Field Evaluation of Almond Rootstocks

Project No: HORT4

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A. Summary

This project is a compilation of long-term field assessments of over 25 rootstocks for the culture of almonds in California under various irrigation, weather, disease, chemical & physical soil conditions. This project encompasses trials conducted in five counties by UC Cooperative Extension Farm Advisors and a CSU Fresno faculty member.

Selecting the appropriate rootstock for specific soil conditions is critically important for the long-term success of an almond orchard. Rootstocks influence the vigor of a tree, anchorage, and date of crop maturity. More importantly, rootstocks can guard against soil-borne pathogens like nematodes, crown gall, Phytophthora, Verticillium wilt and oak root fungus. They can also affect above ground pathogen susceptibility in the case of hull rot or band canker. Rootstocks tolerant to chemical soil challenges such as high pH, sodium, chloride or boron enable growers to successfully farm almonds in marginal soils or where water is of lower quality.

Nemaguard and Lovell, long-time industry standard rootstocks, have some significant flaws. Both often perform poorly in heavy, alkaline soils and are susceptible to Phytophthora, oak root fungus, crown gall, and other diseases. Nemaguard is also susceptible to ring nematode and bacterial canker while Lovell is highly susceptible to rootknot nematode and crown gall. Oftentimes growers should consider alternative rootstocks for a more productive, longer lasting orchard. This project involves several separate field trials evaluating over 25 different rootstocks from various breeding programs around the globe.

Some of the highlights documented in these field trials include:

- High chloride tolerance of most peach x almond hybrids, Rootpac R and Viking.
- Rootstocks least tolerant to chloride include Lovell, Krymsk 86, and Nemaguard.
- Most peach x almond hybrids and Viking accumulate significantly less hull boron than other rootstocks. However, no tested rootstock appears to be highly tolerant of excessive boron.
- Lovell, Krymsk 86, Atlas, Cadaman, and HBOK 50 accumulate the most hull B.
- Krymsk 86, PAC9908-02, Hansen, and Viking have exhibited very good anchorage while Hansen x Monegro (HM2) has unacceptably poor anchorage. Empyrean 1 is dubious in windy areas.
- Atlas appears to be tolerant to Verticillium wilt disease while Lovell and Hansen appear highly susceptible.
- Hansen, Krymsk 86, Cornerstone, & Brights 5 can host high levels of ring nematodes while Krymsk 86 can also host substantial numbers of root knot and root lesion nematodes.

B. Objectives

1. Evaluate sixteen rootstocks irrigated with marginal quality irrigation water in alkaline, heavy soil (Roger Duncan, UCCE Stanislaus County).
2. Evaluate alternative rootstocks under high boron, West San Joaquin Valley conditions (Katherine Jarvis-Shean, UCCE Yolo County).
3. Continue evaluation of variety compatibility with rootstocks for almond, particularly compatibility with Nonpareil, under upper Sacramento Valley growing conditions (Joe Connell, UCCE Butte County Emeritus).
4. Evaluate conventional as well as growth controlling rootstocks for growth, yield, water use efficiency and photosynthetic parameters (Gurreet Brar, CSU Fresno.)
5. Evaluate eleven rootstocks under Kern County growing conditions, especially challenged with periodic high Santa Ana winds (Mohammad Yaghmour, Kern County).

In the past, researchers measured rootstock parameters most relevant to their trial location. In 2019, researchers attempted to measure several standardized parameters in each plot, along with evaluations relevant to each individual location. These included:

- Complete leaf analyses of non-fruiting spur leaves (July)
- Hull analysis for boron (at harvest)
- Soil analyses 0-18" & 18-36" deep
- Rootstock Effect on Hullsplit timing and duration
- Yield and quality assessment
- Trunk circumference
- Trunk angle (measure of anchorage)
- Photosynthetically Active Radiation (PAR)
- Pathogenic nematodes

A. Field Evaluation of Almond Rootstocks for the West Side of the North San Joaquin Valley.

Project leader: Roger Duncan, UCCE Advisor, Stanislaus County
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 sometimes high in chloride.

Interpretive Summary:

- The largest trees as measured by trunk circumference at the end of the 7th leaf were on FxA, PAC9908-02, Empyrean 1, BB 106 and HM2 (Table 4). Paramount (a.k.a. GF 677) and Brights 5 are significantly smaller than the other PxA hybrid rootstocks and are similar in size to trees on peach rootstocks in this trial.
- Hansen x Monegro (HM2) has unacceptably poor anchorage. HBOK 50 and Empyrean 1 have questionable anchorage and may have problems in windy areas.
- July leaf analyses have indicated that chloride levels are the highest in PAC9908-02,

Krymsk 86 and Lovell. Most peach x almond hybrid rootstocks and Rootpac R have significantly lower leaf chloride.

- Lovell, Atlas, Cadaman, and HBOK 50 had the highest hull boron while many rootstocks showed significantly lower hull boron
- The highest yielding rootstocks tend to be the most vigorous. Standard rootstocks Lovell, Nemaguard and Krymsk 86 have the lowest cumulative yields in this trial, producing about 2/3 the crop of the highest yielding rootstocks. Brights 5 appears to have significantly higher yield efficiency due to its high yield on a smaller tree.

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 soil is typically heavy with higher salt and boron levels and the pH is often 7.5 or higher. The irrigation water is typically high in bicarbonates, boron and chloride. Historically westside growers have planted on Lovell or Nemaguard due to lack of information or experience with alternative rootstocks. Partly because of poor rootstock choice, almond yields on the west side are generally lower than the east side of the North San Joaquin Valley.

Materials and Methods:
In this trial, the performance of sixteen rootstocks is being tested under "typical" west side conditions. On December 21, 2011, the 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. The list of rootstocks and their genetic background is shown below (Table 1).

The 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.). After the drought, the orchard has been irrigated with district water which is of much better quality (Table 2). Prior to planting the orchard, the field had a long history of melons, tomatoes and other row crops which has led to expression of Verticillium wilt disease in this trial. Preplant soil samples indicated no detectable rootknot or ring nematodes.

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

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 Water Analysis	1.86	9.40	8.80	8.9	2.50	0.84	7.1
2017 Water Analysis	0.96	4.13	3.07	3.64	2.16	0.31	7.9
Critical Levels	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 (%)
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
Critical level		1.50				5.0	0.5	5.0

Results & Discussion:

Tree Growth. The largest trees as measured by trunk circumference at the end of the 7th leaf were on FxA, PAC9908-02, Empyrean 1, BB 106 and HM2 (Table 4). Paramount (a.k.a. GF 677) and Brights 5 are significantly smaller than the other PxA hybrid rootstocks and are similar in size to trees on peach rootstocks in this trial.

Table 4. Rootstock Effect on Tree Size – December 2016-2019 (end of 4th thru 7th Leaf).				
	2015 Trunk Circumference 4th Leaf (cm)[1]	2016 Trunk Circumference 5th Leaf	2017 Trunk Circumference 6th Leaf	2019 Trunk Circumference 8th Leaf
PAC9908-02	50.8 a	55.4 a	60.3 ab	63.9 bc
Empyrean 1	50.0 ab	55.1 a	59.3 abc	65.9 ab
Flordaguard x Alnem	49.7 abc	55.5 a	60.9 a	67.6 a
Rootpac R	49.0 abc	53.3 ab	58.1 bc	62.2 c
Hansen x Monegro	48.4 bc	53.5 ab	58.4 abc	65.6 ab
BB 106	48.0 bc	53.0 ab	57.5 c	65.0 abc
Hansen	47.9 c	52.5 b	58.3 bc	65.7 ab
HBOK 50	45.6 d	50.0 c	54.4 d	58.5 d
Viking	44.2 de	47.9 cd	51.9 def	56.0 de
Nemaguard	44.6 de	47.7 d	52.7 def	56.3 de
Atlas	44.3 de	47.6 d	52.8 de	55.9 de
Brights 5	43.8 de	47.2 d	52.0 def	56.8 de
Paramount	43.3 ef	47.1 d	51.6 ef	58.1 d
Lovell	42.9 ef	46.2 d	50.2 fg	53.4 e
Cadaman	42.6 ef	47.5 d	--	--
Krymsk 86	41.7 f	45.4 d	48.6 g	55.8 de

Anchorage. Wind can be a problem on the west side of the North San Joaquin Valley, causing young trees to lean excessively. It is therefore important for almond rootstocks to have good anchorage. To quantify tree anchorage, a large protractor was used to measure trunk angles relative to the orchard floor. Trunk leaning of greater than about 15 degrees likely indicates an anchorage problem. Hansen x Monegro (HM2) has unacceptably poor anchorage, with an average trunk angle of 21 degrees in 2017. Two thirds of trees on this rootstock are leaning more than 15 degrees and several have had to be propped with boards or removed. HBOK 50, Empyrean 1 and Lovell may have questionable anchorage in windy areas. All had at least one third of the trees leaning more than 15 degrees.

Table 5. Rootstock Anchorage as Measured by Trunk Angle (degrees of lean)		
	2017	2019
Krymsk 86	5 a	9 a
PAC9908-02	5 a	9 a
Viking	6 a	10 a
Hansen	6 a	12 abc
Flordaguard x Alnem	8 ab	11 ab
Nemaguard	8 ab	12 abc
Rootpac R	9 abc	12 abc
Brights 5	9 abc	12 abc
Lovell	9 abc	13 abc
Atlas	10 bcd	13 abc
Paramount	11 bcd	12 abc
BB 106	14 bcd	12 abc
Empyrean 1	15 cde	16 cd
HBOK 50	16 cde	16 bcd
Cadaman	17 de	--
Hansen x Monegro	21 e	18* d

Table 6 Rootstock Effect on Leaf Nutrient Content. July 2019.								
	N (%)	K (%)	S (ppm)	B (ppm)	Ca (%)	Mg (%)	Mn (ppm)	Na (%)
Lovell	2.73 cde	2.20 cd	2733 b	37.7 e	2.98 g	1.31 cde	76.6 de	0.04 b
Nemaguard	2.81 abc	2.49 abc	2545 bcde	39.7 cde	3.22 f	1.27 efg	71.4 e	0.03 b
Empyrean 1	2.70 def	2.13 de	2560 bcd	42.0 bcd	3.70 cd	1.57 a	88.3 bc	0.04 b
Cadaman	2.84 ab	2.44 abc	2298 cdef	42.7 bc	3.68 cde	1.25 efg	85.3 cd	0.02 b
HBOK 50	2.69 def	2.40 bcd	2558 bcd	37.7 e	3.14 fg	1.33 cd	90.7 bc	0.02 b
Hansen	2.63 f	2.21 cd	2218 def	42.2 bcd	4.29 a	1.30 cdef	105.5 a	0.02 b
Brights 5	2.77 bcd	2.42 abc	2192 ef	39.4 cde	4.13 a	1.26 efg	87.4 bc	0.02 b
BB 106	2.77 bcd	2.60 ab	2298 cdef	46.8 a	3.91 b	1.25 fg	76.2 de	0.02 b
GF 677	2.68 ef	2.36 bcd	2142 f	38.8 de	4.26 a	1.13 h	101.5 a	0.02 b
F x A	2.73 cde	2.59 ab	2152 f	45.0 ab	3.87 bc	1.29 defg	105.6 a	0.03 b
PAC9908-02	2.65 ef	1.92 e	3307 a	38.7 de	3.51 de	1.41 b	95.3 abc	0.09 a
HM2	2.81 abc	2.49 abc	2408 bcdef	42.7 bc	3.56 de	1.36 bc	105.7 a	0.03 b
Viking	2.78 bcd	2.70 a	2515 bcde	36.4 e	3.52 de	1.10 h	86.2 cd	0.02 b
Atlas	2.85 ab	2.38 bcd	2617 bc	42.5 bc	3.46 e	1.24 g	97.8 ab	0.03 b
Krymsk 86	2.87 a	2.35 bcd	2672 b	37.5 e	3.54 de	1.13 h	95.1 abc	0.04 b
Rootpac R	2.77 bcd	2.52 ab	2488 bcdef	37.7 e	3.46 e	1.12 h	104.5 a	0.04 b

[1]Measurements followed by the same letters are not significantly different ($P \leq 0.05$).

Rootstock Effect on Leaf Nutrients and Salt and Boron Tolerance. Rootstocks had statistically different levels of all measured leaf nutrients, ($P< 0.05$), but most were likely not agronomically important and all were above sufficiency in this trial (Table 6). It is difficult to discern leaf nutrient patterns as influenced by genetic backgrounds. In general, peach x almond hybrid rootstocks tended to be higher in calcium. Roots that include plum genetics tended to have lower calcium and magnesium.

Although no obvious signs of ion toxicity are apparent in the trial yet, leaf analyses show that chloride levels are above the published critical level for several of the rootstocks. July leaf analyses have indicated that chloride levels are the highest in PAC9908-02, Krymsk 86 and Lovell (Table 7). Nemaguard also has potentially toxic leaf chloride levels. 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 8). 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.

Table 7. July-Sampled Leaf Chloride Levels of Fourth-Leaf thru Sixth-Leaf Nonpareil Almond Trees Grown on Sixteen Rootstocks. 2015 - 2019				
	% Chloride 2015	% Chloride 2016	% Chloride 2017	% Chloride 2019
Lovell	0.73 a	0.72 a	0.72 b	0.57 ab
Krymsk 86	0.65 b	0.77 a	0.89 a	0.57 ab
Nemaguard	0.43 c	0.57 b	0.57 c	0.54 b
Atlas	0.37 cd	0.42 c	0.42 de	0.34 c
Empyrean 1	0.32 de	0.33 cd	0.33 ef	0.22 def
Cadaman	0.32 de	0.38 c	0.38 def	0.27 cd
HBOK 50	0.30 def	0.31 cde	0.31 ef	0.34 c
PAC9908-02	0.28 defg	0.45 bc	0.45 d	0.63 a
Viking	0.25 efgh	0.30 cde	0.30 f	0.26 de
Rootpac R	0.25 efgh	0.17 de	0.17 g	0.13 gh
Hansen	0.23 efgh	0.15 e	0.15 g	0.16 fgh
Brights 5	0.22 fgh	0.18 de	0.18 g	0.11 h
BB 106	0.20 gh	0.19 de	0.19 g	0.13 gh
Paramount	0.20 gh	0.18 de	0.19 g	0.11 h
F x A	0.20 gh	0.29 cde	0.19 g	0.20 defg
HM2	0.18 h	0.16 e	0.16 g	0.18 efgh
Critical Level	**0.30%**			

Table 8. 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. Due to a malfunction of the weigh cart, we were not able to record yield accurately in 2019. Rootstock has substantially affected past yields in this trial (Table 9). The highest yielding rootstocks have accumulated over 4200 pounds per acre (about 50%) more than the lowest yielding rootstocks through the 7th leaf. The highest yielding rootstocks tend to be the most vigorous trees (peach x almond hybrids and Empyrean 1). Industry standards Lovell, Nemaguard and Krymsk 86 are the lowest yielding rootstocks in the trial. Brights 5 has the highest yield efficiency as measured by dividing cumulative yield by tree size (trunk circumference). Although Rootpac R has not performed well in most other UC trials, it looks pretty good here. Perhaps the combination of tolerance to salt and heavy soil make it an appropriate choice for heavy, alkaline soil.

Table 9. Yield for 4th Thru 7th Leaf Nonpareil Almond Trees on Fifteen Rootstocks. 2015 - 2018.

	2018 Yield (7th Leaf)	Cumulative Yield (4th thru 7th Leaf)	Yield Efficiency*
F x A	3965 a	12,276	35.5
BB 106	3876 ab	12,203	39.9
Brights 5	3701 abc	11,564	48.8
Empyrean 1	3487 abcd	11,461	36.2
HM2	3572 abc	11,361	35.6
Hansen	3665 abc	11,355	36.3
PAC9908-02	3362 bcd	10,916	34.3
Rootpac R	3476 abcd	10,587	34.7
Atlas	3457 abcd	10,506	44.5
Viking	3085 cd	9,704	41.5
Paramount	3194 cde	9,579	39.3
HBOK 50	3060 de	9,201	35.1
Krymsk 86	3004 de	8,866	42.2
Nemaguard	2802 e	8,833	36.3
Lovell	2752 e	8,040	36.5

*Yield efficiency is estimated by dividing yield by trunk circumference

Nematodes. Nematode populations were analyzed for the 9th leaf rootstock trial in clay loam soil and a 17th-leaf rootstock trial in an unfumigated sandy loam (see previous rootstock reports, Gemperle Trial). Soil cores were sampled with an Oakfield Sampler down to a 15 inch depth within the rootstozones of the trees in March, 2019. Soil samples were analyzed for pathogenic nematode numbers by Nematodes Inc (Selma, CA) using sieve and centrifugal flotation extraction. No serious pathogenic nematode species were detected in the Westside clay loam soil (Table 10). Ring and Root Lesion nematodes were present in the sandy loam Gemperle trial (Table 11). Viking, Guardian, Empyrean 1 had very low populations of ring nematodes in this trial.

Table 10. Pin Nematodes per 250 cc of Soil. Del Don Rootstock Trial. Clay Loam soil.	
FxA	1282 a
Nemaguard	1179 a
Viking	1016 ab
Brights 5	749 ab
HM2	691 ab
Empyrean 1	607 ab
Lovell	509 ab
Atlas	397 ab
PAC9908-02	336 ab
K86	301 ab
Rootpac R	299 ab
GF 677	159 b
BB 106	126 b
HBOK 50	98 b
Hansen	48 b

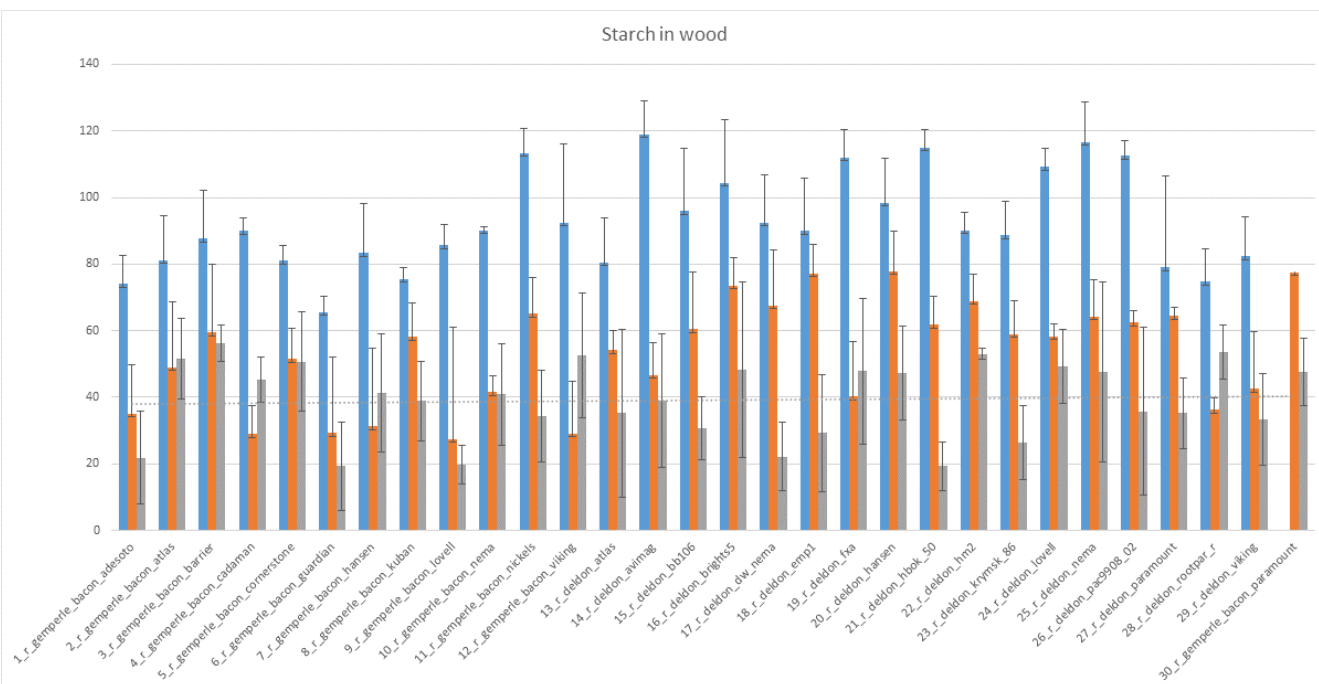
Table 11. Pathogenic Nematodes in 17th-leaf, Unfumigated, Sandy Loam Soil. Gemperle Rootstock Trial, Keyes, CA. March 2019. Nematodes per 250 cc soil.		
	Ring (*Mesocriconema xenoplax)*	Root Lesion (*Pratylenchus vulnus*)
Nickels	1438 a	34 a
Cornerstone	1176 a	2 a
Hansen	396 b	37 a
Adesoto	257 b	112 a
Cadaman	156 b	22 a
Nemaguard	137 b	69 a
GF 677	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

Water stress susceptibility. Midday stem water potential (SWP) was determined for eight of the 16 rootstocks using a pressure chamber (Soil Moisture Equipment Manufacturing, Inc.) on July 9, 2019 (Table 12). This was just prior to an irrigation and all rootstocks showed excessive water stress. Viking and Rootpac R were significantly more water stressed than the other monitored rootstocks (P<0.05).

Table 12. Midday Stem Water Potential (SWP) for Eight Rootstocks Prior to Irrigation. July 9, 2019. Estimated baseline -6.8 bars (80^0 F, 36% RH)	
Viking	-21.9 a
Rootpac R	-21.0 a
Nemaguard	-18.3 b
Atlas	-17.7 b
Brights 5	-17.3 b
Krymsk 86	-16.8 b
Hansen	-16.5 b
Empyrean 1	-16.5 b

Rootstock effect on carbohydrates. One-year-old shoots were sampled from trees on each rootstock and delivered to Dr. Zwieniecki's laboratory at UC Davis for carbohydrate analyses. In general, the peach rootstocks (Guardian, Lovell, Nemaguard, HBOK 50) and plum / plum cross rootstocks (Adesoto, Krymsk 86) had the lowest pre-bloom wood starch levels (Fig. 1). Peach x almond hybrids and Empyrean 1 had the highest level of starch. Higher carbohydrates may be related to higher vigor and yield.

Figure 1. Starch Storage Levels in One-Year-Old Wood in December 2018 (Blue), January 2019 (Red) and Pre-bloom 2019 (Green). Del Don and Gemperle Rootstock Trials, Stanislaus County.



Evaluation of Alternative Rootstocks for Butte County

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Project Cooperators: Luke Milliron, Butte-Glenn-Tehama Farm Advisor, Luis Hernandez and Herman 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 continues. 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 compares 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 is documented with trunk circumference measurements. Nut size and yield data were collected annually. Mortality and anchorage will be noted as opportunities arise. Data is 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 2018 and subsequently with leaf analysis in 2019. Samples were analyzed for mineral nutrient content at the 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’ rooted trees are highest in calcium and among the lowest in leaf 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, 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 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.

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).

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

Rootstock	2018[b] 1% Split[a]	2018[b] 100% Split	2018[b] # Days for Hullsplit	2019[c] 1% Split*	2019[c] 100% Split	2019[c] # 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.

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 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 Nonpareil 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.

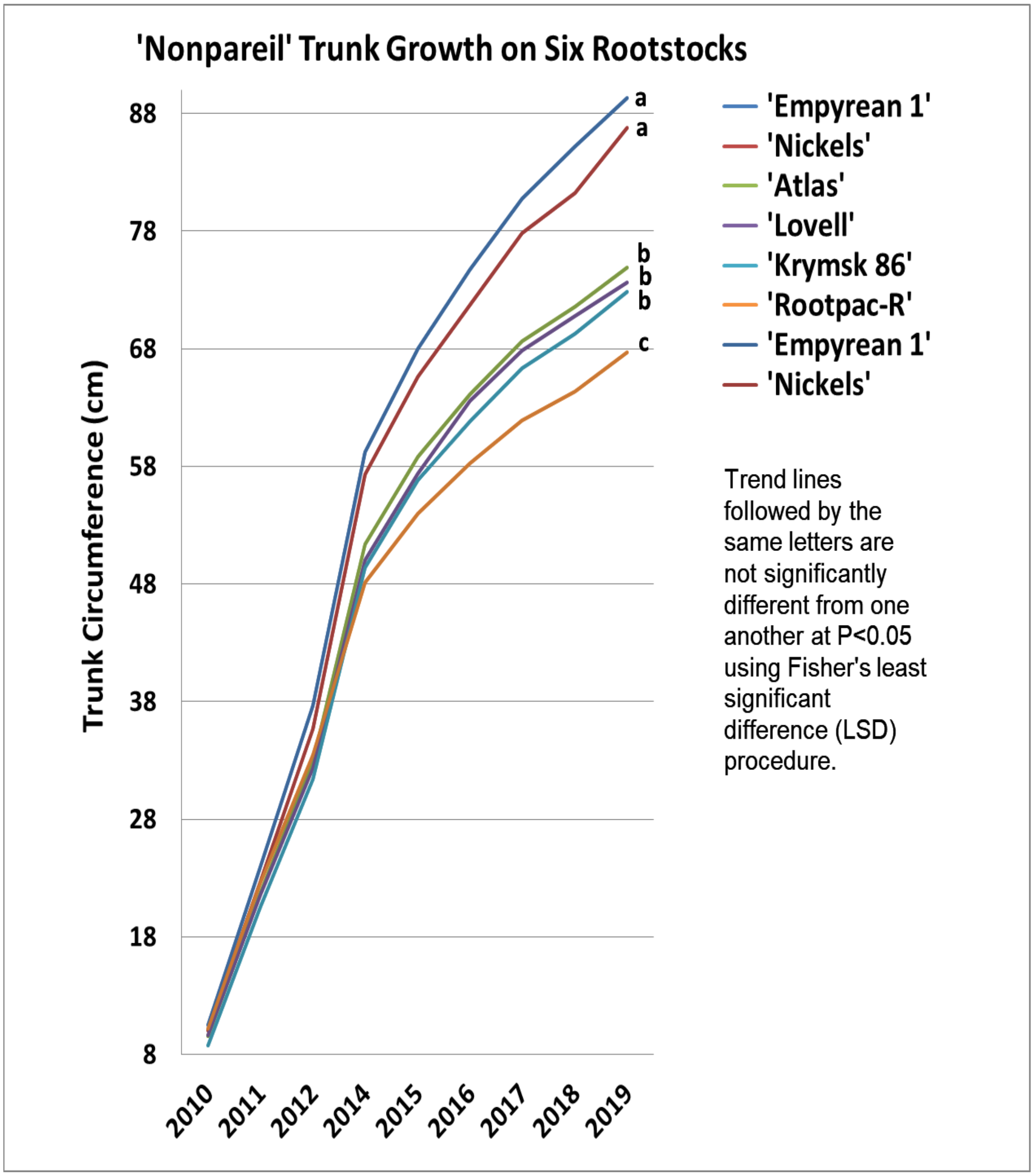
Overall production. Accumulated yield through the tenth leaf is shown in Table 5. The largest trees have the greatest accumulated yield after eight harvests. Trees on 'Atlas' have a greater accumulated yield than its size would suggest as do trees on 'Krymsk 86' compared to 'Lovell'. Trees on 'Rootpac-R' 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 'Empyrean 1' are largest in circumference followed by trees on the 'Nickels' peach/almond hybrid. Trees growing on 'Atlas', an interspecific hybrid (peach/almond x apricot/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%.

Research Publications:

Connell, J.H., R. Buchner, J. Edstrom M. Viveros, R. Duncan, P. Verdegaal, B. Lampinen, W.C. Micke and J. Yeager. 2004. Field evaluation of almond rootstocks. p. 38-50. In: 32nd Annual Almond Industry Conference Proceedings, December 1-2, 2004, Modesto, CA.

Field Evaluation of Almond Rootstocks in the Southern San Joaquin Valley
Sub-project Leader: Mohammad Yaghmour, UCCE Kern County. mayaghmour@ucanr.edu

A. Summary

This new field evaluation site is a replanted orchard grown in a sandy loam soil located at Tejon Ranch in Kern County. This area is prone to strong Santa Ana winds and tree anchorage is a significant problem. Some growers in that part of the county use Krymsk 86 as a rootstock based on previous UC rootstock trials that showed this rootstock to have good anchorage characteristics. However, Krymsk 86 has significant soil chemistry and nematode limitations and alternative rootstocks may perform better.

Trees from the previous orchard were removed in 2018, ground up and reincorporated into the soil. The soil was fumigated with Telone II and potted trees were planted on October 22, 2019. The experimental design is a Randomized Complete Block with 6 blocks and 7 trees per block. In this trial, only the variety Nonpareil was grafted on the test rootstocks and the orchard is planted at 22' x 16' spacing. Initial stem diameter measurements are in progress. Last year and this year, we had many reports of Phytophtora root and crown rot in Kern County. All tree losses will be evaluated for disease development. Also, any nutritional observations due to orchard recycling will be recorded.

B. Objectives

The objective of this trial is to compare eleven rootstocks grown under commercial almond orchard conditions and evaluate rootstock effect 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* is established. This rootknot nematode was recently detected in Kern County. This experiment is also evaluating other rootstocks that were not evaluated under Kern County conditions.

Table 1. Rootstocks planted at the trial in Kern County

1	Hansen 536	*P. 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	
11	Flordaguard X Alnem	

Almond Rootstock Trial at CSU Fresno
Project Leader: Gurreet Brar,

Project Cooperators and Personnel:
Madison Hedge, Research Assistant
Daniel Syverson, Graduate Research Assistant
Hardeep Singh, Graduate Research Assistant
Faranak Hadavi, Research Scientist
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A. Summary

Rootstock selection is always a site-specific consideration. The almond rootstock trial at Fresno State is part of a larger effort to evaluate rootstock performance in a variety of conditions. The main challenge at the Fresno State site is a range of soil EC. Rootstock performance was mediated by leaf nutrition. Divalent cation uptake was likely the main stressor in this field. High leaf Mg levels (0.6-0.8%) were the strongest and most consistent predictor of growth and yield this year.

B. Objectives *(300 words max.)*

1. Compare performance of conventional peach rootstocks 'Guardian' and 'Lovell' with peach almond hybrid rootstocks 'Cornerstone' and 'Empyrean I' and dwarfing rootstocks 'Rootpac-20', 'Rootpac-R'.
2. Evaluate growth, yield, water use efficiency and photosynthetic parameters for each rootstock.

C. Results *(This is the core function of this report)*

1. Canopy volume and yield were each strongly and robustly correlated with leaf Mg levels. This result is surprising because leaf Mg levels were not identified as deficient by the testing lab.
   i. Industry standard 'Nemaguard' takes up divalent cations like the peach rootstocks 'Guardian' and 'Lovell'.
   ii. The hybrid rootstocks 'Cornerstone' and 'Empyrean I' acquired the most divalent cations, including Mg, but the difference did not translate to yield in this year's data.
   iii. 'Rootpac-R' and 'Rootpac-20' acquired less Mg and more of the other divalent cations.
2. 'Nonpareil' grows taller, but not broader than 'Monterey'. This difference between 'Nonpareil' and 'Monterey' is stronger on hybrid rootstocks than on peach rootstocks.
3. 'Empyrean I' and 'Guardian' have slightly higher kernel-to-hull ratio.
4. 'Rootpac-R' may yield smaller nuts.

D. Discussion and Conclusions *(This is the core function of this report)*

1. Significant differences among rootstock were found in terms of canopy growth, height, and trunk girth.
2. Rootstock also influenced the hull split timing in almonds.

3. Rootstock effect on micronutrient ion uptake was found to be significant.
4. Leaf photosynthetic parameters were measured but the data could not be retrieved and analyzed.

E. Materials and Methods *(500 word max.)*

1. LI-6800 was used to measure photosynthetic parameters, including assimilation (A) and stomatal conductance (g_{SW}). Unfortunately, many photosynthesis measurements from this year have been lost to data corruption on the LI-6800 device.
2. Determination of chlorophylls *a*, *b* and total chlorophyll content: In past years, dimethylformamide (DMF) was used as the extraction solvent, but DMF is incompatible with some of our plastic hardware. Additionally, the blanking procedure was inconsistent with the systems of simultaneous equations used to calculate contents. A revised standard protocol based on a methanol extraction was developed, and the spectrophotometric readings can now be taken in 96-well plate format. Re-training of personnel and improved process control will improve future data reliability.
3. Trunk diameter was obtained with calipers in 2018, but in 2019 circumference was obtained using a tailor's tape. Inconsistencies were found with two inches above the graft union so measurements were obtained when the trunk became uniform.
4. Canopy volume was obtained using marked PVC pipe: canopy extent was measured in 3 directions, two horizontals and one vertical
5. Hull split analysis was done by sight.
6. When the irrigation lines were moved out to follow the drip line of the large trees, the trees on the dwarf rootstocks wilted, resulting in reduced growth and yield. These dwarves, specifically Rootstock-20 had no nut yield. Irrigation supporting R-20 rootstocks should be considered.
7. Pesticides were applied by Air-O-Fan and an automated eye which was raised too high to see the trees. To fix this the field manager made special passes with the eye lowered to ensure an even application. The few extra weeks infested with thrips might have also lowered production and yield.
8. Severe shotgun damage was the result of oil application on a sunny morning. This affected the stomatal conductance results using the licor. In 2020, special care should be taken to avoid damage to leaves.
9. The nut samples were obtained by shaking and separating in the rows. Unfortunately, some mixing of treatments resulted. Sampling the trees before being shaken would produce a better representation for nut analyses and avoid the mixing
10. The buffers were also shaken into the samples which added error to our end samples. Reminding harvest crew that buffer trees do not need to be shaken would fix this in the future.

F. Publications that emerged from this work

1. None so far

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 and Nickels continue to produce higher yields in these high boron conditions than the trees on other rootstocks. 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 peach-almond hybrids. Trees on Rootpac-R, Krymsk 86 and Lovell produced the lowest yields, in keeping with their smaller tree size. These results are consistent with previous yields – P-A hybrids except Hansen 536 yielding highest; Krymsk 86 and Lovell yielding lowest. However, this is the first year that Rootpac-R yields have grouped with Krymsk-86 and Lovell. Viking has consistently been in the middle of the pack, yield-wise.

Certainly the larger size of the P-A hybrids plays a role in their higher yields, but the yield-size efficiency numbers in Table 1 also show that even if planted more closely, trees on non-P-A rootstocks would not catch up to P-A yields on a per-acre basis.

Materials and Methods:
Rootstocks with potential high boron tolerance relative to the commonly planted Lovell peach were identified: Hansen 536, Nickels, FxA, Krymsk 86, Brights-5, Rootpac-R, and Viking. This study assesses potential differences in boron tolerance between these rootstocks. Titan SG1 was added after the initial planting. Data collected from this rootstock is reported but considered observational because it is not replicated.

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 6 replicates of each rootstock, 5 trees per replicate.

In 2019, the orchard was in its 9th 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 2019, the seventh harvested crop (Table 1). Trees on peach - almond (P-A) hybrids Titan SG1 and Nickels 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. These results are consistent with previous yields – P-A hybrids except Hansen 536 yielding highest; Krymsk 86 and Lovell yielding lowest. However, this is the first year that Rootpac-R yields have grouped with Krymsk-86 and Lovell. Viking has consistently been in the middle of the pack, yield-wise. P-A hybrid yields in 2019 were unusually high for Yolo County, but the scale, data sheets and calculations were repeatedly checked for errors and none were found. Growers should not expect to consistently achieve these yields under high boron conditions. More than absolute yields, the important take-away from this year is that rootstock ranking by yield is consistent with previous years.

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 2019, hull B was below this toxic threshold in all cases, with rootstock means ranging from 209 ppm to 256 ppm (Table 1). There were not significant differences in hull boron content by rootstock. This is surprising given the yield differences by rootstock, and difference in hull content found in the past. It may be that low yields this year in some rootstock are a result of damage by boron to tree structure in previous years, reducing flowers per unit canopy.

Canopy light interception (PAR%) measurements (Table 1) can help decipher whether trees were low yielding because of smaller canopies or other issues, especially when yield is divided by PAR. The 2019 data shows that not all large peach-almond hybrids produced comparable yields, and that not all small trees that weren't on peach-almond hybrids yielded poorly. Canopy light interception (PAR%) measurements show the rootstocks can be roughly grouped by size into peach-almond hybrids and everything else. Given their comparable size, it is somewhat surprising that trees on Hansen 536 yielded lower than those on Titan and Nickels. It seems from the data so far that not all peach-almond hybrids are equally suitable for high boron conditions. Similarly, though trees on Rootpac-R, Viking, Krymsk 86 and Lovell were of comparable size, trees on Viking produced notably higher yields per unit PAR than the other small trees.

Cumulative yield for the life of the trial, leaf nutrient analysis, stem water potential measurements and hullsplit timing are also presented below.

Table 1. Almond boron rootstock trial results, 2019. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05)

Rootstock	Origin	Avg Yield (kernel lbs/acre)*	Hull B † (ppm)	Light Intercep't (% PAR)	Size Efficiency (Lbs/PAR)	Trunk Circum (inches 18" above soil)
Titan SG1	Peach-Alm	4,354	256	81	53.7	29.4
Nickels	Peach-Alm	4,297 a	235 ns	84 a	51.1	30.5 ab
Brights 5	Peach-Alm	3,625 b	209 ns	77 b	46.8	26.9 abc
FxA	Peach-Bitter Alm	3,624 b	226 ns	85 a	42.4	31.4 a
Hansen 536	Peach-Alm	3,373 bc	222 ns	79 ab	42.7	29.1 abc
Viking	Pch-Al-Myro-Apr	2,875 cd	242 ns	65 c	44.5	26.6 bc
Krymsk 86	Myro Plum-Peach	2,554 de	223 ns	63 c	40.5	25.3 c
Rootpac-R	Myro Plum-Alm	2,532 de	223 ns	64 c	39.5	27.3 abc
Lovell	Peach	2,226 e	210 ns	55 d	40.8	24.7 bc

*Per-acre yield based on average of 5 trees over 6 replications, scaled for the 110 trees per acre spacing. Titan SG1 Not replicated so no statistical comparison made.
† > 300 ppm = "toxicity"

Figure 1. Boron rootstock trial cumulative yield for 3rd through 9th leaf (2013-2019). Scaled from the 5 tree sample average to per acre yields based on the 110 trees per acre spacing.

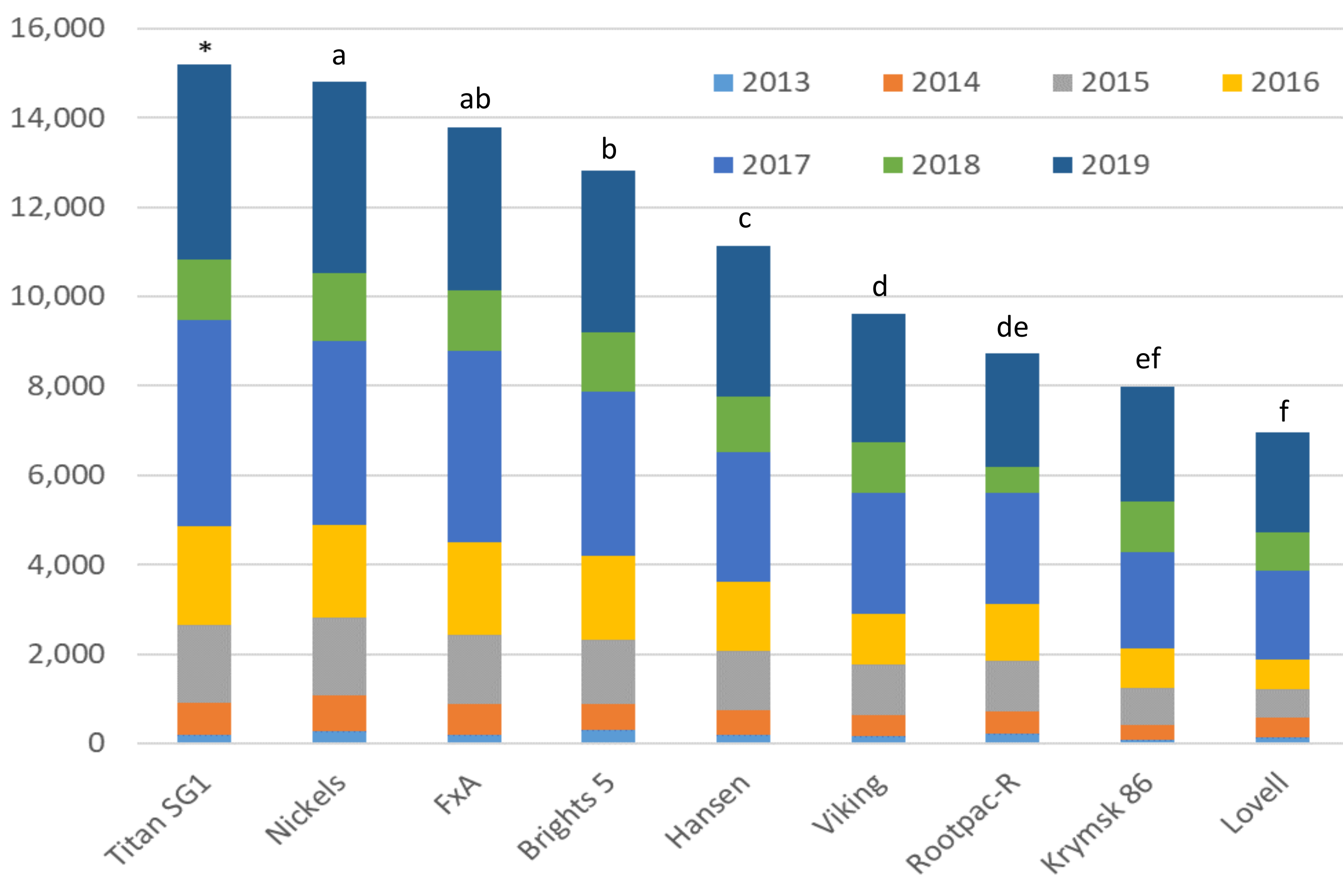

Table 2. Macronutrient Leaf analysis, 2019 (ordered by 2019 yields)

	N (%)		P (%)		K (%)		S (ppm)		Ca (%)		Mg (%)	
Titan SG1	2.1		0.12		0.9		1490		3.8		1.7	
Nickels	2.1	ab	0.10	bc	1.1	ab	1598	bc	4.1	ab	1.7	ab
Brights5	2.1	ab	0.11	bc	0.8	bcd	1605	bc	4.2	a	1.9	a
FxA	2.1	ab	0.11	bc	1.1	a	1527	bc	3.8	bc	1.7	b
Hansen536	1.9	c	0.10	bc	0.9	abcd	1488	c	4.4	a	1.8	ab
Viking	2.2	a	0.12	a	1.0	abc	1517	bc	3.5	cde	1.5	cd
Krymsk86	2.1	ab	0.11	bc	1.1	abc	1733	a	3.4	de	1.4	d
RootpacR	1.9	c	0.10	c	0.8	cd	1622	ab	3.7	cd	1.6	bc
Lovell	2.1	b	0.11	ab	0.7	d	1633	ab	3.2	e	1.7	b

Table 3. Micronutrient Leaf Analysis, 2019 (ordered by 2019 yields)

	B (ppm)		Zn (ppm)		Mn (ppm)		Fe (ppm)		Cu (ppm)	
Titan SG1	44.1		41.0		39.8		160		4.0	
Nickels	43.5	abc	45.5	ab	37.4	bcd	149	ns	4.1	ab
Brights5	46.0	a	47.0	ab	48.5	a	149	ns	4.1	a
FxA	44.4	ab	51.9	a	51.8	a	160	ns	4.3	a
Hansen536	40.7	bc	45.7	ab	47.5	ab	162	ns	3.5	cd
Viking	46.9	a	42.0	ab	34.1	cd	147	ns	3.7	bc
Krymsk86	38.7	cd	47.8	ab	45.6	ab	168	ns	3.2	de
RootpacR	35.1	d	41.3	ab	44.3	abc	160	ns	2.9	e
Lovell	42.4	abc	38.5	b	29.9	d	146	ns	3.0	e

Table 1. Mean hull split levels by rootstock variety, in three sampling dates. (% at 2C or further progressed)

	07/11/2019	07/17/2019	07/26/2019
Brights	0	1	63
FxA	0	10	65
Hansen	0	2	70
Krymsk	0	16	93
Lovell	1	73	100
Nickels	0	3	53
Rootpack	0	5	80
Titan	0	5	65
Viking	0	33	95
Average	0	17	77

Table 5. Stem Water Potential measurements in 2019

Date	**06/25/2019**	**07/08/2019**	**07/29/2019**
Baseline	**-9.2**	**-8.8**	**-8.2**
Lovell	-11.3	-11.0	-11.3
Hansen	-13.8	-15.5	-17.1
Nickles	-4.8	-7.2	-11.1
Brights-5	-5.6	-6.0	-9.8
Viking	-13.1	-14.9	-16.8
Krimsk86	-6.8	-7.0	-9.3
Rootpack-R	-12.8	-15.8	-22.6
FxA	-4.3	-6.5	-11.3
Titan SG	-8.0	-9.7	-10.8