Field Evaluation of Almond Rootstocks

Project No.: **17-HORT4-Duncan**

Project Leader: Roger Duncan
UC Cooperative Extension, Stanislaus County
3800 Cornucopia Way
Modesto, CA 95358
(209) 525-6800
raduncan@ucdavis.edu

Project Cooperators and Personnel:
Joe Connell, UCCE Butte County emeritus
David Doll, UCCE Merced County
Katherine Pope, UCCE Yolo & Solano Counties
Gureet Brar, CSU Fresno
Lee Del Don

Objectives:

1. Evaluate alternative rootstocks irrigated with low quality (saline) irrigation water in alkaline, heavy soil (Stanislaus County).
2. Determine the susceptibility of thirteen almond rootstocks to plant parasitic nematodes (Merced County).
3. Evaluate alternative rootstocks under high boron conditions (Yolo County).
4. Continue evaluation of variety compatibility with rootstocks for almond, particularly compatibility with Nonpareil (Butte County).
5. Evaluate conventional as well as growth controlling rootstocks at CSU Fresno.
6. Evaluate 16 almond rootstocks for their performance in an alkaline clay loam soil moderately high in boron and often irrigated with water high in sodium and chloride.

Interpretive Summary:

- All peach x almond hybrid rootstocks and Rootpac R had significantly lower leaf chloride levels
- Viking and Empyrean 1 showed moderate chloride tolerance while Krymsk 86 and Lovell appear highly susceptible.
- Lovell, Atlas, Cadaman, and HBOK 50 had the highest hull boron while many rootstocks showed significantly lower hull boron
- Hansen x Monegro (HM2) has unacceptably poor anchorage
- The anchorage of several rootstocks including Cadaman, HBOK 50 and Empyrean 1 may by questionable in windy areas
- BB 106, F x A, Empyrean 1, Brights 5 and HM2 have the highest cumulative yields
- Brights 5 appears to have significantly higher yield efficiency
- Despite the heavy soil, most peach x almond hybrids are performing very well so far in this trial

- The past industry standard rootstock (Lovell) has performed poorly compared to alternative rootstocks in almost every parameter measured in this trial.

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 sodium. 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**).

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

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. This water is often high in salts, especially towards the end of the 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**). In 2017, the orchard was irrigated with district water which is of much better quality (**Table 2**). 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 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	3.6	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 6^{th} leaf was on FxA, PAC9908-02, Empyrean 1, and HM2 (**Table 4**). Paramount (a.k.a. GF 677) and Brights 5 are significantly smaller than the other PxA hybrids and are similar in size to trees on peach rootstocks in this trial.

Table 4. Rootstock Effect on Tree Size – End of 4th thru 6th Leaf.

	Trunk Circumference 4th Leaf (cm)	Trunk Circumference 5th Leaf	Trunk Circumference 6th Leaf
PAC9908-02	50.8 a	55.4 a	60.3 ab
Empyrean 1	50.0 ab	55.1 a	59.3 abc
Flordaguard x Alnem	49.7 abc	55.5 a	60.9 a
Rootpac R	49.0 abc	53.3 ab	58.1 bc
Hansen x Monegro	48.4 bc	53.5 ab	58.4 abc
BB 106	48.0 bc	53.0 ab	57.5 c
Hansen	47.9 c	52.5 b	58.3 bc
HBOK 50	45.6 d	50.0 c	54.4 d
Viking	44.2 de	47.9 cd	51.9 def
Nemaguard	44.6 de	47.7 d	52.7 def
Atlas	44.3 de	47.6 d	52.8 de
Brights 5	43.8 de	47.2 d	52.0 def
Paramount	43.3 ef	47.1 d	51.6 ef
Lovell	42.9 ef	46.2 d	50.2 fg
Cadaman	42.6 ef	47.5 d	nd
Krymsk 86	41.7 f	45.4 d	48.6 g

Table 5. Rootstock Anchorage as Measured by Trunk Angle

	Trunk Lean (degrees)	% trees > 15^0 Lean
Krymsk 86	5 a	0
PAC9908-02	5 a	6.7
Viking	6 a	6.7
Hansen	6 a	0
Flordaguard x Alnem	8 ab	6.7
Nemaguard	8 ab	16.7
Rootpac R	9 abc	20.0
Brights 5	9 abc	13.3
Lovell	9 abc	33.3
Atlas	10 bcd	20.0
Paramount	11 bcd	24.1
BB 106	14 bcd	20.0
Empyrean 1	15 cde	40.0
HBOK 50	16 cde	40.0
Cadaman	17 de	25.0
Hansen x Monegro	21 e	66.7

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 excessive leaning. Krymsk 86, PAC9908-02, Viking and Hansen are the straightest trees (**Table 5**). Hansen x Monegro (HM2) has unacceptably poor anchorage, with an average trunk lean of 21 degrees. Two thirds of trees on this rootstock are leaning more than 15 degrees and several have had to be propped with boards. 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.

<u>Salt and Boron Tolerance:</u> Although no obvious signs of ion toxicity are apparent in the trial yet, leaf analyses show that chloride levels are above the critical level for several of the rootstocks. July leaf analyses have indicated that chloride levels are the highest in Krymsk 86 and Lovell (**Table 6**). 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 7**). Boron levels were highest in Lovell, Cadaman, Atlas and HBOK 50 in 2017. Boron levels were lowest in the peach x almond hybrid rootstocks and Viking.

Table 6. July-Sampled Leaf Chloride Levels of Fourth Leaf thru Sixth-Leaf Nonpareil Almond Trees Grown on Sixteen Rootstocks. 2015 - 2017

	% Chloride 2015	% Chloride 2016	% Chloride 2017
Lovell	0.73 a	0.72 a	0.72 b
Krymsk 86	0.65 b	0.77 a	0.89 a
Nemaguard	0.43 c	0.57 b	0.57 c
Atlas	0.37 cd	0.42 c	0.42 de
Empyrean 1	0.32 de	0.33 cd	0.33 ef
Cadaman	0.32 de	0.38 c	0.38 def
HBOK 50	0.30 def	0.31 cde	0.31 ef
PAC9908-02	0.28 defg	0.45 bc	0.45 d
Viking	0.25 efgh	0.30 cde	0.30 f
Rootpac R	0.25 efgh	0.17 de	0.17 g
Hansen	0.23 efgh	0.15 e	0.15 g
Brights 5	0.22 fgh	0.18 de	0.18 g
BB 106	0.20 gh	0.19 de	0.19 g
Paramount	0.20 gh	0.18 de	0.19 g
F x A	0.20 gh	0.29 cde	0.19 g
HM2	0.18 h	0.16 e	0.16 g
Critical Level	**0.30%**		

<u>Yield:</u> The highest overall yielding rootstocks in 2017 (6^{th} leaf) were BB 106, FxA, Hansen and Empyrean 1 (**Table 8**). Lovell again had the lowest numerical yield in 2017 and has cumulated 3038 pounds per acre less than the highest yielding rootstock over the three-year history of this 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, perhaps the combination of salt tolerance and tolerance of heavy soil make it an appropriate choice for heavy, alkaline soil.

Table 7. Hull Boron Levels of Fourth Leaf Thru Sixth-Leaf Nonpareil Almond Trees Grown on Sixteen Rootstocks. September 2015 - 2017

	ppm Boron 2015	ppm Boron 2016	ppm Boron 2017
Lovell	180 a	125 a	180 a
Cadaman	170 ab	107 ab	170 ab
Atlas	158 ab	123 a	158 ab
HBOK 50	156 ab	108 ab	158 ab
Nemaguard	153 bc	114 ab	153 bc
Krymsk 86	152 bc	100 ab	152 bc
Empyrean 1	133 cd	89 bc	133 cd
Rootpac R	132 cd	93 b	132 cd
Hansen	126 de	86 bc	126 de
Paramount	120 de	78 bc	120 de
HM2	116 de	82 bc	116 de
Viking	109 e	74 c	109 e
PAC9908-02	108 e	75 c	108 e
Brights 5	106 e	76 c	106 e
F x A	104 e	80 bc	104 e
BB 106	102 e	76 c	102 e
Critical Level	**300 ppm**		

Table 8. Yield for 4th Thru 6th Leaf Nonpareil Almond Trees on Fifteen Rootstocks. 2015 - 2017

	2017 Yield (6th Leaf)	Cumulative Yield (4th thru 6th Leaf)	Yield Efficiency*
BB 106	4209 a	8327	0.50 bc
F x A	4112 ab	8311	0.45 cd
Hansen	3881 abc	7690	0.45 cd
Empyrean 1	3775 abc	7974	0.45 cd
HM2	3686 bcd	7789	0.45 cd
Brights 5	3604 bcde	7863	0.58 a
PAC9908-02	3537 cdef	7554	0.41 d
Paramount	3239 defg	6385	0.48 bcd
Rootpac R	3192 defgh	7111	0.42 cd
Atlas	3104 efgh	7049	0.50 bc
Viking	3085 efgh	6463	0.48 bcd
HBOK 50	3026 fgh	6141	0.41 d
Nemaguard	2965 gh	6031	0.43 cd
Krymsk 86	2846 gh	5862	0.49 bc
Lovell	2696 h	5289	0.42 cd

*Yield efficiency is estimated by dividing yield by trunk circumference

Project Title:	Performance of Thirteen Almond Rootstocks in a Sandy Location Irrigated with Well Water.
Project Leader:	David Doll Farm Advisor University of California Cooperative Extension, Merced County
Cooperating personnel:	Glen Arnold, Arnold Farms Craig Arnold, Arnold Farms Cameron Zuber, UC Cooperative Extension, Merced County Allen Vizcarra, UC Cooperative Extension, Merced County

Objective:

To determine susceptibility of 13 almond rootstocks to plant parasitic nematodes.

Background: This replicated trial was established in January 2011 on a site with Atwater Sand in Winton, CA. The trial compares the performance of 'Nonpareil' on 13 rootstocks, and the performance of 'Fritz' and 'Monterey' on six rootstocks (**Table 1**). Each of six replicate blocks is comprised of six trees of each rootstock and variety combination. Many of the rootstocks selected for the trial are peach-almond hybrids, as the grower developed an interest in peach-almond hybrids after participating in a previous University of California rootstock trial. Prior to planting, the location was cover cropped with Merced Rye, tree sites were excavated, and the row-strips were fumigated with 1,3-dichloropropene (Telone-II) at 33 gallons per acre. Trees were planted in January 2011 with the exception of the trees grafted to Cadaman and Cornerstone, which were planted in April 2011. Trees are spaced at 22'x18' and irrigated using double line drip.

Materials and Methods:

Soil mapping was done using Veris Electrical Conductivity Mapping (Strategic Farming). Differences in soil zones were identified (**Figure 1**), analyzed (see previous reports), and used to design experimental blocks. Trunks were measured shortly after planting and subsequently after the end of each growing season through 2013. Yields (kernel pounds per acre) were determined for all rootstock and scion combinations for the years 2013 through 2015. Due to tree loss and the large number of replants due to practices not related to rootstock performance, plot harvest was discontinued after 2015. Previous growth, tissue and yield data can be found in previous year reports.

Nematode samples were collected in October 2017. Ten soil cores sampled from the depth of 12-18 inches were pooled from each replicate located within sandy soils (n=5) and sent for analysis by Nematodes, Inc (Selma, CA). Nematodes were extracted with the sieving and centrifugal flotation extraction method using 500g of soil. This method often favors higher counts of Ring nematode (*Mesocriconema xenoplax*). Extraction counts for *Meloidogyne* spp. (Rootknot), Ring, *Pratylenchus vulnus* (Lesion), *Paratylenchus* spp. (Pin), *Paratrichodorus* spp. (Stubby Root), and a free-living composite were reported.

Results and Discussion:

Nematode counts varied among rootstocks (**Table 2**). Differences in rootknot nematodes were detected amongst the rootstocks. Krymsk-86 had higher rootknot counts than all other rootstocks (312 nematodes/liter). With the exception of Floridaguard x Alnem (14 nematodes/liter), all other rootstocks did not have any rootknot nematodes detected. There were no differences among the rootstocks in counts of ring, root lesion, pin, stubby root or free-living nematodes.

Due to the variability of nematode counts, it may be better to evaluate rootstock susceptibility to nematode parasitism by evaluating nematode population changes over time. The presence of rootknot nematodes has only occurred within a single rootstock, Krymsk-86, in which populations were first detected in 2013 and have been found in subsequent years (**Table 3**). This suggests that this rootstock is not resistant to rootknot nematode which is present in many Central Valley soils. Root lesion nematode populations have been more varied, in which populations have not been detected in soils sampled from the rootzone of the rootstocks Cadaman, Floridaguard x Alnem and Nemaguard (**Table 4**). It is unknown if this is due to resistance, low population due to plot location, or random sampling error. Root lesion populations have been inconsistently found on the other rootstocks with Krymsk-86 having high populations detected in 2014 and 2015. In contrast to rootknot and root lesion nematodes, ring nematodes have been found more consistently across all the rootstocks (**Table 5**) which may be due to the type of nematode extraction performed. High populations of ring nematode have been found in several rootstocks for multiple years. Rootstocks with high populations of ring nematode generally include the peach-almond hybrids, but also includes Krymsk-86 and RootpacR. Interestingly, the peach-almond hybrid rootstocks BB#106 and TemproPac differ from the other peach-almond hybrids by having lower ring nematode populations. Viking, as indicated in previous trials, consistently had the lowest ring nematode populations in previous years, but higher-than-normal counts were found in 2017.

Table 1: Almond rootstocks selected for January 2011 planting at a location with sandy soil and low-quality irrigation water. Six rootstocks were planted on 'Nonpareil', 'Fritz' and 'Monterey'; seven additional rootstocks were planted on 'Nonpareil' only. Asterisk indicates rootstocks planted in April 2011 due to nursery availability.

Rootstocks Planted on Nonpareil, Fritz, & Monterey	Rootstocks Planted on Nonpareil Only
Nemaguard	RootpacR
Hansen 536	TemproPac
BH5	Krymsk-86
Viking	Cornerstone*
Atlas	Cadaman*
Empyrean-1	BB#106
	Floridaguard x Alnem (USDA)

Table 2: Plant parasitic soil-borne nematodes detected from soils sampled from 13 different almond rootstocks from 2017. Soil samples were taken at 12-18 in depths from within the dripline of rootstocks grafted to 'Nonpareil'. Nematodes were isolated using the sieve and sugar centrifugation using a commercial lab. Letters indicate statistical differences at p≤0.05) (Steel-Dwass All Pairs ln count +1).

Nematode species	Rootknot (*Meloidogyne* sp.)	Ring (*Mesocriconema xenoplax*)	Root Lesion (*Pratylenchus vulnus*)	Pin (*Paratylenchus* spp.)	Stubby Root (*Trichodorus* spp.)	Free-living Nematodes (various)
Rootstock	-------- 500 gram of soil --------					
Atlas	0 A	390	16	6	6	347
BB106	0 A	978	0	0	0	176
BH5	0 A	824	0	0	0	320
Cadaman	0 A	702	0	0	2	156
Cornerstone	0 A	861	51	0	0	280
Empyrean-1	0 A	630	29	0	0	213
Floridaguard x Alnem	14 A	2506	0	0	14	181
Hansen 536	0 A	1367	0	0	0	85
Krymsk-86	312 B	926	47	0	0	597
Nemaguard	0 A	265	0	1	1	437
RootpacR	0 A	909	25	0	5	252
TemproPac	0 A	811	0	3	4	90
Viking	0 A	923	26	1	1	190

Table 3: Rootknot nematode (*Meloidogyne* sp.) detected from soil sampled within the rootzone of 13 different rootstocks from the years 2011 through 2017. Soil samples were taken at 12-18-inch depths from within the dripline of rootstocks grafted to 'Nonpareil'. Nematodes were isolated using sieve and sugar centrifugation from a commercial lab.

	Root knot nematodes per 500 grams of soil

Rootstock	2011	2012	2013	2014	2015	2016	2017
Atlas	0	0	0	0	0	0	0
BB106	0	0	0	0	0	0	0
BH5	0	0	0	0	0	0	0
Cadaman	0	0	0	0	0	0	0
Cornerstone	0	0	0	0	0	0	0
Empyrean-1	0	0	0	0	0	0	0
Floridaguard x Alnem	0	0	0	0	0	0	15
Hansen 536	0	0	0	0	0	0	0
Krymsk-86	0	0	1	131	88	13	312
Nemaguard	0	0	0	0	0	0	0
RootpacR	0	0	0	0	0	0	0
TemproPac	0	0	0	0	0	0	0
Viking	0	0	0	0	0	0	0

Table 4: Root lesion nematode (*Pratylenchus vulnus*) detected from soil sampled within the rootzone of 13 different rootstocks from the years 2011 through 2017. Soil samples were taken at 12-18-inch depths from within the dripline of rootstocks grafted to 'Nonpareil'. Nematodes were isolated using sieve and sugar centrifugation from a commercial lab.

	Root lesion nematodes per 500 grams of soil[1]						
Rootstock	2011	2012	2013	2014	2015	2016	2017
Atlas	0	0	0	0	0	0	16
BB106	0	0	0	0	0	12	0
BH5	0	0	0	38	6	46	0
Cadaman	0	0	0	0	0	0	0
Cornerstone	0	311	31	0	2	13	51
Empyrean-1	0	0	0	0	0	0	29
Floridaguard x Alnem	0	0	0	0	0	0	0
Hansen 536	0	0	0	0	131	34	0
Krymsk-86	0	0	33	547	160	0	47
Nemaguard	0	0	0	0	0	0	0
RootpacR	0	0	0	9	33	2	25
TemproPac	0	0	0	34	26	0	0
Viking	0	0	0	0	41	55	26

[1]Colors indicate the occurrence of nematodes at varying populations. Green, yellow, orange, red, and deep red colored boxes indicate the occurrence of 1-25, 26-99, 100-249, 250-500, and >500 nematodes/500grams of soil, respectively.

Table 5: Ring nematode (*Mesocriconema xenoplax*) detected from soil sampled within the rootzone of 13 different rootstocks from the years 2011 through 2017. Soil samples were taken at 12-18 in depths from within the dripline of rootstocks grafted to 'Nonpareil'. Nematodes were isolated using sieve and sugar centrifugation at a commercial lab.

	Ring nematodes per 500 grams of soil[1]

Rootstock	2011	2012	2013	2014	2015	2016	2017
Atlas	0	0	0	0	75	418	290
BB106	0	0	0	46	1	122	978
BH5	0	0	0	123	282	934	824
Cadaman	0	0	0	1	624	510	702
Cornerstone	0	0	0	0	150	610	861
Empyrean-1	0	0	0	0	229	91	630
Floridaguard x Alnem	0	0	0	12	656	774	2506
Hansen 536	0	0	1	1832	1066	470	1367
Krymsk-86	0	0	8	247	319	730	926
Nemaguard	0	0	0	0	8	230	265
RootpacR	0	0	0	0	530	1586	909
TemproPac	0	0	0	0	86	188	811
Viking	0	0	0	0	6	11	923

[1]Colors indicate the occurrence of nematodes at varying populations. Green, yellow, orange, red, and deep red colored boxes indicate the occurrence of 1-25, 26-99, 100-249, 250-500, and >500 nematodes/500grams of soil, respectively.

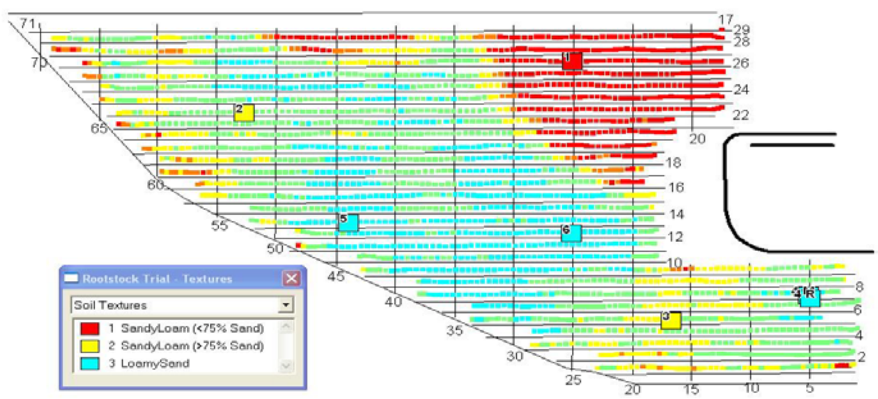


Figure 1: Soil electrical conductivity (EC) map of the rootstock plot. Red areas indicate heavier soil, while blue indicates lighter, coarser soil. EC mapping provides the ability to distinguish soil variations that are not detectable from viewing soil surveys. Differences in EC indicate different water and nutrient holding capacities.

Project Title: **Exploring 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
jhconnell@ucanr.edu

Project Cooperators: Sam Richardson 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 acquired the orchard in 2016 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 are collected annually. Mortality and anchorage will be noted as opportunities arise. Data is processed by an analysis of variance and using Fishers protected LSD 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).

<u>Tree size.</u> After eight 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 (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 trunk circumference (**Table 1**).

Nut size and yield. 'Nonpareil' kernels from trees on 'Rootpac-R' rootstock are significantly smaller than kernels from trees on all other rootstocks (**Table 1**). Kernels from trees on 'Krymsk 86' and 'Lovell' are of similar size while trees on 'Empyrean1', 'Nickels', and 'Atlas' all produced kernels significantly larger than those produced on the other rootstocks. Thus, the lowest yield noted on 'Rootpac-R' rooted trees 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 had both larger nut size and a significantly greater yield. 'Nonpareil' yield in the 8th leaf is heaviest on 'Nickels', 'Empyrean 1', and 'Atlas' (**Table 1**).

Table 1. Tree size, Kernel size, and Yield of 'Nonpareil' almond

	2017, 8th Leaf			
Rootstock	Trunk Circ. (cm)	Kernel wt. in Grams	Lbs. Kernel per tree	Lbs. Kernel per Acre
'Empyrean 1'	80.8 a	1.33 a	37.4 a	4,231 a
'Nickels'	77.9 b	1.35 a	35.6 a	4,019 a
'Atlas'	68.6 c	1.32 a	36.4 a	4,111 a
'Krymsk 86'	66.3 c	1.27 b	29.0 b	3,279 b
'Lovell'	67.8 c	1.27 b	28.4 b	3,211 b
'Rootpac-R'	61.9 d	1.22 c	21.5 c	2,434 c

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.

Overall production. Accumulated yield through the eighth leaf is shown beginning in the third leaf (**Table 2**). The largest trees have the greatest accumulated yield after six 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 2. Accumulated 'Nonpareil' almond yield shown as kernel pounds per acre at 113 trees per acre.

Rootstock	3rd Leaf	4th Leaf	5th Leaf	6th Leaf	7th Leaf	8th Leaf	Total Accumulated Yield
'Empyrean 1'	69	1,321	2,183	3,378	3,289	4,231	14,471
'Nickels'	96	1,162	2,157	3,332	3,642	4,019	14,408
'Atlas'	113	1,190	2,060	2,826	3,252	4,111	13,552
'Krymsk 86'	105	1,018	1,524	2,435	2,923	3,279	11,284
'Lovell'	74	1,042	1,426	2,208	1,978	3,211	9,939
'Rootpac-R'	90	1,025	1,553	1,714	1,526	2,434	8,342

Research Publications or References Cited:

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.

No other publications produced, or citations included at this point. Research is ongoing.

Project Title: **Rootstock Trial at CSU Fresno: Performance Evaluation and Studies on New Training Systems for Almonds**

Project Leader: Gurreet Brar
CSU Fresno
2415 E San Ramon, M/S AS 72
Fresno, CA, 93730
(559) 278-4119
gurreetbrar@csufresno.edu

Objectives:

Evaluation of conventional as well as growth controlling rootstocks at CSU Fresno.

Interpretive Summary:

During the current report period, growth differences and growth increase are being reported for all 7 rootstock treatments and 2 cultivars. There were significant differences in rate of growth in trunk diameter and overall trunk diameters of all rootstocks and cultivars. However, no significant differences were noted in other parameters measured, like midday stem water potential, net photosynthesis and stomatal conductance.

Materials and Methods:

This rootstock trial was established to have a trial in a Fresno county location that will compare performance of conventional peach rootstocks with peach almond hybrid and dwarfing rootstocks. Other than growth and yield performance evaluation, water use efficiency and photosynthetic parameters for these rootstocks are also being studied.

The trial was planted in 2017. It is a replicated trial (randomized Complete Block Design) with 7 different rootstocks (**Table 1**) with trees of two commercial cultivars Nonpareil and Monterey on them. Each rootstock-cultivar combination (one experimental unit) consists of 6 trees and is replicated 6 times. Therefore, the total number of replicated blocks of experimental units is: 7 rootstocks X 2 cultivars X 6 replicates= 84 blocks. The soil type in the field plot is Hanford sandy loam and the plot was mapped for EC prior to planting.

Table 1: List of rootstocks and cultivars at Fresno state Campus.

2 cultivars	**7 rootstocks**	
Non-pareil	Nemaguard	Lovell
Monterey	Guardian	Empyrean 1
	RootpacR	Cornerstone
	Rootpac20	

During the year 2017-18, truck diameter was measured, 2 inches above the graft union. Midday stem water potential was measured using a pressure chamber on select trees in each experimental unit during the growing season. Instantaneous net photosynthesis was measured weekly on selected trees for 3 rootstocks- Nemaguard, Cornerstone and Rootpac20 to compare conventional, peach-almond hybrid and dwarfing rootstocks in terms of their net photosynthesis, stomatal conductance and transpiration.

Results and Discussion:

The results pertaining to trunk diameter measurements are plotted in (**Figure 1a and 1b)** and (**Figure 2)**. Spring 2018 data shows that in Nonpareil (NP) trees, there were no significant differences between trunk diameters of trees on Cornerstone, Empyrean 1, Guardian, Lovel and Nemaguard while the trees on two growth controlling rootstocks, Rootpac 20 and RootpacR has smaller trunk diameters. In Monterey, only the trees on Rootpac20 had significantly smaller diameters and all other rootstocks didn't show significant differences. It was noted that in the case of NP trees, the trees on Rootpac rootstocks started with a significantly lower trunk diameter at planting while the trunk diameter of Monterey trees on RootpacR were among the highest at planting. In addition to statistically significant differences in trunk diameters in both rootstocks and cultivars, the interaction of rootstock*cv was also found significant.

Figure 2 shows the increase in growth between 2017 and 2018. The analysis of variance shows that the rootstock differences in growth were significant but not the cultivar differences. Also, no interaction of rootstock*cv was found significant.

Figures 3 and 4 show the midday stem water potential data on all 7 rootstocks and 2 cultivars. No significant difference was found among rootstocks or cultivars, but Nonpareil trees tended to have relatively lower stem water potential than Monterey trees.

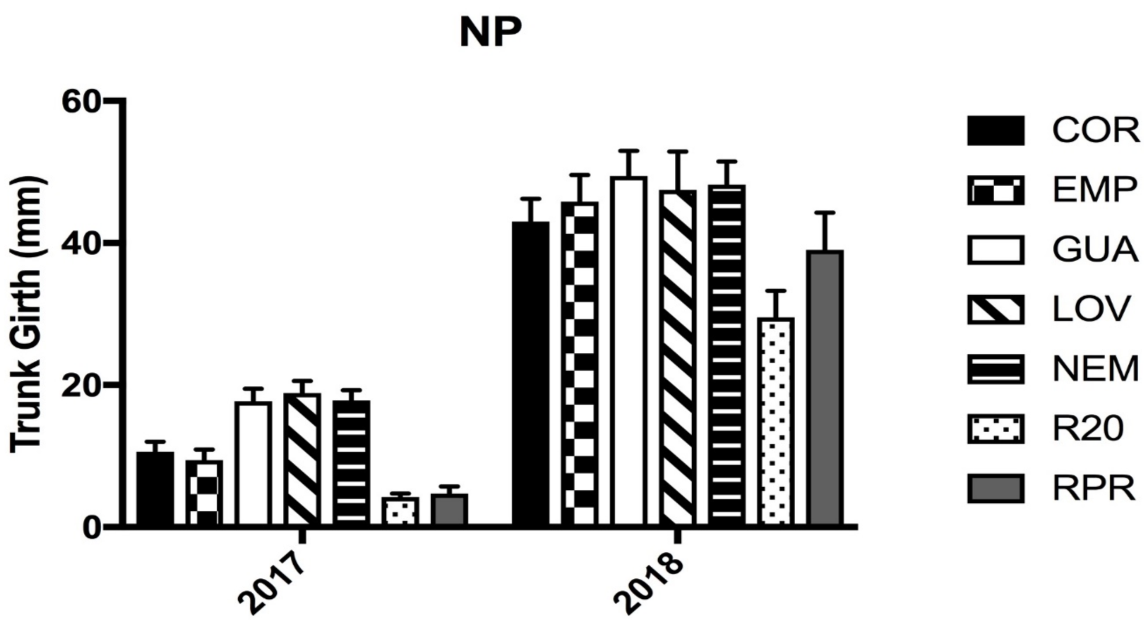
The photosynthetic parameters like net photosynthesis, stomatal conductance and transpiration were measured and the data on net photosynthesis and stomatal conductance are plotted in **(Figure 5)**. The trends in net photosynthesis followed the trends in stomatal conductance. Generally, no significant differences were found, except in some cases where growth controlling rootstock Rootpac20 exhibited higher net photosynthesis as compared to conventional and hybrid rootstocks.

Table 2: ANOVA for trunk girth of 7 different rootstocks for 2017.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3363.046[a]	13	258.696	33.170	.000
Intercept	18218.688	1	18218.688	2336.006	.000
Rootstock	2579.371	6	429.895	55.121	.000
CV	32.756	1	32.756	4.200	.042
Rootstock * CV	893.144	6	148.857	19.087	.000

Table 3: ANOVA for trunk girth of 7 different rootstocks for 2018.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3363.046[a]	13	258.696	33.170	.000
Intercept	18218.688	1	18218.688	2336.006	.000
Rootstock	2579.371	6	429.895	55.121	.000
CV	32.756	1	32.756	4.200	.042
Rootstock * CV	893.144	6	148.857	19.087	.000



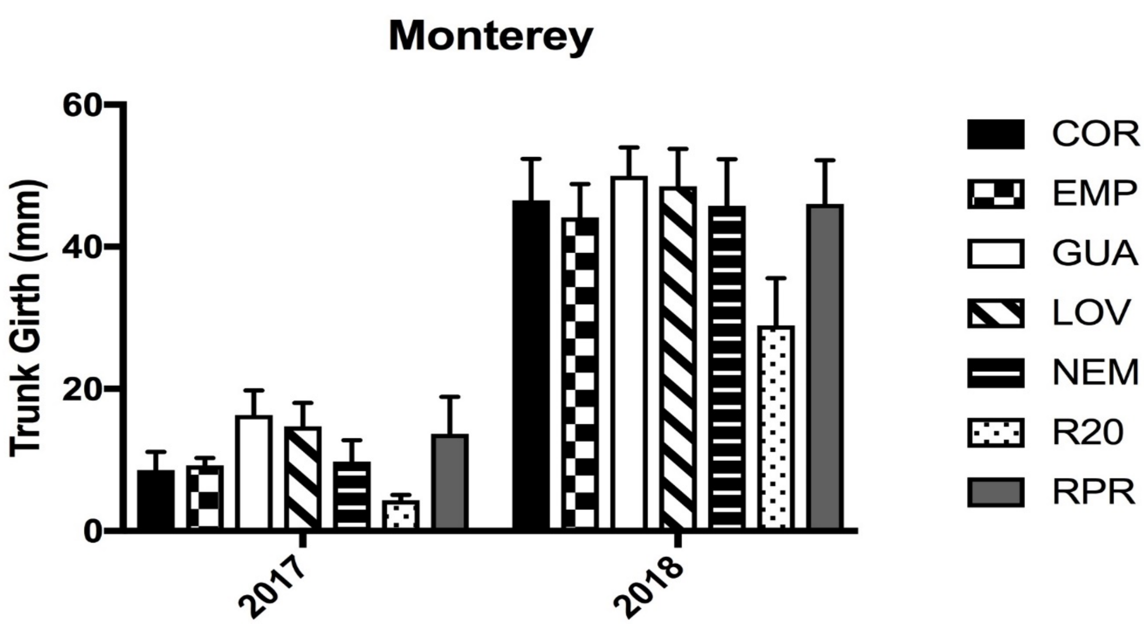


Figure 1. Trunk diameter (in mm) of almond trees of cultivar (a). Non-Pareil and (b). Monterey on 7 different rootstocks, for the years 2017 and 2018, year 1 and 2, respectively.

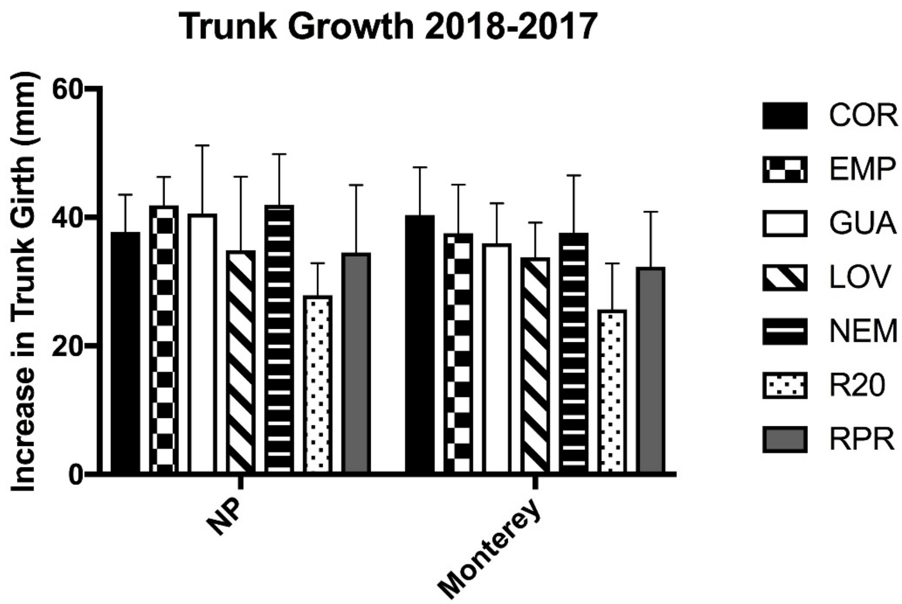


Figure 2. Increase in growth in trunk diameter of almond trees of cultivars Non-Pareil and Monterey on 7 different rootstocks between the years 2017 and 2018.

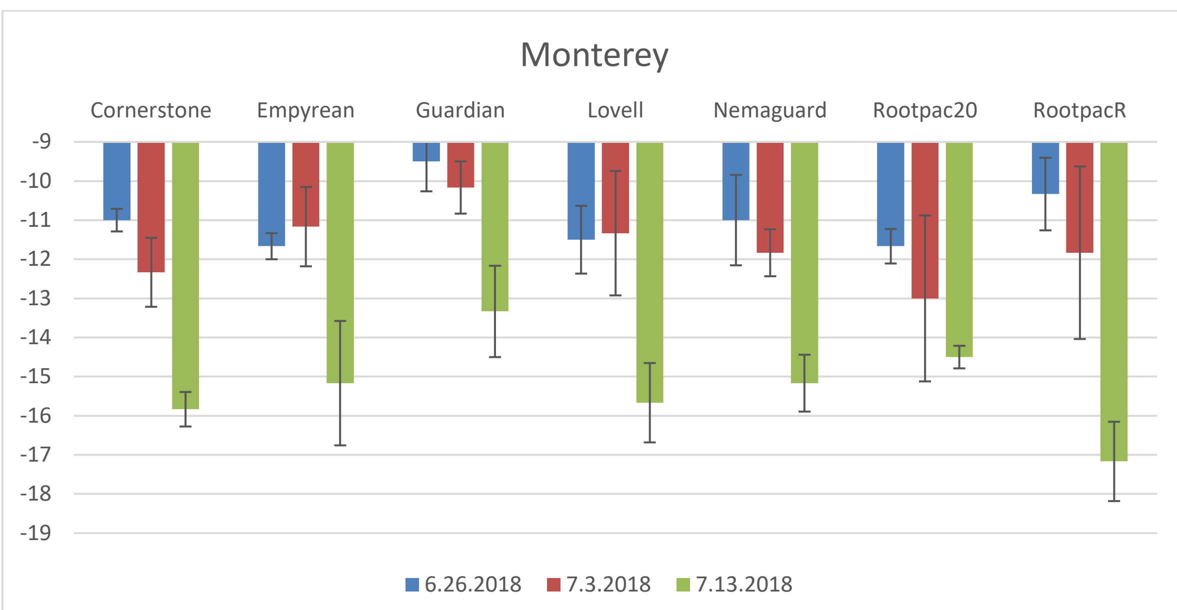


Figure 3. Midday Stem Water Potential of almond trees of cv. Monterey on 7 different rootstocks during 2018 season.

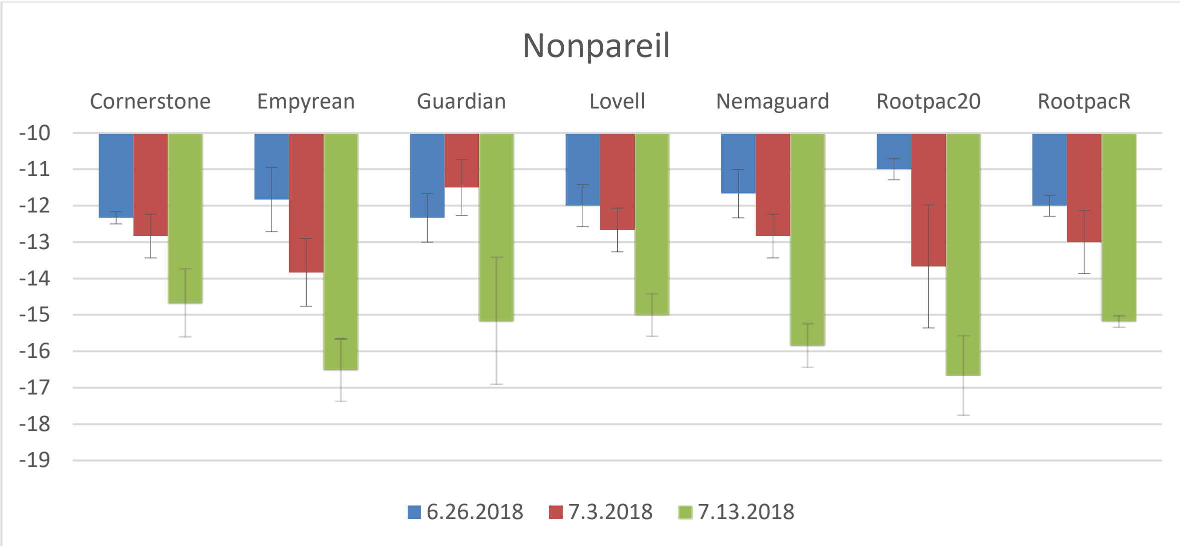


Figure 4. Midday Stem Water Potential of almond trees of cv. Non-pareil on 7 different rootstocks during 2018 season.

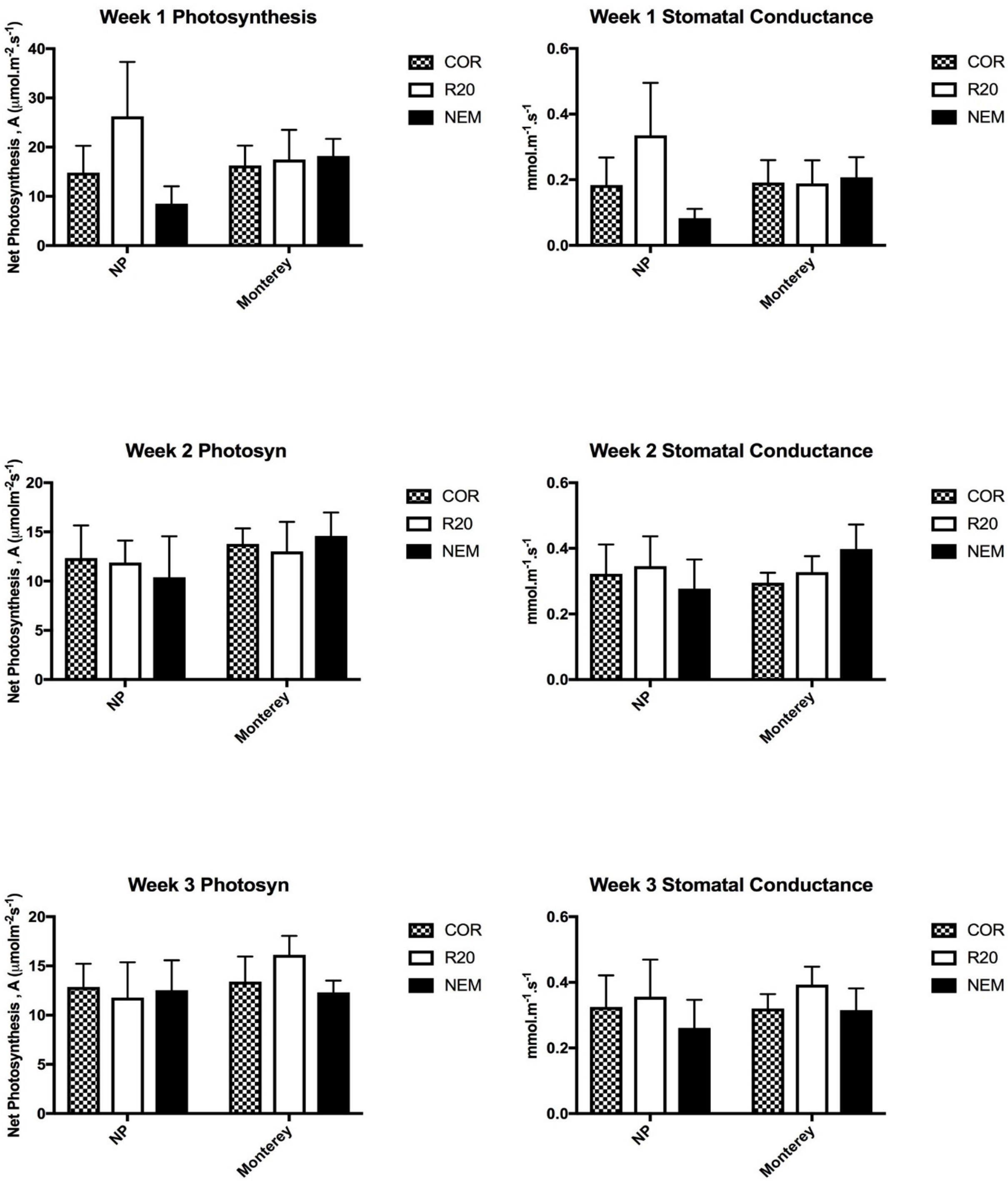


Figure 5. Net photosynthesis and stomatal conductance of Non-Pareil and Monterey trees on three rootstocks during May-June 2018.

Project Title: **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, FxA, Nickels and Brights 5 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 listed. Trees on Krymsk 86 and Lovell continue to produce 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. Viking and Rootpac-R switch places in yield ranking some years but are consistently in the middle of the pack.

In 2017, trees on Viking showed a higher yield-size efficiency (pounds of yield per unit of light interception) than trees on Hansen 536. Trees on Rootpac-R were in the middle but not significantly different in yield from Hansen 536, Viking, Krymsk 86 or Lovell.

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 2017, the orchard was in its 7^{th} 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 2017, the fifth harvested crop (**Table 1**). Trees on peach - almond (P-A) hybrids Titan SG1, FxA, Nickel and Brights 5 produced the highest average yields per acre while Lovell 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. Viking and Rootpac-R switch places in yield ranking some years but are consistently in the middle of the pack. P-A hybrid yields in 2017 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 have expected 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 2017, hull B was below this toxic threshold in all cases, with rootstock means ranging from 177 ppm to 265 ppm **(Table 1**). Hull boron levels varied significantly by rootstock, but interesting, trees with higher yields had higher boron concentrations in their hulls. Though this was not a tight relationship (R^2 = 0.33), it was highly significant ($p<0.001$). This runs counter to expectations that higher yield would dilute the boron among more hulls. It may be the larger trees simply had larger rootzones, consequently accessing more boron from the soil.

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 2017 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, FxA, Nickels and Brights 5. 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 significantly higher yields per unit PAR than the other small trees (**Figure 1)**.

Table 1. Almond boron rootstock trial results, 2017. Letters behind numbers indicate statistically significant differences (Tukey, α=0.05)

Rootstock	Origin	Avg. Yield (kernel lbs/acre)	Hull B (ppm)† (2016)	Light Intercep't (% PAR)	Lbs / PAR
Titan SG1	Peach-Alm	4,596	262	81%	57
FxA	Peach-Bitter Alm	4,278 a	265 a	87% a	49 a
Nickels	Peach-Alm	4,129 a	227 abcd	87% a	48 a
Brights 5	Peach-Alm	3,697 a	243 ab	79% b	47 a
Hansen 536	Peach-Alm	2,903 b	215 abcd	82% ab	35 bc
Viking	Pch-Al-Myro-Apr	2,704 bc	177 d	68% cd	40 b
Rootpac-R	Myro Plum-Alm	2,495 bcd	184 cd	68% c	36 bc
Krymsk 86	Myro Plum-Pch	2,154 cd	203 bcd	66% cd	33 c
Lovell	Peach	1,993 d	235 abc	63% d	32 c

*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.
† > 300 ppm = "toxicity"

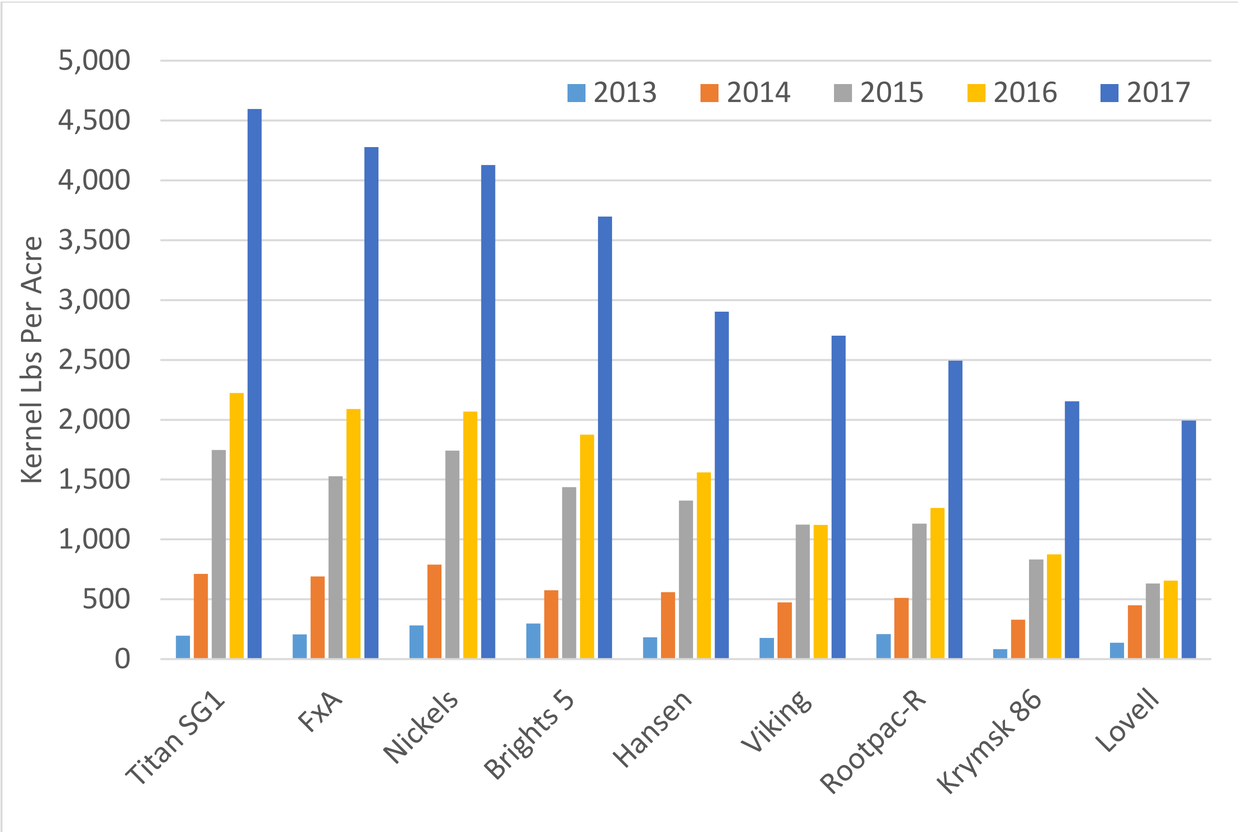


Figure 1. Boron rootstock trial yield results for 3rd, 4th, 5th, 6th & 7th leaf (2013, 2014, 2015, 2016 & 2017). Scaled from the 5-tree sample average to per acre yields based on the 110 trees per acre spacing.