1	0	3.8
Rootpac R	2-16	2-22	3-1	+2	4.7

Rootstock effect on hullsplit. The onset and duration of hullsplit is substantially affected by rootstock. For example, trees on HBOK 50 initiated hullsplit on July 7 while trees on Lovell, Nemaguard, Krymsk 86, Rootpac R and Viking started July 14 (Fig 1). In contrast, most peach x almond hybrid rootstocks did not begin hullsplit until around July 25. Lovell was at 100% hullsplit and dry enough to shake by July 27, a hullsplit duration of 13 days. Peach x almond hybrid rootstocks, especially Hansen and Brights Hybrid 5, did not reach 100% hullsplit until at least August 20, a duration of approximately 26 days. Delaying the initiation of hullsplit by two weeks and the harvest date by more than three weeks can have significant implications for NOW control and hull rot severity. Hull rot has typically been more extensive in the peach x almond hybrid trees, likely a result of the extended hull split process. Nitrogen is not typically higher in peach x almond hybrid rootstocks (Table 5).

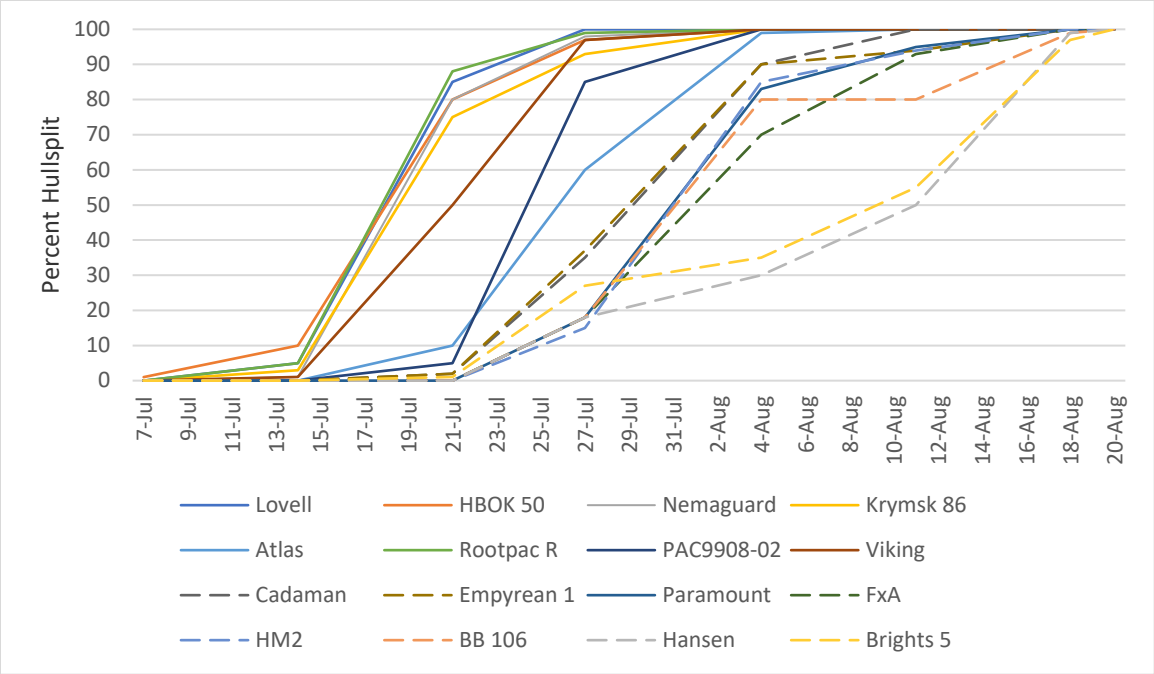


Fig. 1. Hullsplit dynamics of Nonpareil almonds on trees of different rootstocks. 2021. More vigorous trees initiated hullsplit 10-14 days later and completed hullsplit an average of 19 days later than standard rootstocks Krymsk 86, Lovell, and Nemaguard.

Tree Growth. The largest trees as measured by trunk circumference at the end of the 11th leaf were on FxA, BB106, Hansen, and HM2 (Table 5). Trees on Paramount (a.k.a. GF 677) and Brights 5 are significantly smaller ($P<0.05$) than the other PxA hybrid rootstocks. Trees on Lovell and Krymsk 86 are the smallest in this trial.

Table 5. Rootstock Effect on Trunk Circumference – 4th – 11th leaf.

	2015 4th Leaf (cm)[1]	2017 6th Leaf	2019 8th Leaf	2020 9th Leaf	2022 11th leaf
Flordaguard x Alnem	49.7 abc	60.9 a	67.6 a	73.0 a	79.5 a
BB 106	48.0 bc	57.5 c	65.0 abc	71.4 ab	77.7 ab
Hansen	47.9 c	58.3 bc	65.7 ab	70.9 abc	76.9 ab
Hansen x Monegro	48.4 bc	58.4 abc	65.6 ab	68.0 abc	77.2 ab
Empyrean 1	50.0 ab	59.3 abc	65.9 ab	68.3 abc	72.4 bc
PAC9908-02	50.8 a	60.3 ab	63.9 bc	67.5 bc	68.6 cd
Rootpac R	49.0 abc	58.1 bc	62.2 c	65.4 bc	67.9 cde
Paramount	43.3 ef	51.6 ef	58.1 d	62.6 cd	67.5 cde
Brights 5	43.8 de	52.0 def	56.8 de	61.7 d	66.3 def
HBOK 50	45.6 d	54.4 d	58.5 d	61.4 de	62.7 efg
Atlas	44.3 de	52.8 de	55.9 de	60.8 de	61.7 fg
Viking	44.2 de	51.9 def	56.0 de	60.4 de	60.8 fg
Nemaguard	44.6 de	52.7 def	56.3 de	59.0 de	60.2 g
Krymsk 86	41.7 f	48.6 g	55.8 de	56.3 e	58.2 g
Lovell	42.9 ef	50.2 fg	53.4 e	56.1 e	57.7 g

Anchorage. Trees that lean at an early age are more prone to windfall and shaker injury. It is important for almond rootstocks to have good anchorage. To quantify tree anchorage, a large protractor was used to measure the trunk angle relative to the orchard floor. Trunk leaning of greater than about 15 degrees likely indicates an anchorage problem. Rootstocks showing good anchorage in this trial include Krymsk 86, PAC9908-02, Hansen, Viking, FxA, and Brights Hybrid 5. Rootstocks exhibiting excessive leaning include HM2, Empyrean 1, HBOK 50, and Lovell. Hansen x Monegro (HM2) has unacceptably poor anchorage, and some trees were removed early in the life of the orchard due to excessive leaning (Table 6).

Table 6. Rootstock Anchorage as Measured by Trunk Angle (degrees of lean from center) After Eleven Years. 2022 (11th Leaf)[1]

	Degrees from Center
Krymsk 86	3.1 a
PAC9908-02	5.4 ab
Hansen	5.6 ab
Viking	6.6 ab
Flordaguard x Alnem	6.7 ab
Brights 5	7.0 ab
Paramount	7.9 b
BB 106	8.2 bc
Rootpac R	8.4 bc
Atlas	9.4 bc
Nemaguard	9.6 bc
Lovell	12.0 cd
HBOK 50	14.3 d
Empyrean 1	14.7 d
Hansen x Monegro	18.3[2] e

[1]Measurements followed by the same letters are not significantly different ($P \leq 0.05$).
[2]Some seriously leaning trees of HM2 were removed in previous years, improving the average rating of remaining trees.

Rootstock Effect on Leaf Nutrients, Salt, and Hull Boron. With the exception of phosphorus, leaf nutrient levels differed significantly among rootstocks ($P < 0.05$). While differences in most nutrients were statistically significant, they were not agronomically important in many cases because levels were well above recommended levels (Table 7). The most notable differences occurred in leaf levels of potassium, sodium, and chloride. All peach x almond hybrids except PAC9908-02 had high levels of potassium when sampled in July 2019 (> 2.1%) while PAC9908-02, Lovell and Krymsk 86 were deficient on average (< 1.4%). There were significant calcium level differences among rootstocks, although it is unknown what, if any, agronomic effect this may have. Peach rootstocks Lovell, Nemaguard, and HBOK 50 had the lowest calcium leaf levels while peach x almond hybrids tended to be higher in calcium, especially Hansen (Table 7).

Leaf symptoms of chloride toxicity on the most susceptible rootstocks are apparent by mid-season each year in this trial. Chloride levels are well above the published critical level (0.3%) for most rootstocks in this trial (Table 8). July leaf analyses have indicated that chloride levels are the highest in Krymsk 86 and the Spanish peach x almond hybrid PAC9908-02 while levels are also very high in Lovell and Nemaguard (Table 8). All peach x almond rootstocks except PAC9908-02 had comparatively low chloride levels, most below the critical threshold. There are significant differences in the accumulation of boron in hulls among the rootstocks, although all are well below the critical hull boron level of 300 ppm (Table 9). Boron levels were highest in Lovell, Cadaman, Atlas and HBOK 50 in most years. Boron levels were lowest in the peach x almond hybrid rootstocks, Rootpac R and Viking and have become B deficient.

Table 7. Effect of Rootstock on Leaf Nutrient Content. July 2019.

	K (%)	N (%)	P (%)	Sulfur (ppm)	Ca (%)	Mg (%)	Mn (ppm)	Na (%)
F x A	2.48 a	2.44 ab	0.12 a	1923 d	3.64 bc	1.32 cde	90.8 ab	0.06 d
Brights 5	2.46 a	2.35 abc	0.12 a	2030 d	3.65 bc	1.32 cde	72.3 bcd	0.04 d
Cadaman	2.44 a	2.43 ab	0.12 a	2003 d	3.53 bcd	1.29 de	74.8 bcd	0.04 d
BB 106	2.40 a	2.48 a	0.12 a	2500 bcd	3.79 b	1.39 bcd	61.8 d	0.05 d
Hansen	2.22 ab	2.34 abc	0.12 a	2080 cd	4.21 a	1.41 bcd	91.5 ab	0.09 d
GF 677	2.15 ab	2.38 abc	0.12 a	2143 cd	3.66 bc	1.21 e	82.3 abc	0.04 d
HM2	2.14 ab	2.41 abc	0.11 a	2625 bcd	3.29 cdef	1.42 bcd	82.9 abc	0.10 d
Empyrean 1	1.95 abc	2.34 abc	0.11 a	2480 bcd	3.21 def	1.53 ab	63.9 bcd	0.12 cd
Atlas	1.94 abc	2.43 abc	0.11 a	2538 bcd	3.12 ef	1.28 de	81.6 abcd	0.22 bc
Viking	1.90 abcd	2.37 abc	0.11 a	2968 ab	3.27 cdef	1.39 bcd	82.2 abc	0.06 d
Nemaguard	1.85 abcd	2.37 abc	0.11 a	2570 bcd	2.93 fg	1.31 cde	65.9 cd	0.25 b
HBOK 50	1.63 bcd	2.28 c	0.11 a	2578 bcd	2.93 fg	1.49 ab	92.7 a	0.06 d
Rootpac R	1.57 bcd	2.40 abc	0.11 a	2808 bc	3.23 def	1.29 de	90.8 ab	0.40 a
Krymsk 86	1.39 cd	2.47 a	0.11 a	3208 ab	3.49 bcde	1.46 abc	92.4 a	0.22 bc
Lovell	1.38 cd	2.33 bc	0.11 a	2600 bcd	2.69 g	1.33 cde	72.4 bcd	0.15 bcd
PAC9908-02	1.23 d	2.41 abc	0.11 a	3623 a	3.37 cde	1.55 a	80.8 abcd	0.24 b

[1]Measurements followed by the same letters are not significantly different ($P \leq 0.05$).
[2]Zinc values not shown. In-season foliar sprays made analyses inconclusive.

Table 8. July-Sampled Leaf Chloride Levels of Fourth-Leaf thru Ninth-Leaf Nonpareil Almond Trees Grown on Sixteen Rootstocks. 2015 - 2020				
	% Chloride 2015	% Chloride 2016	% Chloride 2017	% Chloride 2020
Krymsk 86	0.65 b	0.77 a	0.89 a	1.21 a
PAC9908-02	0.28 defg	0.45 bc	0.45 d	1.10 a
Nemaguard	0.43 c	0.57 b	0.57 c	0.96 b
Lovell	0.73 a	0.72 a	0.72 b	0.95 b
HBOK 50	0.30 def	0.31 cde	0.31 ef	0.68 c
Atlas	0.37 cd	0.42 c	0.42 de	0.57 cd
Viking	0.25 efgh	0.30 cde	0.30 f	0.55 d
Cadaman	0.32 de	0.38 c	0.38 def	0.54 d
HM2	0.18 h	0.16 e	0.16 g	0.39 e
Empyrean 1	0.32 de	0.33 cd	0.33 ef	0.36 e
F x A	0.20 gh	0.29 cde	0.19 g	0.28 ef
Hansen	0.23 efgh	0.15 e	0.15 g	0.28 ef
BB 106	0.20 gh	0.19 de	0.19 g	0.25 ef
Rootpac R	0.25 efgh	0.17 de	0.17 g	0.22 f
Brights 5	0.22 fgh	0.18 de	0.18 g	0.17 f
Paramount	0.20 gh	0.18 de	0.19 g	0.16 f
Critical Level	**0.30%**			

Table 9. Hull Boron Levels of Fourth-Leaf Through Seventh-Leaf Nonpareil Almond Trees Grown on Sixteen Rootstocks. September 2015 – 2018				
	ppm Boron 2015	ppm Boron 2016	ppm Boron 2017	ppm Boron 2018
Lovell	180 a	125 a	180 a	125 a
Cadaman	170 ab	107 ab	170 ab	110 ab
Atlas	158 ab	123 a	158 ab	122 a
HBOK 50	156 ab	108 ab	158 ab	114 ab
Nemaguard	153 bc	114 ab	153 bc	110 ab
Krymsk 86	152 bc	100 ab	152 bc	97 b
Empyrean 1	133 cd	89 bc	133 cd	93 bc
Rootpac R	132 cd	93 b	132 cd	93 bc
Hansen	126 de	86 bc	126 de	91 bc
Paramount	120 de	78 bc	120 de	79 c
HM2	116 de	82 bc	116 de	86 bc
Viking	109 e	74 c	109 e	77 c
PAC9908-02	108 e	75 c	108 e	80 c
Brights 5	106 e	76 c	106 e	75 c
F x A	104 e	80 bc	104 e	83 c
BB 106	102 e	76 c	102 e	88 bc
Critical Level	**300 ppm**			

Yield. Rootstock has substantially affected yields and gross profit opportunities in this trial (Table 10). The highest yielding rootstocks, BB 106, FxA, and Brights 5, have accumulated 7,892, 7,199, and 6,936 pounds per acre, respectively, more than the lowest yielding rootstock (Lovell) in the six years of harvest in this trial. Industry standards Lovell, Nemaguard and Krymsk 86 are the lowest yielding rootstocks in the trial. The highest yielding rootstocks tend to be the most vigorous trees (peach x almond hybrids and Empyrean 1) but are also more yield efficient per unit of canopy. The best yielding rootstocks would have returned over $10,000 more per acre than the standard Nemaguard, at a conservative kernel value of $2.00 per pound over the six years of measured harvest.

Table 10. Yield for 4th Thru 7th, 9th, & 11th Leaf Nonpareil Almond Trees on Fifteen Rootstocks. 2015 – 2018, 2020, 2022.

	2022 Yield (11th Leaf)[1]	2022 Kernel Mass (g / kernel)	2022 PAR (%)[2]	2022 Yield Efficiency (Yield / PAR)[3]	Cumulative Yield	Difference in Gross Income over Nemaguard[4]
BB 106	3201 ab	1.23 ab	83.6 a	38.8 b	19,495	$11,738
F x A	3356 ab	1.31 a	82.1 ab	40.7 ab	18,802	$10,352
Brights 5	3116 ab	1.21 ab	79.5 abc	39.1 b	18,539	$9,826
HM2	3447 a	1.17 bc	77.1 bcd	44.8 a	18,255	$9,258
Hansen	3095 ab	1.16 bc	81.6 ab	38.0 bc	18,111	$8,970
Empyrean 1	2759 bcd	1.11 bcd	74.9 cdef	36.9 bcd	17,316	$7,380
Rootpac R	2373 cde	0.95 ef	69.9 fg	34.0 cde	15,786	$4,320
Paramount	2844 abc	1.23 ab	75.7 cde	37.3 bc	15,507	$3,762
PAC9908-02	2067 e	1.03 de	72.6 defg	28.4 f	15,453	$3,654
Atlas	2223 cde	1.06 cde	68.7 gh	32.4 def	15,355	$3,458
Viking	2823 abc	1.06 cde	71.1 efg	40.0 b	15,318	$3,384
HBOK 50	2131 de	0.98 def	66.8 gh	32.0 ef	13,658	$64
Nemaguard	2002 e	0.99 def	69.0 g	28.8 f	13,626	-
Krymsk 86	1925 e	1.01 def	63.0 hi	30.5 ef	13,265	-$722
Lovell	1883 e	0.90 f	58.8 i	31.9 ef	11,603	-$4,046

[1]Data followed by the same letters are not statitically different (LSD, P≤0.05)
[2]PAR = Photosynthetically Active Radiation, a measure of the amount of light intercepted by the canopy, an indirect measurement of canopy size
[3]Yield efficiency is estimated by dividing yield by canopy size as measured by Photosynthetically Active Radiation (PAR)
[4]Gross income calculated at $2.00 per kernel pound

Midday Stem Water Potential. Midday stem water potential (SWP) data were collected for eight rootstocks (Nemaguard, Atlas, Brights 5, Hansen, Empyrean 1, Viking, Krymsk 86, and Rootpac R) five times during the 2022 season, using a pump-up pressure chamber (PMS Instruments, Albany, OR). Rootpac R consistently had the most negative SWP (most stressed) on all sampling dates, with an average SWP of 9.1 bars below baseline (Table 11). Viking and Krymsk 86 also consistently had more negative SWP, averaging 7.4 and 6.8 bars below baseline, respectively. Atlas and Brights 5 consistently had less negative SWP (less water stress), with an average of 5.2 and 5.3 bars below baseline, respectively.

Table 11. Average midday stem water potential and bars below baseline measured at five points through the season, 2022. Westley CA.

	June 3	June 11	June 25	July 8	July 23	Mean Below Baseline (bars)
Rootpac R	-13.7 a	-14.6 a	-18.2 a	-15.8 a	-22.3 a	-9.1
Viking	-11.3 b	-13.2 ab	-15.2 b	-14.8 ab	-21.5 ab	-7.4
Krymsk 86	-10.9 b	-13.4 ab	-14.7 bc	-14.1 ab	-19.9 ab	-6.8
Nemaguard	-10.7 b	-12.3 bc	-14.2 bc	-14.0 ab	-19.8 ab	-6.4
Empyrean 1	-11.9 b	-11.8 bc	-13.2 bc	-13.8 ab	-20.4 ab	-6.4
Hansen	-10.5 b	-11.9 bc	-13.3 bc	-14.0 ab	-18.5 ab	-5.8
Brights 5	-10.5 b	-11.6 bc	-12.0 c	-13.3 ab	-18.1 b	-5.3
Atlas	-10.2 b	-10.8 c	-12.7 bc	-12.6 b	-18.7 ab	-5.2
Baseline	-6.2	-9.2	-8.8	-7.1	-7.6	

2. Evaluation of 14 rootstocks in an Unfumigated, Sandy Loam Soil

Keyes, CA. Grower: Christine Gemperle

This orchard was planted bareroot in 2003 without fumigation after an almond orchard was removed and a one-year fallow period. The varieties are Nonpareil and Carmel, planted at a spacing of 17' x 21'. The orchard was established on flood irrigation, followed by microsprinklers after about eight years. Data from many previous years were published in prior almond board reports. Yield, trunk circumference, leaf sodium, ring nematode, and rootstock longevity data are updated in this report.

Yields were taken in this trial in the 4th thru 8th, 11th, 15th, and 20th leaf (2022) (Table 12). The peach x almond hybrid rootstocks Nickels, Cornerstone, Hansen, and GF677, along with peach hybrid Empyrean 1, have the highest cumulative yields. Plum and plum hybrid rootstocks Empyrean 2 and Empyrean 101 have the lowest cumulative yields.

Table 12. 2022 (20th Leaf) and Cumulative Yield[1] for Rootstocks in an Unfumigated, Sandy Loam Replant Soil Keyes, CA. Grower: Gemperle Farms				
	Nonpareil		Carmel	
	2022	Cumulative	2022	Cumulative
Nickels	3668 ab	29,384	2375 bc	27,742
Paramount (GF 677)	--	--	3088 a	26,524
Cornerstone	3985 ab	28,351	--	--
Empyrean 1	4372 a	27,952	--	--
Hansen	3602 b	27,577	3368 a	25,580
Cadaman	3548 b	24,377	2824 ab	22,839
Atlas	3474 bc	24,138	3246 a	24,801
Viking	3250 bc	22,998	2303 bc	20,499
Nemaguard	2784 c	20,778	1511 d	16,812
Lovell	2733 cd	20,631	1740 cd	16,691
Guardian	2106 d	19,332	1826 cd	17,889
Krymsk 86	2738 cd	16,127	--	--
Emp. 101 (Adesoto)	2185 d	13,416	--	--
Empyrean 2 (Penta)	2073 d	12,378	--	--

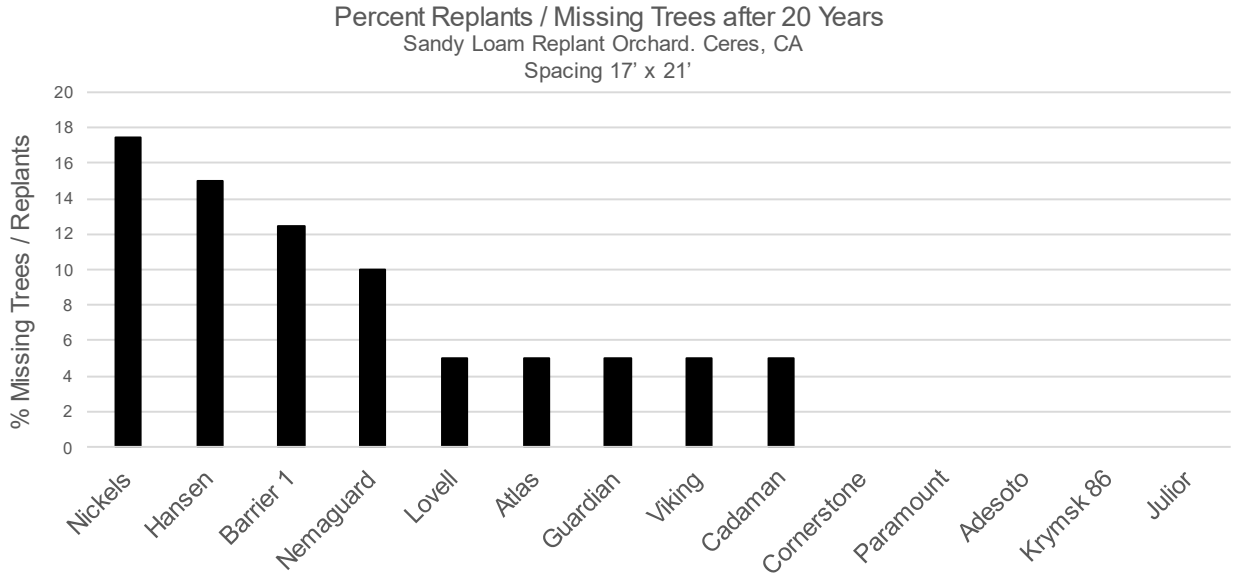
[1]Cumulative yields are from 4th thru 8th, 11th, 15th, and 20th leaf.

Nematodes. Soil cores to 16” were extracted with an Oakfield tube from around the base of data trees and analyzed for parasitic nematodes at a commercial lab (Nematodes, Inc.) during the 17th leaf. Nickels, Cornerstone and Hansen had very high numbers of ring nematodes, significantly higher than other rootstocks. No ring nematodes were found on Viking or Guardian.

Table 13. Number of Ring and Root Lesion Nematodes on Rootstocks in Unfumigated Hanford Sandy Loam. 17th Leaf.		
	Ring Nematodes / 250 cc Soil	Root Lesion
Nickels	1438 a	34 a
Cornerstone	1177 a	2 a
Hansen	1396 a	37 a
Adesoto	257 b	112 a
Cadaman	156 b	22 a
Nemaguard	137 b	69 a
Paramount	118 b	103 a
Atlas	97 b	35 a
Lovell	19 b	36 a
Krymsk 86	10 b	0 a
Empyrean 1	1 b	13 a
Guardian	0 b	38 a
Viking	0 b	18 a

Rootstock Longevity. After the 20th leaf, the total number of replanted or missing trees was assessed for each rootstock (Fig. 2). Most tree loss in this trial was due to scaffold failure, trunk shaker injury, or blow over due to wood decay of the roots and crown. The rootstocks Nickels, Hansen, and Barrier 1 have the most replants or missing trees (12.5% - 17.5%). These vigorous trees had the most scaffold failure and also more windthrow, largely due to crown gall infestations and subsequent decay of the supporting wood structure. The plum / plum hybrid rootstocks Julior, Adesoto, and Krymsk 86 have lost no trees, nor did Cornerstone or Paramount.

Figure 2. Rootstock attrition over 20 years, mostly from scaffold failure and late-life blowover due to crown decay. October 2022



3. **Revisitation of 1997 Rootstock Trial for Rootstock Longevity and Crown Gall**

   Escalon, CA. Grower: Gary Darpinian.

This trial was planted in 1997 on a replant site with a loamy sand infested with ring nematodes. Soil was fumigated with a tarped application of 400 lb methyl bromide prior to planting. The orchard was flood irrigated. Details of this experiment have been published in previous Almond Board reports.

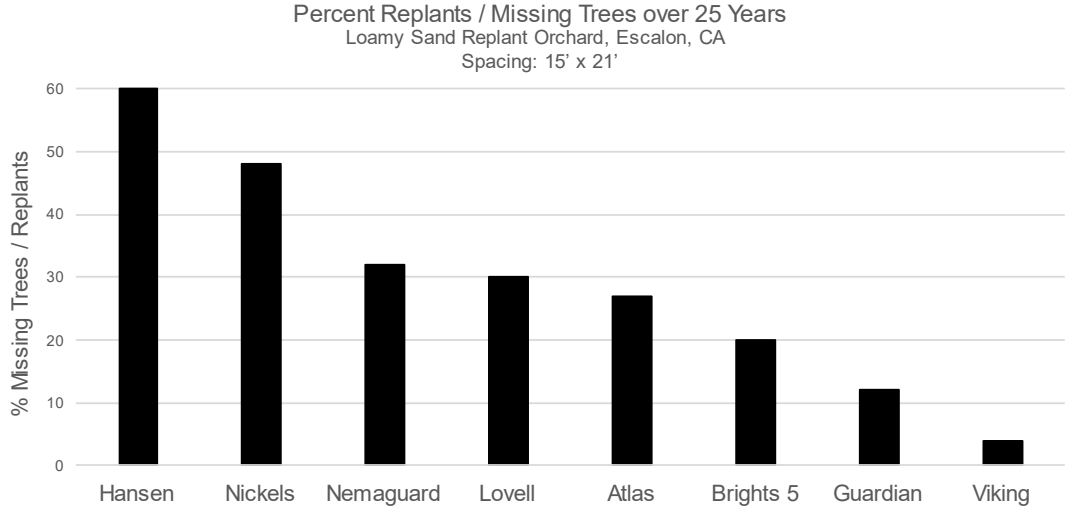
Crown gall. In 2022, the 25th leaf of the orchard, trees were assessed for crown gall severity. Hansen 536 and Nickels were severely affected by crown gall, with more than 50% of the crown circumference affected by crown gall of many trees, substantially affecting tree performance (Table 14). Guardian and Lovell also had substantial crown gall, although less severe than Hansen and Nickels. Viking and Atlas exhibited very low levels of crown gall.

Table 14. Crown gall severity rating for eight rootstocks. Darpinian & Sons, Escalon, CA	
	Crown Gall Severity Rating (0-3)[1]
Hansen 536	2.7
Nickels	2.6
Guardian	1.8
Lovell	1.7
Brights 5	1.0
Nemaguard	0.9
Atlas	0.6
Viking	0.3

1Crown gall was rated on a scale from 0 – 3:
0 = no obvious galls
1 = mild; one gall present; no effect on tree performance
2 = moderate; galls up to half way around tree
3 = severe; over half tree with galls; affecting tree performance

Rootstock Longevity. To assess rootstock longevity over the twenty-five years of this trial, the total number of replanted or missing trees was counted for each rootstock (Fig. 3). Sixty and 48 percent of the original experimental trees on Hansen and Nickels, respectively, were missing or had been replaced over the life of the orchard. Thirty-two, 30, and 27 percent of trees on Nemaguard, Lovell, and Atlas also failed during this trial. In comparison only 4% of the original trees on Viking had failed. Peach x almond hybrid rootstocks were substantially affected by bacterial canker during the first ten years of this trial (about 1/3 of trees on Hansen died). Hansen and Nickels also are severely infested with crown gall, and many were lost to windthrow after substantial wood decay at the tree crowns. Viking trees, being resistant to bacterial canker and crown gall, have survived very well in this trial and appear able to continue producing for many years.

Figure 3. Rootstock attrition over 25 years, mostly from early-life bacterial canker (Hansen, Nickels, Brights 5) and/or late -life blowover due to crown decay. July 2022.



Outreach Methods.

- Presentation at the San Joaquin Valley Almond Day (online). *Field screening of almond rootstocks.* January 14, 2021.
- Article in Western Fruit Grower (by David Eddy). *Are you using the right almond rootstock?* May 2021
- Presentation: *Rootstock options for California almond growers.* Nickels Field Day, Arbuckle CA. May 29, 2021.
- Presentation: *Update on current almond rootstock trials*. Almond Board of California workgroup meeting. Modesto, CA. June 9, 2021.
- Grower field day. Westley, CA. June 23, 2021.
- Article posted on San Joaquin Valley Tree & Vine website. *Consider Alternative Rootstocks for a More Profitable Almond Orchard*. Roger Duncan, Katherine Jarvis-Shean & Joe Connell.
- Presentation: Crop Consultant Conference. *The Role of New and Future Varieties and Rootstocks in an IPM Program in Nut Crops*. Visalia, CA. September 16, 2021.
- Presentation: *A History of Almond Rootstock Trials.* Almond Breeding Field Day. Parlier, CA. November 21, 2021.
- Podcast: Almond rootstocks. December, 2021. https://www.growingthevalleypodcast.com/podcastfeed/almondrootstocks
- Presentation: *Almond Rootstocks; vigor, salt tolerance and yield efficiency.* Almond Board of California Annual Conference, Sacramento, CA. December 8, 2021.
- *Rootstocks*. Chapter in UC Almond Production Manual. In press.
- *Almond Rootstocks*. 2022. UC ANR publication 21675.

B. Effects of Eight Almond Rootstocks on Nonpareil Tree Growth Grown on Marginal Soil High in Boron

Project Leader: Katherine Jarvis-Shean, UCCE Farm Advisor, UCCE Sacramento/Solano/Yolo Counties, 70 Cottonwood Street, Woodland, CA 95695, kjarvisshean@ucanr.edu

Project Cooperators and Personnel:
Lampinen Lab*, UC Davis;* Carolyn DeBuse, *USDA*

Objectives:
To evaluate plant growth, tree crop yield and boron uptake of Nonpareil almond variety on nine different rootstocks in the Sacramento Valley when grown on a marginal soil high in boron.

Interpretive Summary:
The trees on Titan SG1, Nickels, and FxA have produced higher cumulative yields in these high boron conditions than the trees on other rootstocks over the nine years of yield data collection, although Titan SG1 is not a fully replicated part of this trial. Brights 5 rootstock yields were statistically similar to FxA. Lovell and Krymsk 86 have the lowest cumulative yields in this trial while Rootpac R yields were statistically similar to Krymsk 86. Hansen has not performed as well as other peach x almond hybrids in this trial, and yields were similar to Viking.

Materials and Methods:
Rootstocks with potential high boron tolerance relative to the commonly planted Lovell peach were identified for this trial: Hansen 536, Nickels, FxA, Krymsk 86, Brights-5, Rootpac-R, and Viking. This study assessed potential differences in boron tolerance between these rootstocks. Titan SG1 was added after the initial planting. Data collected from this rootstock are reported but considered observational.

The trial is located in Yolo County north of Cache Creek. The soil is classified as Marvin silty clay loam (Storie Index (CA) = 65). Soils in this series are listed as moderately well to poorly drained. Irrigation water boron concentrations range between 1-3 ppm B.

Nonpareil almond nursery grafted trees on eight different rootstocks (Lovell, Hansen, Nickels, FxA, Krymsk 86, Brights-5, Rootpac-R, and Viking) were planted on February 9, 2011. All trees were bareroot except Brights-5, which was potted. Trees were planted at 22’ across the row and 18’ down the row. Twenty trees of Titan SG1 (potted) were planted on April 22, 2011, within the same orchard but not in the replicated trial. The trial is a randomized complete block design with six, 5-tree replicates of each rootstock.

These data are through 2021, the orchard’s 11th leaf. Yield per acre was calculated following harvest of 5-tree replicates by the grower. Hull nutrient assessment was done using samples collected at harvest, with hulls from all 5 trees in each replicate pooled into a single sample. Samples were analyzed for boron by UC Davis Analytical Lab.

Results and Discussion:

Significant differences in average yield per acre were measured between rootstocks in 2021, the ninth and final harvested crop year (Table 1). Trees on peach - almond (P-A) hybrids Nickels, FxA and Brights 5, along with the complex hybrid Viking, produced the highest average yields per acre, while Lovell, Rootpac R and Krymsk 86 rooted trees produced the lowest yields. Hansen 536, despite also being a peach-almond (P-A) hybrid and showing no significant difference in terms of size, continues to be lower yielding than other P-A hybrids, perhaps related to its higher incidents of crown gall (data not shown). In 2021, the yields of FxA and Hansen were not statistically significantly different (p=0.05) from the other P-A hybrids and Viking, Lovell and Krymsk 86. Titan yields should be taken with an extra grain of salt this final year, as PG&E tree removal resulted in only one replicate of six trees available for harvesting.

Table 1. Almond boron rootstock trial results, 2021 and cumulative yield from 2013-2021. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05). Ordered by cumulative yield.

Rootstock	Origin	Avg Yield (kernel lb/acre)[1]	Hull B (ppm)[2]	Light Intercep't (% PAR)	Size Efficiency (lbs/PAR)	Cumulative Yield (lb/acre)
Nickels	Peach-Alm	2,893 a	212 bcd	87 a	33	21,504 a
Titan SG1	Peach-Alm	1,563		80	20	20,551
FxA	Peach-Bitter Alm	2,522 ab	190 cd	88 a	29	19,992 ab
Brights 5	Peach-Alm	2,859 a	213 bcd	80 b	36	18,982 b
Hansen 536	Peach-Alm	2,465 abc	219 bcd	82 ab	30	15,911 c
Viking	Pch-Al-Myro-Apr	2,710 a	183 d	68 c	40	15,240 c
Rootpac-R	Myro Plum-Alm	1,732 c	237 bc	68 c	25	12,429 d
Krymsk 86	Myro Plum-Peach	1,770 bc	257 b	65 c	27	12,032 de
Lovell	Peach	1,902 bc	323 a	58 d	33	10,329 e

[1]Per-acre yield based on average of 5 trees over 6 replications, scaled for the 110 trees per acre spacing. Titan SG1 Not replicates so statistical comparison made.

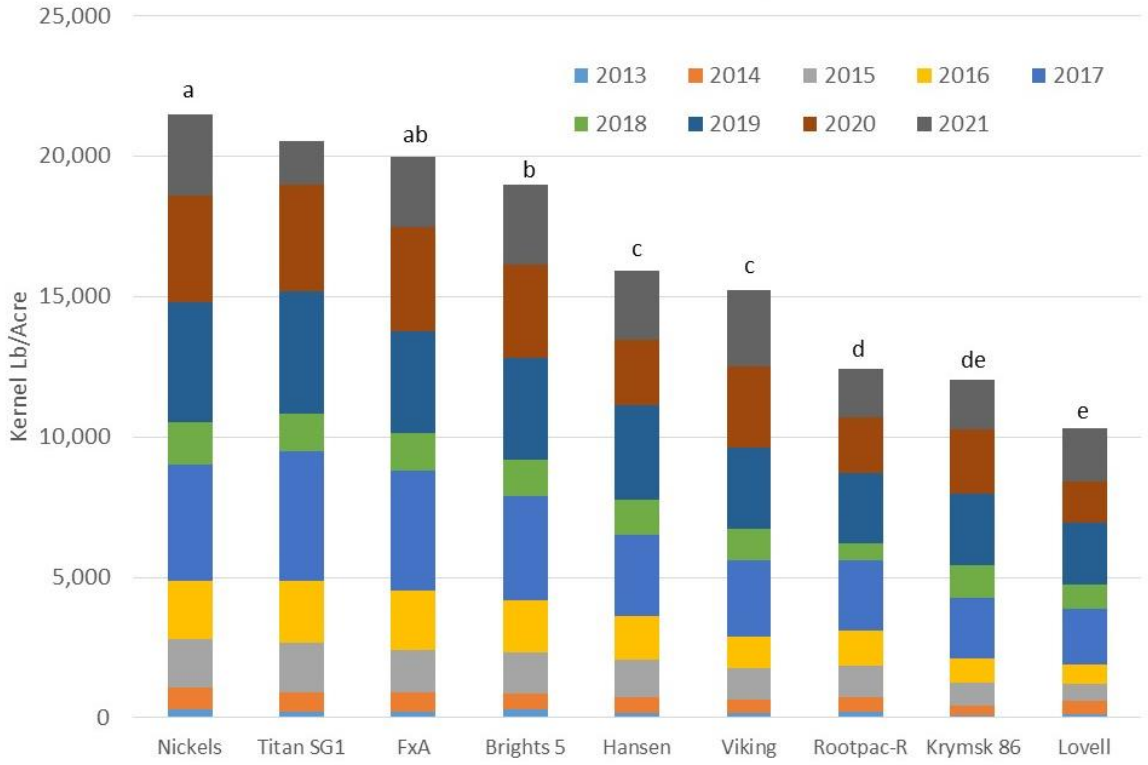
[2] > 300 ppm = "toxicity"

Yield results were somewhat consistent with previous yields (Table 2, Figure 1) – P-A hybrids except Hansen 536 yielded highest; Krymsk 86 and Lovell yielded lowest. However, it is notable that in the final three years, Rootpac-R yields grouped with Krymsk-86 and Lovell as the lowest yielding rootstocks in the trial. Also, Viking had been consistently in the middle of the pack, yield-wise, however in 2021 grouped among the highest yielders. This is not a result of unusually high Viking yields, but instead unusually low yields from the P-A hybrids.

Table 2. Almond boron rootstock trial annual yield results in kernel pounds per acre equivalent, 2016-2020. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05). Ordered by cumulative yield.

	2016		2017		2018		2019		2020		2013-2020	
Titan SG1	2,220		4,600		1,370		4,350		3,790		18,990	
Nickels	2,070	a	4,130	a	1,520	a	4,300	a	3,790	a	18,610	a
FxA	2,090	a	4,280	a	1,360	a	3,620	b	3,690	ab	17,470	ab
Brights 5	1,880	ab	3,700	a	1,300	a	3,630	b	3,300	ab	16,120	b
Hansen	1,560	bc	2,900	b	1,240	ab	3,370	bc	2,310	cd	13,450	c
Viking	1,120	de	2,700	bc	1,150	ab	2,880	cd	2,910	bc	12,530	c
Rootpac-R	1,260	cd	2,500	bcd	590	c	2,530	de	1,960	de	10,700	d
Krymsk 86	880	ef	2,150	cd	1,160	ab	2,550	de	2,280	cde	10,260	d
Lovell	660	f	2,000	d	860	bc	2,230	e	1,480	e	8,430	e

Figure 2. Boron rootstock trial cumulative yield for 3rd through 11th leaf (2013-2021). Scaled from the 5 tree sample average to per acre yields based on the 110 trees per acre spacing, with the exception of Titan. Letters indicate statistically significant differences (Tukey, α=0.05)



Canopy light interception (PAR%) measurements (Table 1, 3, 4) can help decipher whether trees were low yielding because of smaller canopies or other issues, especially when yield is divided by PAR. The 2021 data show that this year larger trees on P-A hybrids did not necessarily produce higher yields than smaller trees on other rootstocks. Canopy light interception (PAR%) measurements indicate the rootstocks could be grouped by size into peach-almond hybrids, other hybrids, and pure peach.

The low yields in the final year were not substantial enough to change the ranking of the rootstocks by cumulative yield over the life of the orchard (Figure 1). Over the years, FxA and Brights 5 have often had lower yields then Titan and Nickels, but in each year these differences were not large enough to distinguish performance statistically. However, adding up yields over nine years, Nickels shows was significantly higher yielding than Brights 5.

Table 3. Almond boron rootstock trial annual percent of Photosynthetically Active Radiation intercepted, 2015-2020. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05).

Rootstock	2015		2016		2017		2018		2019		2020	
FxA	72	a	78	a	87	a	87	a	86	a	80	a
Nickels	73	a	77	a	87	a	86	a	84	a	77	a
Titan SG1	62		76		81		83		81		77	
Brights 5	62	b	68	b	79	b	81	ab	77	b	71	ab
Hansen 536	69	a	74	a	82	ab	79	b	79	ab	73	ab
Viking	53	cd	57	cd	68	c	72	c	65	c	64	bc
Krymsk 86	49	d	52	d	66	cd	65	d	63	c	54	cd
Rootpac R	56	c	58	c	68	c	66	d	64	c	53	cd
Lovell	54	cd	55	cd	63	d	65	d	55	d	46	d

Table 4. Almond boron rootstock trial annual yield efficiency (yield per percent PAR), 2015-2020. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05).

	2015		2016		2017		2018		2019		2020	
Titan SG1	29		29		57		17		54		53	
Nickels	24	a	27	a	48	a	18	a	51	a	49	a
Brights5	23	ab	28	a	47	a	16	a	47	ab	45	a
FxA	21	ab	27	a	49	a	16	a	43	ab	46	a
Viking	21	abc	20	bc	40	b	16	a	45	ab	46	a
Krymsk86	17	c	17	c	33	c	18	a	40	b	42	ab
RootpacR	20	abc	22	b	36	bc	9	b	40	b	37	ab
Lovell	12	d	12	d	32	c	13	ab	41	b	33	b
Hansen536	19	bc	21	b	35	bc	16	a	43	ab	32	b

Unlike most plant species, plants in the *Prunus* genus (almond and other stone fruit) accumulate boron in the fruit. *Leaf boron levels are not a good indicator of toxicity in almond.* Instead, boron in the hulls at harvest is used. Boron conditions are considered toxic if hull boron accumulates above 300 ppm. In 2021, average hull B was below this toxic threshold in all but one rootstock. Levels were significantly higher on Lovell, with rootstock means ranging from 183 ppm to 257 ppm in all rootstocks except Lovell, which had 323 ppm B in hull on average (Table 1, 5). This is not surprising given the low yields and poor health of Lovell trees in this trial over the course of the experiment.

Table 5. Almond boron rootstock trial annual hull boron (parts per million), 2015-2020. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05).

	2013		2014		2015		2016		2017		2018	
Titan SG1	598		540		349		253		263		198	
Nickels	519	c	439	c	265	c	237	bc	227	abcd	191	abc
FxA	559	bc	471	c	312	abc	243	bc	265	a	154	bc
Brights 5	590	abc	541	ab	322	ab	278	b	243	ab	221	ab
Hansen	624	ab	566	a	333	ab	257	bc	215	abcd	166	bc
Viking	511	c	444	c	269	c	220	c	177	d	181	bc
Rootpac-R	570	bc	497	bc	290	bc	235	bc	184	cd	145	c
Krymsk 86	544	bc	493	bc	322	ab	281	ab	203	bcd	193	abc
Lovell	673	a	582	a	360	a	327	a	235	abc	266	a

2019: 210-256 ppm, No significant difference; 2020: Lovell 262, Others n.s. 148-178

C. Performance and Evaluation of Almond Rootstocks in the Southern San Joaquin Valley

Project Leader: Mohammad Yaghmour, UCCE Kern County, mayaghmour@ucanr.edu

A. Summary

Trees were planted on October 22, 2019, in fumigated soil. The experiment is part of a replanted orchard on a sandy loam soil where orchard recycling was performed. Also, high winds in this part of the valley are one of the biggest challenges. Trees continued to grow well, and a significant difference in tree circumference was observed among the different rootstocks. Rootstock Flordaguard x Alnem expressed the biggest growth despite the fact that we lost a whole replicate out of six replicates; and Krymsk 86 had the smallest trunk circumference among all rootstocks. The growth of Flordaguard x Alnem was not significantly different to most peach-almond hybrids or our standard (Hansen 536), and it was only 0.4 cm (0.15 inch) larger than Titan SG1 and 1.4 cm (0.5 inch) larger than Hansen 536 in circumference. Growth of Flordaguard, resistant to a population of peach root-knot nematode, was not statistically different from other peach-almond hybrids such as Hansen 536 and Bright's hybrid 5. We will be monitoring this rootstock for its horticultural characteristics and yield. All rootstocks had nitrogen levels below adequate range value of 2.2%, with the most vigorous rootstocks such as Hansen 536, FXA, Empyrean-1, and Titan SG1 showing nitrogen status slightly below 2.0%. However, we have not observed any nitrogen deficiency symptoms on any trees grafted on all rootstocks. Furthermore, leaf tissue analyses revealed the beginning of chloride accumulation in almond trees grafted on Krymsk 86 and Flordaguard, However, sodium was not detected in samples collected from all rootstocks except for Hansen 536. We did not detect any significant differences in midday stem water potential among the different rootstocks in 2021. In 2022, significant differences were observed in August before shaking the trees, and stem water potential before harvest ranged from -13.3 to -23 bars with a baseline of approximately -9 bars. Trees grafted on rootstocks showing the biggest tree growth as measured by tree trunk circumference had the biggest stress compared to the trees with the least tree growth. We have also evaluated the progression of hull split for Nonpareil on the different rootstocks during the 2022 season with hull split initiation and progression faster with trees grafted on Krymsk86, Rootpac R, and Viking. Furthermore, we measured tree anchorage and trees grafted on Krymsk 86, Rootpac R, Hansen, and Viking, are most the straight trees, while rootstocks BB106, Cornerstone, and Empyrean-1 were leaning the most in the orchard.

B. Objectives

The objective of this trial is to compare different rootstocks and evaluate the effect of rootstocks on scion growth and yield in Kern County. Among the rootstocks that will be tested is Flordaguard which is recommended for peach growers in Florida where *Meloidogyne floridensis* was detected for the first time in the US. This experiment is also evaluating other rootstocks that were not evaluated under Kern County conditions.

C. Results and Discussion

In the third year of the orchard's life, the rootstock FXA is now the leading rootstock among all the rootstocks in size and had the biggest growth as expressed by trunk circumference measurements (Tables 1 & 2). However, another four rootstocks have had the most tree growth for the past three seasons since we have been measuring tree growth. Those rootstocks include peach-almond hybrids Titan SG1 clonal, Hansen 536, and BB106, and the peach hybrid Empryrean-1, and all of them were not statistically different from each other.

The peach-almond hybrid rootstock; Bright's hybrid 5; ranked in the middle when compared to other peach-almond rootstocks. It was statistically smaller than Titan SG1 clonal, and BB106, but was statistically similar to Hansen 536. However, Cornerstone had the smallest trunk circumference among all peach-almond hybrids and was not statistically different from Krymsk 86 rootstock which had the smallest trunk circumference.

Flordaguard ranked in the middle and was not statistically different from Hansen 536 and BH5, Flordaguard showed resistance to a population of peach root-knot nematode (PRKN) in Florida and was recommended at the beginning to be planted in soils infested with PRKN. While this rootstock experiment is not going to test resistance for this nematode at this site since this site is free of this invasive nematode, the purpose of including this rootstock in this experiment is to measure it is growth and how it is going to affect yield under Kern County conditions.

It is worth noting that the tree growth results from 2022 was not generally different from 2021. Peach-almond hybrid rootstocks such as Hansen 536, and BH5 rootstocks are among the most planted rootstocks in Kern County with few orchards planted to Viking. Furthermore, there are very few plots planted on Krymsk 86 because it proved to have good anchorage in a previous experiment in Kern County. Plum rootstocks such as Krymsk 86 and Rootpac R had the best anchorage among all the rootstocks but not statistically different from Hansen 536, and BH5; the two most plant peach-almond hybrids in Kern County. In the coming years, we will be measuring the yield and continue with all the measurements we collected in the past years since the start of this project.

Mid-July leaf analysis of Nonpareil shows that all the trees in the orchard had nitrogen level below the adequate range values of 2.2-2.5% (Tables 3, 4, & 5). Despite that, significant differences in leaf nitrogen and potassium levels were detected, and phosphorus levels were not statistically different from trees grafted on the different rootstocks (Tables 3, 4, & 5). The most vigorous rootstocks as expressed by trunk circumference such as FXA, and many peach-almond hybrids had the least amount of nitrogen levels in the leaf. While the plum rootstocks Krymsk 86 and Rootpac R had the highest leaf nitrogen content. In certain cases where orchard recycling is performed, trees may show nitrogen deficiency early in the first year's growth. However, we did not observe any nitrogen deficiency symptoms since the start of this experiment, neither in the most vigorous ones that are showing values below 2% and lower than the critical

value. Leaf phosphorus and potassium content has always been within the adequate range for almonds (Tables 3, 4, & 5).

Furthermore, leaf analysis for chloride and sodium shows the beginning of chloride accumulation in the past two growing season in trees grafted on Krymsk 86 or Flordaguard with chloride content of 0.19, and 0.17% respectively in 2022, however, sodium was not detected in leaf samples on average except in Hansen 536 for the first time (Table 6). Chloride is considered excessive when chloride content in the leaf is greater than 0.3%. Previous rootstock research done in California Central Valley had shown that Krymsk 86 and peach rootstocks are susceptible to high chloride. We will continue to assess leaf analyses every year to detect any further changes in tree nutritional status.

No significant differences in midday stem water potential readings have been detected between the different rootstocks in 2021 (Figure. 1, and Table 7). However, in 2022 significant differences were detected in August just before shaking the trees. Stem water potential before harvest ranged from -13.3 to -23 bars with a baseline of approximately -9 bars. Trees grafted on rootstocks showing the biggest tree growth showed the most stress. We also evaluated the progression of hull split for Nonpareil on the different rootstocks during the 2022 season with hull split initiation and progression faster with trees grafted on Krymsk 86, Rootpac R, and Viking (Figure. 2).

Tree anchorage was determined by measuring the trunk angle relative to the soil surface, with trees at 90 degrees to be perfectly upright, and trees with 80 degrees or less to be considered to have good anchorage. Krymsk 86, Rootpac R, Hansen, and Viking, are most straight trees with an angle greater than 80 degrees. Rootstocks BB106, Cornerstone, and Empyrean-1 were leaning the most in the orchard (Figure. 3). No tree loss was recorded due to high winds, nor due to diseases, however, some of the trees have been replanted due to bird damage, gophers, and other abiotic causes.

D. Outreach Activities

Results regarding tree growth from the first year of this project were presented at the Kings and Tulare Co. CAPCA meeting in 2021, and a field meeting was conducted to present the project to the Almond Board of California. Also, first year results were presented at the Almond Conference in Sacramento, CA.

E. Materials and Methods:

Nonpareil scion grafted on eleven rootstocks were planted on October 22, 2019, in a fumigated soil (Table 8). The experiment is part of a replanted orchard on a sandy loam soil at Tejon Ranch. Orchard recycling was performed at this site prior to planting the trial. High winds in this part of the valley are one of the biggest challenges. Some growers in that part of the county use Krymsk 86 as a rootstock based on a previous UC rootstock trial that showed this rootstock to have good anchorage characteristics. The experimental design is a Randomized Complete Block Design with 6 blocks and 7 trees per block. The orchard is planted at 22’ x 16’ spacing. Trunk diameter measurements were taken to assess tree growth and it is used to calculate tree circumference.

The soil at the experimental site is classified as sandy loam based on the soil map, and it is uniform across the experimental site. Soil samples were taken in May 2020 at 6 inches, one, two, three, four, and down to five feet deep. Samples were also taken at two locations at those depths, the soil was taken within the tree row between trees, and between the rows (Table 9).

Leaf analysis for nutrient content was performed in mid-July. Leaves were collected from each rootstock from 4 blocks only (Blocks 2 to 5), dried, and submitted to Dellavalle Laboratory Inc in Fresno, CA. Soil samples were also analyzed at Dellavalle Laboratory Inc in Fresno, CA. All trees at the experimental site were monitored for tree loss due to diseases. Also, trees were monitored for any nutritional issues due to orchard recycling, and midday stem water potential was measured using pressure chamber during the growing season in 2021 and 2022. Furthermore, Hull split data was recorded during 2022 growing season. However, the official yield collection data will start in 2023.

Table 1. Table 1. Least square means of trunk circumference (cm) for the growing seasons 2021, and 2022. Nonpareil scions were grafted on 11 different rootstocks. Different letters indicate significant differences at p<0.05 using Tukey-Kramer HSD.

2021		**2022**	
Rootstock	**trunk circumference (cm)**	**Rootstock**	**trunk circumference (cm)**
Titan SG1 Clonal	28.57 A	FxA	41.5 A
Hansen 536	27.06 AB	Titan SG1 Clonal	41.1 AB
BB106	27.04 AB	Empyrean-1	40.7 AB
Empyrean-1	26.81 ABC	BB106	40.2 AB
F X A	26.66 ABCD	Hansen 536	40.1 ABC
Flordaguard	24.99 BCDE	Flordaguard	39.0 BCD
Brights 5	24.61 BCDE	Brights hybrid 5	38.2 CDE
Cornerstone	23.81 CDE	Viking	36.7 CDE
Viking	23.72 DE	Cornerstone	36.2 DE
Rootpac R	23.23 E	Rootpac R	35.8 DE
Krymsk 86	22.13 E	Krymsk 86	34.5 E

Table 2. Mean change in trunk circumference (cm) during the 2020 season. Different letters indicate significant differences at p<0.05 using Tukey-Kramer HSD.

Rootstock	Mean increase in Tree circumference (cm)
Titan SG1	11.87 A
FXA	10.37 AB
BB106	10.32 AB
Empyrean-1	9.48 BC
Hansen 536	9.26 BCD
BH5	9.25 BCD
Flordaguard	8.20 CDE
Rootpac R	7.60 CDE
Viking	7.42 DE
Cornerstone	7.29 E
Krymsk 86	7.22 E

Table 3. Leaf concentrations of N, P, and K. Leaves were collected in July 2022 and processed at a commercial lab. Different letters indicate significant differences at p<0.05 using Tukey-Kramer HSD.

Rootstock	N (%)	P (%)	K (%)
Krymsk 86	2.17 A	0.10	2.04 A
Rootpac R	2.08 AB	0.10	1.96 AB
Titan SG1 Clonal	2.07 BCD	0.11	1.94 ABC
Cornerstone	2.04 BCD	0.09	1.54 CDEF
Flordaguard	2.03 BCD	0.10	1.79 ABCD
Viking	2.02 BCD	0.09	1.87 ABC
FxA	1.98 BCD	0.10	1.58 BCDEF
Brights hybrid 5	1.96 CD	0.09	1.44 DEF
Hansen 536	1.94 D	0.10	1.23 EF
Empyrean-1	1.94 D	0.09	1.22 F
BB106	1.96 D	0.09	1.62 BCDE

Table 4. Leaf concentrations of N, P, and K. Leaves were collected in July 2021 and processed at a commercial lab. Different letters indicate significant differences at p<0.05 using Tukey-Kramer HSD.

Rootstock	N (%)	P (%)	K (%)
Krymsk 86	2.28 A	0.12 AB	2.13 AB
Cornerstone	2.25 A	0.12 AB	1.72 BCDEF
Brights hybrid 5	2.24 A	0.11 AB	1.57 DEF
Rootpac R	2.23 A	0.13 A	2.21 A
BB106	2.23 A	0.11 B	1.71 CDEF
Viking	2.23 A	0.12 AB	1.93 ABCD
Flordaguard	2.20 AB	0.12 AB	1.82 ABCDE
Titan SG1 Clonal	2.19 AB	0.12 AB	2.00 ABC
Empyrean-1	2.13 AB	0.11 B	1.36 F
FxA	2.12 AB	0.11 B	1.74 BCDEF
Hansen 536	2.03 B	0.11 AB	1.48 EF

Table 5. Leaf concentrations of N, P, and K. Leaves were collected in July 2020 and processed at a commercial lab. Different letters indicate significant differences at $p<0.05$ using Tukey-Kramer HSD

Rootstock	N (%)	P (%)	K (%)
Titan SG1	2.80 A	0.16 A	1.76 AB
BB106	2.64 AB	0.15 A	1.46 CDE
FXA	2.63 AB	0.15 A	1.56 BCD
Krymsk 86	2.62 AB	0.16 A	1.81 AB
Empyrean-1	2.61 AB	0.15 A	1.27 E
Hansen 536	2.57 AB	0.16 A	1.42 DE
BH5	2.52 AB	0.15 A	1.35 DE
Rootpac R	2.50 AB	0.15 A	1.86 A
Flordaguard	2.45 B	0.15 A	1.79 AB
Cornerstone	2.44 B	0.15 A	1.43 DE
Viking	2.35 B	0.14 A	1.71 ABC

Table 6. Leaf analysis of Chloride and Sodium. Leaves were collected in July 2021 and processed at a commercial lab.

	2021		2022	
Rootstock	Cl (%)	Na (%)	Cl (%)	Na (%)
Krymsk 86	0.28	ND*	0.19	ND*
Flordaguard	0.20	ND	0.17	ND
Rootpac R	0.10	ND	0.07	ND
BB106	0.05	ND	0.06	ND
Viking	0.05	ND	0.03	ND
Flordaguard X Alnem	0.05	ND	0.03	ND
Hansen 536	ND	ND	0.00	0.01
Brights 5	ND	ND	0.00	ND
Cornerstone	ND	ND	0.00	ND
Titan SG1 Clonal	ND	ND	0.00	ND
Empyrean-1	ND	ND	0.00	ND

*****ND=not detected

Table 7. Average midday stem water potential for Nonpareil trees grafted on eleven rootstocks 2022. Different letters indicate significant differences at p<0.05 using Tukey-Kramer HSD.

Rootstock	**6/24/2022**	**7/8/2022**	**7/20/2022**	**8/5/2022**
Baseline	**-9.4**	**-7.4**	**-10.2**	**-8.8**
Krymsk 86	-9.9	-9.7	-11.3	-13.3 A
Rootpac R	-11.3	-10.4	-11.9	-13.5 A
Cornerstone	-9.3	-8.1	-10.5	-13.9 A
BB106	-10.1	-8.0	-10.1	-15.7 AB
Empyrean-1	-9.1	-9.8	-10.2	-15.9 AB
Flordaguard	-11.3	-8.8	-10.4	-16.8 AB
Viking	-9.2	-7.7	-9.8	-16.8 AB
Brights hybrid 5	-10.6	-9.0	-11.0	-18.1 AB
Hansen 536	-9.2	-8.2	-10.4	-19.1 AB
FxA	-10.3	-8.5	-12.7	-20.7 AB
Titan SG1 Clonal	-11.3	-9.7	-11.0	-23.0 B

Table 8. Rootstocks planted at the trial in Kern County

1	Hansen 536	*Prunus persica* X *P. dulcis*
2	Brights hybrid 5	*P. persica* X *P. dulcis*
3	BB106	*P. persica* X *P. dulcis*
4	Cornerstone	*P. persica* X *P. dulcis*
5	Titan SG1 Clonal	*P. persica* X *P. dulcis*
6	Empyrean-1	*P. persica* X *P. davidiana*
7	Krymsk 86	*P. cerasifera X P. persica*
8	Rootpac R	*P. cerasifera x P. dulcis*
9	Viking	*P. persica* X *(P. dulcis) X ((P. cerasifera x P. armeniaca))*
10	Flordaguard	*P. persica*
11	FxA	Flordaguard X Alnem

Table 9. Soil analysis of the experimental site within tree row or between tree rows at different soil depths . Samples were collected in May, 2020 and analyzed at Dellavalle.

Soil ID	OM (%)	pH	EC (dS/m)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	Cl (meq/l)	PO_4-P (mg/kg)
Tree 00-06"	1.09	7.6	1.38	6.2	2.2	4.1	2.6	14
Tree 06-12"	1.03	7.6	1.80	10.4	3.4	4.0	2.8	10
Tree 12-24"	0.90	8.0	1.27	6.9	2.0	3.2	2.5	5
Tree 24-36"	0.85	8.0	1.32	6.8	1.4	4.6	2.3	3
Tree 36-48"	0.79	8.0	1.31	5.3	1.0	5.8	2.4	3
Tree 48-60"	0.77	8.1	1.46	6.5	1.2	6.4	2.1	2
Middle 00-06"	1.49	7.5	1.31	6.4	3.0	2.8	0.4	13
Middle 06-12"	1.25	7.5	1.56	7.3	3.1	4.3	0.8	8
Middle 12-24"	0.91	7.8	1.45	5.9	1.8	5.4	0.6	4
Middle 24-36"	0.95	8.0	1.96	5.5	1.1	11.2	2.4	3
Middle 36-48"	0.93	8.1	1.66	4.0	0.7	10.1	2.2	3
Middle 48-60"	0.69	8.0	1.81	4.4	0.7	11.5	2.8	2

Figure 1. Average midday stem water potential for Nonpareil trees grafted on eleven rootstocks in 2021.

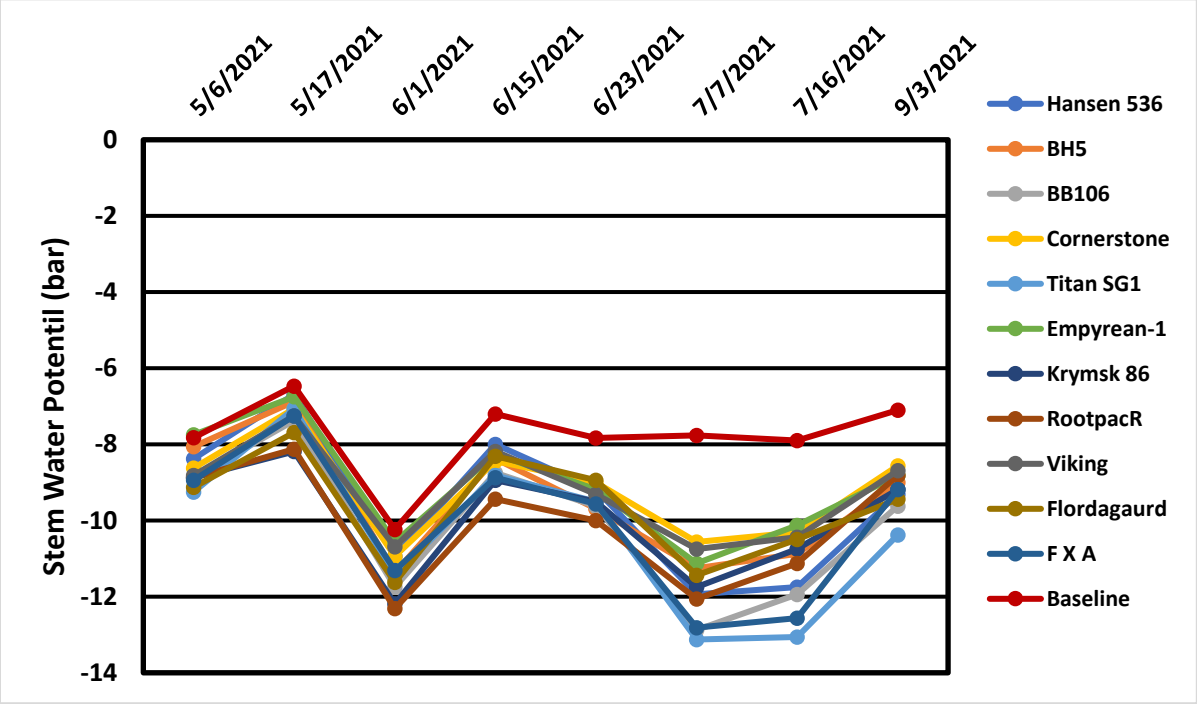


Figure 2. Effect of Different Rootstocks on Progression of Hull split.

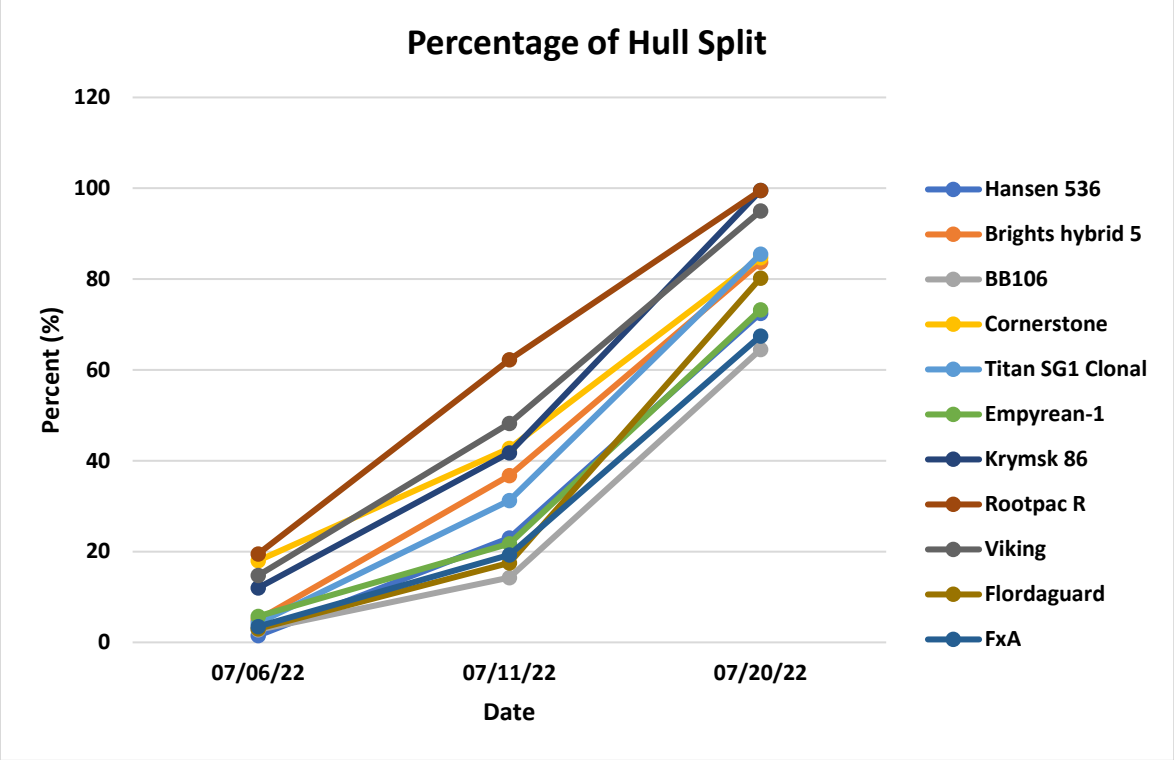
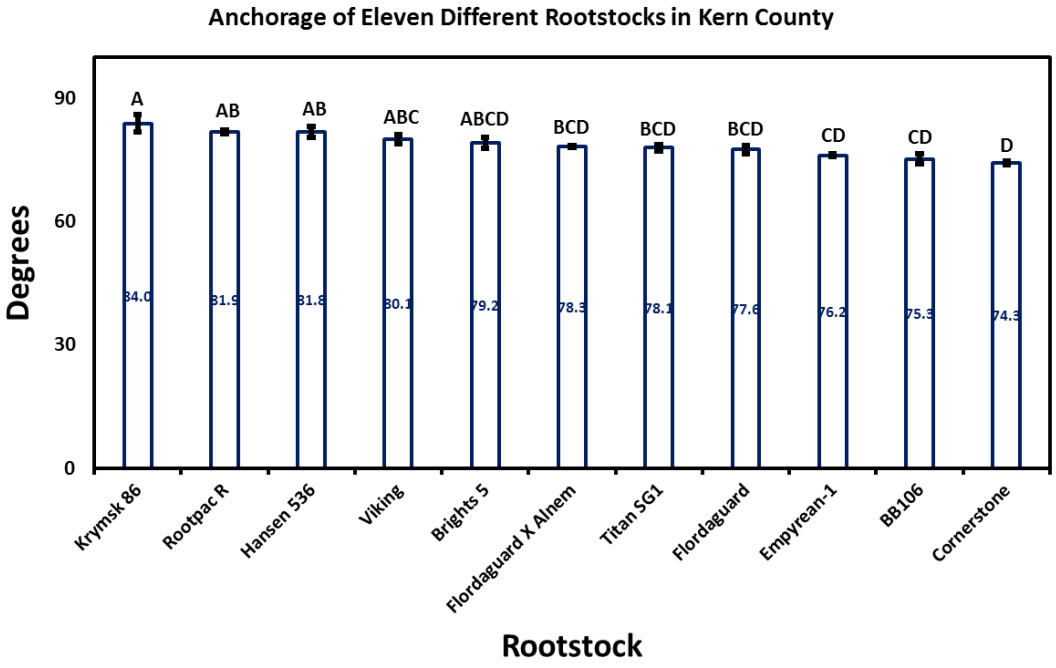


Figure 3. Effect of different rootstocks on anchorage. Different letters indicate significant differences at $p<0.05$ using Tukey-Kramer HSD.



D. Evaluation of Alternative Rootstocks in Butte County

Sub-Project Leader: J.H. Connell, UCCE Farm Advisor Emeritus, Butte County, 2279 Del Oro Ave. Suite B, Oroville, CA 95965, (530) 538-7201, Email: jhconnell@ucanr.edu
Project Cooperators: Luke Milliron, Butte-Glenn-Tehama Farm Advisor, Luis Hernandez and German Campos, Deseret Farms of California–Durham, and Fowler Nursery

Objectives: Evaluate Nonpareil vigor and compatibility with rootstocks for almond and assess tree field performance.

Materials and Methods:
Working with Brouwer Orchards and Fowler Nursery, a rootstock trial was planted on March 15, 2010 following the removal of a previous 'Lovell' peach-rooted orchard containing some plum rooted replants. Deseret Farms of California--Durham subsequently acquired the orchard and research continued. Tree spacing in this orchard is 24 feet across the middles by 16 feet down the tree row giving a tree population of 113 trees per acre. This replicated randomized trial compared six rootstocks, all with 'Nonpareil' as the scion, planted with five replicates of ten trees each. The trial is planted on Farwell Loam soil, a relatively heavy series bordering Stockton Clay Adobe. The rootstocks 'Rootpac-R', 'Atlas', 'Krymsk 86', and 'Empyrean 1' are compared to standard rootstocks 'Nickels' and 'Lovell'.

Tree growth was documented with trunk circumference measurements. Nut size and yield data were collected annually through the tenth growing season. Nut quality was reported following the 2019 harvest. Tree nutrition was characterized with leaf analysis in the seventh, ninth, and tenth growing seasons. Nut maturity measured as the timing and progression of hullsplit was determined in the ninth and tenth growing seasons; as was pre-harvest stem water potential.

Soil sampling for nematodes was done in each replicate for all rootstocks on February 14, 2020 and submitted to Nematodes, Inc. in Selma for analysis. Extraction from a 250 cc sample was done by sieving and centrifugal flotation. Results are reported at 100% extraction.

Mortality and anchorage will be noted as opportunities arise over the long term. Data was processed by an analysis of variance and using Fishers protected LSD procedure for mean separation.

Results and Discussion:
Four of six rootstocks established well in the first growing season with no tree losses. 'Atlas' suffered 10% mortality at planting and 'Nickels' lost 16% of the new trees (data presented in 2012 annual report).

Nutrient levels. Tree nutrition was characterized using leaf and hull analysis in 2016, 2018 and subsequently with leaf analysis in 2019. Samples were analyzed for

mineral nutrient content at the University of California Agriculture and Natural Resources Analytical Laboratory at UC Davis.

Certain rootstocks forage better for some mineral nutrients and are better at excluding other elements. This knowledge will help select rootstocks with the best fit for orchard site challenges. Rootstocks defend against specific challenges and some stocks are more tolerant of high pH, salt, and alkali than others.

The following is a summary of leaf nutrient level ranking for each rootstock relative to other rootstocks in the trial (Table 1).

- Trees on 'Lovell' are intermediate in some nutrient levels but are among the highest in chloride and among the lowest in potassium, calcium, and boron.
- 'Krymsk 86' rooted trees are highest in leaf nitrogen, among the highest in potassium, chloride, and boron, but were among the lowest in leaf calcium and magnesium.
- 'Atlas' rooted trees are among the highest in boron and potassium levels, intermediate for most other nutrients, but among the lowest in chloride.
- 'Empyrean 1' rooted trees are highest in magnesium, among the highest in manganese, zinc, and boron, but among the lowest in nitrogen, potassium, and chloride.
- 'Nickels' trees are highest in calcium and among the lowest in nitrogen and chloride.
- Trees on 'Rootpac-R' are among the highest in leaf potassium and manganese, among the lowest in boron, calcium, and magnesium, and are intermediate in nitrogen and chloride.

Table 1. Rootstock effects on nutrient content of 'Nonpareil' almond leaves and hulls.

Durham, California, August 3, 2016

Rootstock	N (%)	P (%)	K (%)	S (ppm)	B (ppm)	Ca (%)	Mg (%)	Zn* (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Cl (%)	Na (ppm)
'Krymsk 86'	2.64 a	0.139 a	2.68 a	2418 a	39 ab	3.47 d	0.92 d	90 ab	26	473	7.6 a	0.06 a	144
'Atlas'	2.54 b	0.131 b	2.38 b	2186 bc	42 a	3.83 c	1.09 c	82 bc	31	419	7.1 bc	0.03 c	206
'Lovell'	2.48 c	0.129 bc	2.07 c	2034 de	34 c	3.51 d	1.16 b	73 c	25	473	6.7 cd	0.06 a	133
'Rootpac-R'	2.40 d	0.129 bc	2.73 a	2234 b	31 d	3.27 d	0.89 d	76 c	35	438	6.4 d	0.04 b	190
'Empyrean 1'	2.38 d	0.128 c	1.82 d	2124 cd	42 a	4.29 b	1.35 a	95 a	31	390	6.8 bcd	0.02 c	243
'Nickels'	2.37 d	0.128 c	2.13 c	1956 e	38 b	4.99 a	1.07 c	93 ab	31 ns	365 ns	7.3 ab	0.03 c	194 ns

Durham, California, July 8, 2018

Rootstock	N (%)	K (%)	Ca (%)	Mg (%)	Zn*(ppm)	Mn(ppm)	Cl (%)	Na(ppm)	B (ppm)	Hull B (ppm)
'Lovell'	2.60 bc	2.03 bc	3.56 c	1.41 a	51.9	20.7 b	0.09 a	293.0	35.6 b	48.96 e
'Krymsk 86'	2.79 a	2.34 a	3.61 c	1.10 c	53.0	21.5 b	0.07 b	192.8	38.8 a	56.72 bc
'Atlas'	2.65 b	2.46 a	3.62 c	1.21 b	58.7	21.4 b	0.04 d	316.4	41.1 a	66.56 a
'Empyrean 1'	2.47 d	1.92 c	4.08 b	1.49 a	65.4	27.3 a	0.03 e	250.6	40.1 a	62.08 ab
'Nickels'	2.47 d	2.26 ab	4.68 a	1.20 b	63.9	20.9 b	0.03 e	260.0	39.7 a	54.4 cd
'Rootpac-R'	2.58 c	2.47 a	3.73 c	1.09 c	54.9 ns	30.8 a	0.05 c	219.8 ns	35.6 b	51.1 de

Durham, California, July 15, 2019

Rootstock	N (%)	K (%)	Ca (%)	Mg (%)	Zn*(ppm)	Mn(ppm)	Cl (%)	Na(ppm)	B (ppm)
'Lovell'	2.38 c	2.26 c	2.99 cd	1.16 b	27.8 b	22.8 b	0.05 a	108.4	37.6 d
'Krymsk 86'	2.59 a	2.58 ab	2.88 d	0.89 d	30.0 b	22.1 b	0.05 a	137.8	41.6 c
'Atlas'	2.46 b	2.70 a	3.13 c	1.04 c	32.0 b	25.0 b	0.03 b	134.8	46.5 a
'Empyrean 1'	2.37 c	2.11 c	3.66 b	1.31 a	39.0 a	35.5 a	0.02 c	125.2	44.7 ab
'Nickels'	2.36 c	2.38 bc	4.19 a	1.08 c	38.3 a	26.6 b	0.02 c	181.2	42.6 bc
'Rootpac-R'	2.40 bc	2.78 a	3.03 cd	0.88 d	28.0 b	31.7 a	0.03 b	125.6 ns	38.1 d

Values followed by the same letters are not significantly different from one another at P< 0.05 using Fisher's least significant difference (LSD) procedure.

*** Zinc levels are high likely due to leaf surface contamination.**

Hullsplit Timing. The approximate order of 'Nonpareil' hullsplit influenced by rootstock in both 2018 and 2019 from earliest to latest was 'Rootpac-R', 'Lovell', 'Atlas' and 'Krymsk 86', and finally 'Empyrean1' and 'Nickels'. While 'Rootpac-R' was ready to shake by the end of July 2019, the much larger 'Empyrean1' and 'Nickels' rooted trees weren't ready to shake until roughly August 16th, over two weeks later (Table 2).

The most dwarfing rootstock, 'Rootpac-R', completed hullsplit earlier in both 2018 and 2019 than the more vigorous rootstocks. For instance, on July 27, 2018, 'Nonpareil' on 'Rootpac-R' ranged between 60% and 80% hullsplit, while on the same day, most of the other rootstocks were less than 5% split. On July 30, 2019, 'Nonpareil' on 'Rootpac-R' was at 100% hullsplit (i.e. ready to shake), while the vigorous 'Empyrean 1' trees were only 10-20% split.

Different orchards with the same variety will vary in hullsplit timing and harvest maturity depending on rootstock. The progression of 'Nonpareil' hull split is shown in table 3. Hulls begin to split naturally and the shell becomes visible at values of 4 to 5. Values of 6 to 8 indicate hulls are open and drying on the tree and nuts are ready to shake.

Table 2. Dates in 2018 and 2019 when 'Nonpareil' reached 100% hullsplit.

	2018[b]			2019[c]		
Rootstock	1% Split[a]	100% Split	# Days for Hullsplit	1% Split*	100% Split	# Days for Hullsplit
'Lovell'	7/25	8/5	12	7/20	8/5	17
'Krymsk 86'	7/27	8/12	17	7/22	8/7	17
'Atlas'	7/26	8/8	14	7/23	8/8	17
'Empyrean 1'	7/27	8/15	20	7/27	8/15	20
'Nickels'	7/27	8/16	21	7/26	8/17	23
'Rootpac-R'	7/24	8/3	11	7/19	7/28	10

[a] Dates are a 3 replicate average with interpolation between observations.

[b] 2018 commercially shaken on 8/20 with pickup on 8/31.

[c] 2019 commercially shaken on 8/16 with pickup on 8/26.

Table 3. Progression of 'Nonpareil' hullsplit as affected by rootstock.

2018 Observation dates*

Rootstock	7/23	7/27	8/2	8/8	8/13
'Lovell'	2.0 b	3.7 b	4.7 b	5.3 ab	6.0 ab
'Krymsk 86'	1.0 c	3.3 b	3.7 cd	4.7 bc	5.3 b
'Atlas'	1.0 c	3.7 b	3.7 cd	5.0 ab	6.0 ab
'Empyrean 1'	1.0 c	2.7 bc	4.0 bc	4.7 bc	6.0 ab
'Nickels'	1.0 c	2.0 c	3.0 d	4.0 c	5.3 b
'Rootpac-R'	3.7 a	5.0 a	5.7 a	5.7 a	6.7 a

2019 Observation dates*

Rootstock	7/18	7/23	7/30	8/5	8/12
'Lovell'	2.0 b	4.3 ab	5.3 ab	6.3 a	7.0 ab
'Krymsk 86'	2.0 b	3.3 bc	5.0 ab	6.0 ab	6.7 b
'Atlas'	1.7 bc	3.3 bc	4.3 bc	5.3 bc	6.3 b
'Empyrean 1'	1.0 c	1.0 d	3.0 d	5.0 c	5.0 c
'Nickels'	1.0 c	2.3 c	3.3 cd	5.0 c	5.0 c
'Rootpac-R'	3.7 a	5.0 a	6.0 a	6.7 a	7.7 a

Dominant Hullsplit Stage	1	2a	2b	2c	3	4	5	6
Value Assigned	1	2	3	4	5	6	7	8

Values followed by the same letters are not significantly different from one another at P< 0.05 using Fisher's least significant difference (LSD) procedure.

*** Higher values indicate more advanced hullsplit. Hullsplit begins at a value of 4. Hulls are drying at values of 6-8.**

Stem Water Potential (SWP). In both 2018 and 2019 SWP measurements between trees were quite variable and thus differences between treatments were not statistically significant at P<0.05. SWP was measured after the last pre-harvest irrigation while nuts were on the ground in 2018 but still in the trees in 2019.

In both years, trees on 'Rootpac-R' and 'Lovell' appeared to be the most stressed. 'Krymsk 86' and 'Atlas' had the least stress in 2018 while 'Atlas' and 'Nickels' appeared to have less stress in 2019. 'Empyrean 1', the largest most vigorous tree was intermediate in stress (Table 4).

Table 4. Pre-harvest Stem Water Potential in bars in 'Nonpareil' almond as affected by rootstock.

Rootstock	Mean SWP[1] 8/24/2018	Mean SWP[2] 8/16/2019
'Lovell'	-22.4	-19.2
'Krymsk 86'	-17.1	-16.6
'Atlas'	-17.5	-14.6
'Empyrean 1'	-20.1	-15.7
'Nickels'	-18.1	-14.8
'Rootpac-R'	- 22.1 ns	-17.9 ns

[1] Mean of four replicates. Baseline = - 6.5 bars

[2] Mean of five replicates. Baseline = - 8.9 bars

Values are not significantly different at P<0.05 using Fisher's least significant difference (LSD) procedure.

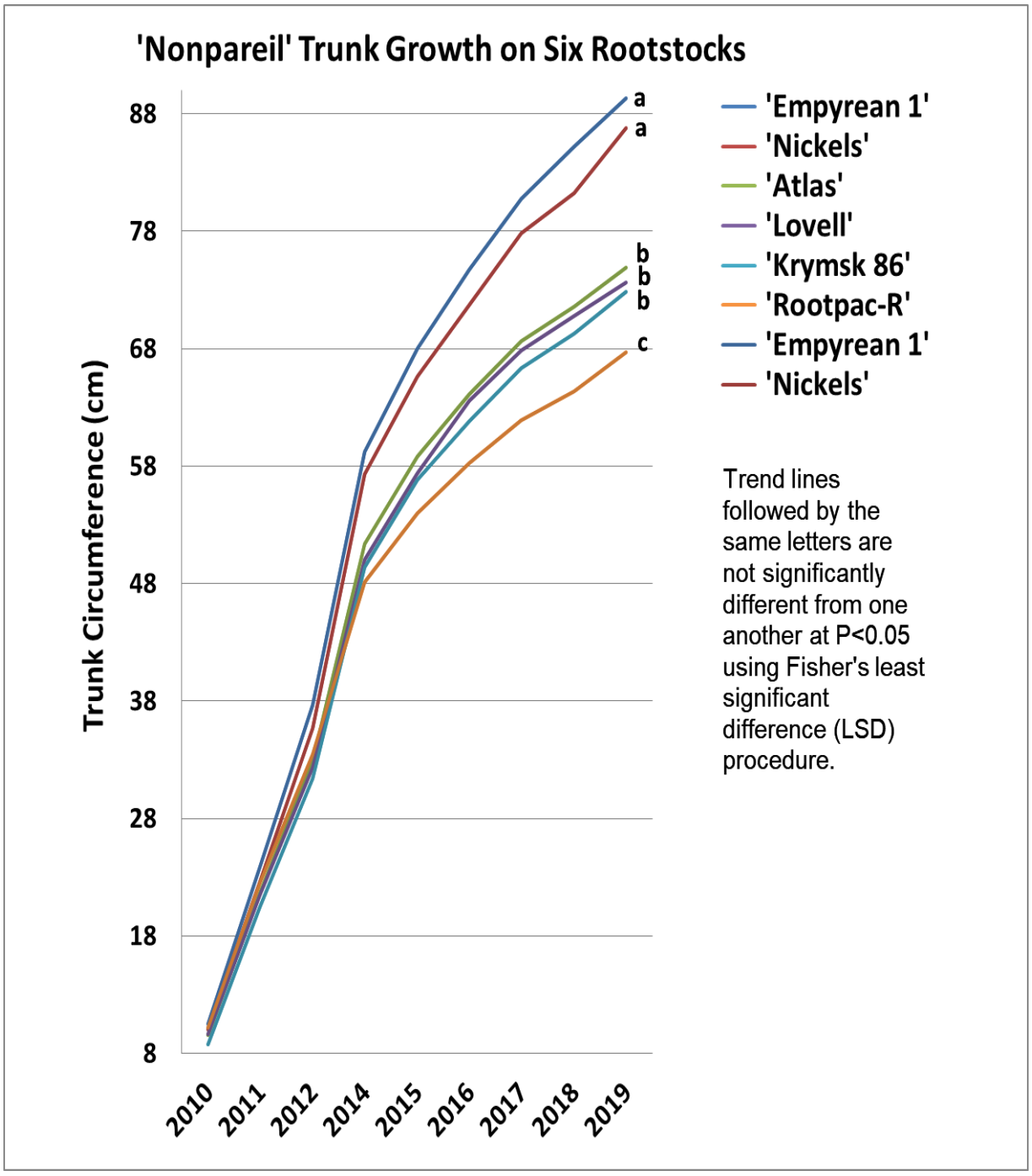
Overall production. Accumulated yield through the tenth leaf is shown in Table 5. The largest trees have the greatest accumulated yield after eight harvests. Trees on 'Atlas' have a greater accumulated yield than its size would suggest as do trees on 'Krymsk 86' compared to 'Lovell'. Trees on 'Rootpac-R' are the least vigorous and have the lowest accumulated yield.

Table 5. Accumulated 'Nonpareil' yield, kernel pounds/acre at 113 trees/acre.

Rootstock	3rd Leaf	4th Leaf	5th Leaf	6th Leaf	7th Leaf	8th Leaf	9th Leaf	10th Leaf	Accumulated Total Yield
'Lovell'	74	1,042	1,426	2,208	1,978	3,211	3,572	2,083	15,595
'Krymsk 86'	105	1,018	1,524	2,435	2,923	3,279	3,786	2,459	17,529
'Atlas'	113	1,190	2,060	2,826	3,252	4,111	4,486	2,722	20,759
'Empyrean 1'	69	1,321	2,183	3,378	3,289	4,231	4,425	3,758	22,654
'Nickels'	96	1,162	2,157	3,332	3,642	4,019	4,602	3,645	22,655
'Rootpac-R'	90	1,025	1,553	1,714	1,526	2,434	2,818	1,381	12,541

Tree size. After ten growing seasons, trees on the 'Empyrean 1' peach hybrid rootstock are largest in circumference followed by trees on the 'Nickels' peach/almond hybrid. Trees growing on 'Atlas', an interspecific hybrid of peach, almond, apricot, and plum), 'Lovell' peach, and the peach/plum hybrid, 'Krymsk 86' are similar in trunk circumference. Trees on 'Rootpac-R', a plum/almond hybrid, are the smallest in circumference and are the weakest growing trees in the trial (Figure 1).

Figure 1. ‘Nonpareil’ trunk circumference on six rootstocks after ten growing seasons.



Nut size and yield. ‘Nonpareil’ kernels from trees on ‘Rootpac-R’ rootstock were significantly smaller in two of the last four years than kernels from trees on all other rootstocks (Table 6). Kernels from trees on ‘Krymsk 86’ and ‘Lovell’ were often of similar size while trees on ‘Empyrean1’, ‘Nickels’, and ‘Atlas’ mostly produced kernels significantly larger than those produced on the other rootstocks. Thus, the

significantly lower yield noted on 'Rootpac-R' rooted trees (Table 7) is a function of both smaller trees and small kernels. The intermediate yield noted on 'Lovell' and on 'Krymsk 86' rooted trees appears to be related to tree size and nut set since both trees and kernels on these rootstocks are similar in size. Although similar in tree size to both 'Lovell' and 'Krymsk 86' rooted trees, trees on the 'Atlas' rootstock often had both larger nut size and a significantly greater yield (Fig.1 and Tables 6 & 7). 'Nonpareil' yield in the 10th leaf is heaviest on 'Nickels' and 'Empyrean 1' (Table 7).

Table 6. Rootstock effects on 'Nonpareil' kernel size – Durham, California.

	Weight in Grams/Kernel			
Rootstock	**2016**	**2017**	**2018**	**2019**
'Lovell'	1.22 bc	1.27 b	1.15 d	1.16 b
'Krymsk 86'	1.18 c	1.27 b	1.17 cd	1.24 a
'Atlas'	1.24 ab	1.32 a	1.19 bc	1.23 a
'Empyrean 1'	1.29 a	1.33 a	1.24 a	1.26 a
'Nickels'	1.25 ab	1.35 a	1.23 ab	1.27 a
'Rootpac-R'	1.07 d	1.22 c	1.14 d	1.16 b

Values followed by the same letters are not significantly different from one another at P< 0.05 using Fisher's least significant difference (LSD) procedure.

Table 7. Yield per tree of 'Nonpareil' almond on six rootstocks through the 10th leaf**.**

	Pounds of kernel per tree							
	2012	2013	2014	2015	2016	2017	2018	2019
Rootstock	3rd Leaf	4th Leaf	5th Leaf	6th Leaf	7th Leaf	8th Leaf	9th Leaf	10th Leaf
'Lovell'	0.65 cd	9.2 cd	12.6 b	19.5 c	17.5 c	28.4 b	31.6 b	18.4 c
'Krymsk 86'	0.93 ab	9.0 d	13.5 b	21.6 c	25.9 b	29.0 b	33.5 b	21.8 b
'Atlas'	1.00 a	10.5 ab	18.2 a	25.0 b	28.8 ab	36.4 a	39.7 a	24.1 b
'Empyrean 1'	0.61 d	11.7 a	19.3 a	29.9 a	29.1 ab	37.4 a	39.2 a	33.3 a
'Nickels'	0.85 abc	10.3 bc	19.1 a	29.5 a	32.2 a	35.6 a	40.7 a	32.3 a
'Rootpac-R'	0.79 bcd	9.1 d	13.7 b	15.2 d	13.5 d	21.5 c	24.9 c	12.2 d

Values followed by the same letters are not significantly different from one another at P< 0.05 using Fisher's least significant difference (LSD) procedure.

Nut quality in 2019. 100 'Nonpareil' nuts were cracked out from each replicate for all rootstocks. Quality attributes noted included good light-colored kernels, dark kernels, doubles, wrinkled kernels, shriveled kernels, pest damage (worms or ants), and gummy nuts.

Good nuts with light colored kernels and no blemishes constituted the majority of each sample ranging from 74 to 85 percent. 'Nickels' and 'Empyrean 1' were harvested early in 2019 with higher moisture in green nuts that created more sticktights. As a result, nuts from trees on these rootstocks had significantly fewer good nuts, 74% and 80% respectively, with most of the remainder being darker kernels with spots of suspected mold, data not shown.

There were no significant or meaningful differences in nuts between rootstocks in the percent doubles, wrinkled kernels, pest damage, or gummy nuts. 'Nickels' had significantly more shriveled kernels at 1.6% while 'Empyrean' had no shriveled kernels. The other rootstocks produced kernels that were intermediate in shrivels ranging from 0.2% to 1.4%.

Nematode analysis in 2020. Nematodes have not been a serious a problem in Butte County almond orchards in the past. With high rainfall and mostly loam and clay loam soils, nematodes had minimal impact when 'Lovell' peach rootstock was dominant. Now that 'Krymsk 86' rootstock predominates in new Butte County orchards the data in Table 1 suggests this situation may continue as long as root-knot nematode is not present. Trees on 'Krymsk 86' in other locations have been seriously stunted when root-knot nematode is present.

There were no significant differences in lesion and pin nematode populations found on the six rootstocks in this trial (Table 8). Root-knot nematodes (*Meloidogyne spp*.) were not detected in this orchard and lesion nematodes were found in one of 5 replicates only on the 'Lovell' peach rootstock. The 'Nickels' peach-almond hybrid rootstock had the lowest population of dagger nematodes while the 'Empyrean 1' peach hybrid rootstock had the highest dagger nematode population. The other rootstocks were intermediate in dagger nematode populations.

Table 8. Rootstock effects on Nematode susceptibility, Durham, CA

	Mean Nematode Population / 250cc sample		
	Lesion	Dagger	Pin
Rootstock	*Pratylenchus vulnus*	*Xiphinema americanum*	*Pratylenchus*
'Lovell'	10.4	24.4 abc	192.8
'Krymsk 86'	0	6.0 ab	220.0
'Atlas'	0	29.2 bc	609.2
'Empyrean 1'	0	38.4 c	627.6
'Nickels'	0	2.4 a	435.2
'Rootpac-R'	0 ns	8.4 ab	170.8 ns

Values followed by the same letters are not significantly different at P< 0.05 using Fisher's least significant difference (LSD) procedure; ns indicates there were no significant differences between rootstocks in nematode populations.

This completes my field work in the Durham, California rootstock trial. Although the data mentioned above and in previous annual reports is complete, if extreme environmental conditions result in tree loss in future years, impacts on tree mortality and anchorage related to rootstock will be noted.

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