Field Evaluation of Almond Rootstock

Project No.: **15-HORT4-Duncan**

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Objectives:

1. Evaluate alternative rootstocks irrigated with low quality (saline) irrigation water in alkaline heavy soil (Stanislaus County) and low pH, sandy soil (Merced County).
2. Evaluate alternative rootstocks under high boron conditions (Yolo County).
3. Continue evaluation of alternative rootstocks for tolerance to *Armillaria* root and crown rot (Butte & Stanislaus Counties).
4. Continue evaluation of variety compatibility with rootstocks for almond, particularly compatibility with Nonpareil.
5. Continue observation of alternative rootstocks in a sandy, unfumigated replant location (Stanislaus).

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

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Objective:

Evaluate 16 almond rootstocks for their performance in a heavy, alkaline soil, moderately high in boron, and irrigated with water high in sodium and chloride.

Interpretive Summary:

1. In general, trees on peach x almond hybrid rootstocks are the largest in the trial. Trees on Empyrean 1 and Rootpac R had trunk circumferences as large as trees on peach x almond hybrid rootstocks.
2. The smallest trees are on Krymsk 86, Cadaman, Lovell and Paramount

3. Krymsk 86, PAC9908-02, Hansen, and Viking have the best anchorage while Hansen x Monegro (HM2) has unacceptably poor anchorage.
4. The rootstocks most intolerable to chloride are Lovell, Krymsk 86, and Nemaguard.
5. Rootstocks accumulating the highest boron levels were Lovell, Cadaman, Atlas, and HBOK 50. Several rootstocks, mostly PA hybrids & Viking, had very low boron hull levels.
6. Several rootstocks had nearly double the 4th leaf yields of industry standards, Lovell and Nemaguard.

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 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 as a result of poor rootstock choice, almond yields on the west side are significantly 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. Due to the ongoing drought, this orchard has been irrigated primarily 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 indicate very high total salinity (2.5 – 3.4 dS/m), high sodium (9.4-14.7 meq/l) and very high chloride (11.0 – 17.1 meq/l) (**Table 3**.). The field has 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, and Boron.							
	EC (dS/m)	Na (meq/l)	Adj. SAR	Cl (meq/l)	CO3 +HCO3 (meq/l)	B (mg/l)	pH
Water Sample	1.86	9.40	8.80	8.9	2.50	0.84	7.1
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.

Trees with the largest trunk circumference at the end of the 4th leaf are on PAC9908-02, Empyrean 1, F x A and Rootpac R (**Table 4**). Other large trees are on Empyrean 1 (peach hybrid) and Rootpac R (plum x almond hybrid). Paramount (a.k.a. GF 677), the peach x almond hybrid commonly grown in Europe, is significantly smaller than the other PxA hybrids and is similar in size to Nemaguard. Krymsk 86, Cadaman, Lovell and Paramount are the smallest rootstocks in the trial. Brights 5, Avimag (a.k.a. Cadaman), and HBOK 50 were planted as potted trees and started out smaller than the other trees which were planted as bare root tress. It may take another year or two before Brights 5 catches up to the other P x A hybrid rootstocks.

Table 4. Rootstock Effect on Tree Size and Anchorage – End of 4th Leaf. December, 2015		
	Trunk Circumference (cm)	Trunk Angle (degrees)
PAC9908-02	50.8 a	85 a
Empyrean 1	50.0 ab	75 cde
Flordaguard x Alnem	49.7 abc	82 ab
Rootpac R	49.0 abc	81 abc
Hansen x Monegro	48.4 bc	69 e
BB 106	48.0 bc	76 bcd
Hansen	47.9 c	84 a
HBOK 50	45.6 d	74 cde
Nemaguard	44.6 de	82 ab
Atlas	44.3 de	80 abcd
Viking	44.2 de	84 a
Brights 5	43.8 de	81 abc
Paramount	43.3 ef	79 abcd
Lovell	42.9 ef	81 abc
Cadaman	42.6 ef	73 de
Krymsk 86	41.7 f	85 a

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. In order to quantify tree anchorage, a large protractor was used to measure trunk angles relative to the orchard floor. Acute trunk angles of less than 80 degrees is likely excessive. Krymsk 86, PAC9908-02, Viking, and Hansen are the straightest trees (**Table 4**). Hansen x Monegro (HM2) has unacceptably poor anchorage, with an average trunk angle of 69 degrees. Several of the HM2 trees in the trial have had to be propped with boards. Cadaman, HBOK 50, and Empyrean 1 may have questionable anchorage in windy areas. All had average trunk angles of 73-75 degrees.

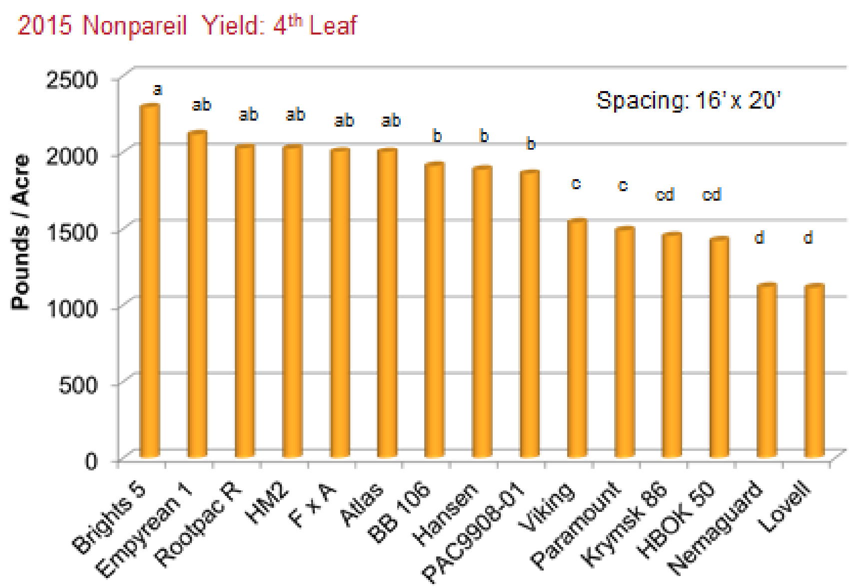
Salt Tolerance.
Although no obvious signs of ion toxicity are apparent in the trial yet, leaf analyses show that chloride levels are above the critical level for several of the rootstocks. July 2015 leaf analyses indicated that chloride levels are the highest in Lovell (0.73%), followed by Krymsk 86 (0.65%) and Nemaguard (0.43%) (**Table 5**). There are significant differences in the accumulation of boron in hulls among the rootstocks, although all are below the critical hull boron level of 300 ppm. Boron levels were highest in Lovell, Cadaman, Atlas, and HBOK 50 (180-156 ppm). Boron levels were lowest in BB106, FxA, Brights 5, PAC9908-02 and Viking (102-109 ppm).

Table 5. Leaf Sodium and Chloride Levels and Hull Boron Content of Fourth-Leaf Nonpareil Almond Trees Grown on Different Rootstocks. July & September, respectively, 2015

	% Chloride	% Sodium	ppm Boron
Lovell	0.73 a	0.08 ab	180 a
Krymsk 86	0.65 b	0.05 abc	152 bc
Nemaguard	0.43 c	0.06 abc	153 bc
Atlas	0.37 cd	0.07 abc	158 ab
Empyrean 1	0.32 de	0.09 a	133 cd
Cadaman	0.32 de	0.06 abc	170 ab
HBOK 50	0.30 def	0.06 abc	156 ab
PAC9908-02	0.28 defg	0.06 abc	108 e
Viking	0.25 efgh	0.07 abc	109 e
Rootpac R	0.25 efgh	0.08 ab	132 cd
Hansen	0.23 efgh	0.05 abc	126 de
Brights 5	0.22 fgh	0.06 abc	106 e
BB 106	0.20 gh	0.05 c	102 e
Paramount	0.20 gh	0.05 bc	120 de
F x A	0.20 gh	0.07 abc	104 e
HM2	0.18 h	0.07 abc	116 de
Critical Level	**0.30%**	**0.25%**	**300 ppm**

Yield.

2015 yield (4th leaf) is depicted in the figure below. Many of the highest yielding rootstocks are peach x almond hybrids, which tend to be larger trees. These include Brights 5, HM2, and FxA (2003 – 2293 lb/acre). Empyrean 1, Rootpac R, and Atlas also had equally high early yields. The lowest yielding rootstocks were the industry standards, Lovell and Nemaguard (1113 and 1118 lb/a, respectively).



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

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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:

More years of data will give a clearer picture of how the nine rootstocks in this trial compare in terms of boron tolerance. But for those who need to make decisions now, based on the results we have so far, it looks like Lovell and Krymsk 86 are inadvisable for high boron conditions. Nickels, Titan and FxA yielded the highest under high boron conditions given the spacing at the trial.

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 2014, the orchard was in its 4th leaf. Leaf nutrient assessment was done in July by collecting and bulking leaves from all 5 trees in each replicate into a single sample. Hull samples were similarly taken (bulked for each replicate) at harvest. Samples were analyzed for boron by UC Davis Analytical Lab. Yield per acre was calculated following harvest of 5-tree replicates by the grower.

Results and Discussion:

Significant differences in average yield per acre were measured between rootstocks in 2015, the third harvested crop (**Table 1**). Peach x almond hybrids Nickels, Titan SG1 and FxA produced the highest average yields per acre while Lovell and Krymsk 86 rooted trees produced the lowest yields. The yield ranking of all the rootstocks will require more years of data.

Approximately 60% of the variability in yield can be explained by tree size, as measured by canopy light interception (PAR). Are the lower-yielding trees naturally smaller, or are the high levels of boron reducing size? Hull boron levels explain 14% of the yield variability that PAR does not explain. Thus the lower yields are likely partly, or in some cases, due to lower boron tolerance.

Table 1. Almond boron rootstock trial results, 2015. Letters behind numbers indicate statistically significant differences (REGWQ, α=0.05)

Rootstock	Origin	Bloom Vigor (1-5)	Canopy Light Interception (% PAR)	Avg Yield (kernel lbs/acre)
Nickels	Peach-Alm	3.9a	72a	1741a
Titan SG1	Peach-Alm	3.9	62	1746
FxA	Peach-Bitter Alm	4.0a	72a	1529ab
Brights 5	Peach-Alm	3.7ab	62b	1438b
Hansen 536	Peach-Alm	3.3ab	69a	1324bc
Rootpac-R	Myro Plum-Alm	3.1bc	56c	1133c
Viking	Pch-Alm-Myro-Apr	3.0bc	53cd	1125c
Krymsk 86	Myro Plum-Peach	2.4c	49d	831d
Lovell	Peach	1.5d	54cd	632d

C. Performance of 14 Almond Rootstocks in a Sandy Location Irrigated with Well Water.

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Objective:

To compare rootstock performance based on growth, tissue sampling, stem water potential, and yield on a test site that has sandy, low exchange-capacity soils with shallow areas and hardpans, as well as presence of ring, root-knot, and root-lesion nematodes, and is irrigated with high sodium and high nitrate groundwater. Efforts will also be made to observe various phenological differences of these rootstocks such as bloom and harvest timing and influence on various diseases.

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 14 rootstocks, and the performance of Fritz and Monterrey on seven rootstocks (**Table 1).** Each of 6 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 (P/A-Hybrids), as the grower developed an interest in P/A-Hybrids after participating in a previous UC rootstock trial. Prior to planting, the location was cover cropped with Merced Rye, tree sites were excavated, and the row-strips were fumigated with Telone-II at 33 gallons per acre. Trees were planted in January 2011 with the exception of the trees grafted to Cadamen and Cornerstone, which were planted in April 2011. Trees are spaced at 22’x18’ and irrigated using double line drip.

Methods:

Soil mapping was done using Veris Electrical Conductivity Mapping (Strategic Farming). Differences in soil zones were identified, analyzed (**Table 2**), 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 after harvest in August 2013, 2014 and 2015. Approximately 100 leaves from three trees in each rootstock x block combination were collected from ‘Nonpareil’ trees in mid-July 2014 and analyzed for nutrient content by DellaValle Laboratory, Inc (Fresno, CA). Water samples from irrigation lines were collected during the growing season to determine water quality, and sent to DellaValle Laboratory Inc for analysis. Nematode samples were collected in November 2014 and sent for analysis by Nematodes, Inc (Selma, CA). Observations of bloom percentage as influenced by variety and rootstock were taken on February 24, 2012, March 4th, 2013, February 14, 2014, February 17, 2015, February 12th, 2016.

Results and Discussion:

Initial analysis indicated soil quality was suitable for almond production (**Table 2**), though differences in soil nutrient and water holding capacities (as measured by soil EC) were observed. Well water used for irrigation has shown to have higher-than-normal nitrate concentrations since 2011 (**Table 3**), and may be contributing to the high observed vigor. We found deficient hull boron in all rootstocks except 'Nemaguard' which may explain the reduced yields of the rootstocks (**Table 4).** Hull data does suggest that there are differential boron nutrient allocation strategies among these rootstocks (**Table 4**).

Overall yields from the 2015 season were highest among rootstocks grafted to ‘Monterey’ for the third consecutive year (**Tables 5, 6, 7**). Yields of ‘Nonpareil’ varied among rootstocks, with ‘Floridaguard x Alnem’ and 'Empyrean-1' producing significantly greater kernel pounds-per-acre than ‘RootPac(R)’, ‘Krymsk-86', and ‘Nemaguard’

(**Table 5**). Yields among rootstocks grafted to 'Fritz' were not significantly different in 2015 (**Tables 6**), while 'Monterey' grafted to 'Hanson-536' outperformed 'Nemaguard' (**Table 7**). 'Empyrean-1', 'Floridaguard x Alnem' rootstocks on 'Nonpareil' have greater cumulative yields (2013-2014) than 'RootPac(R),' 'Krymsk-86,' and 'Nemaguard' (**Table 5**), while 'Fritz' on 'Atlas,' or 'Viking' has produced significantly higher cumulative yields than 'Nemaguard' (**Table 6**). Within 'Monterey', cumulative yields were the greatest with 'Hansen-536,' which outperformed 'Nemaguard'(**Table 7**).

Differences in bloom period, as determined by the proportion of open flowers on a given date, were observed among varieties and some rootstocks (**Tables 8, 9, 10**). We experienced very rapid bloom progression in 2016, and began evaluations when the trees were full bloom. 'Nonpareil' trees exhibited a more even onset of bloom in comparison to previous years, and crop set appeared to be heavier than in years past. Nematode counts varied among rootstocks (**Table 11**). The differences were not statistically significant, but the nature of nematode sampling results in high variability among samples that can obscure potentially real differences. Root knot nematodes (*Meloidogyne* spp.) were found only in Krymsk-86. Ring nematodes (*Criconemella* spp.) were found on 'Hansen 536', 'BH #5', 'BB #106', 'Floridaguard x Alnem', and 'Krymsk-86'. Lesion nematodes (*Pratylenchus* spp.) were found on 'BH #5,' 'Krymsk-86,' 'RootPacR,' and 'TemproPac.'

Table 1: Almond rootstocks selected for January, 2011 planting at a location with sandy soil and low quality irrigation water. Seven 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	RootPac (R)
Hansen 536	TemproPac
BH5	Krymsk-86
Viking	Cornerstone*
Atlas	Cadamen*
Empyrean-1	BB#106
Red Titan III	Floridaguard x Alnem (USDA)

Table 2: Soil analysis of the six blocks established within the rootstock trial. Samples were collected in October, 2010 and analyzed by the UC Davis Analytical Laboratory.

Block	Soil Classification	Organic %	P - PPM	K PPM	Mg PPM	Ca PPM	Na PPM	pH	CEC meq/100	Base Saturation % K	Mg	Ca	H	Na
1	Sandy Loam	0.7	16	68	264	1172	85	7	8.6	2	25.4	68.3	0	4.3
2	Sandy Loam	0.5	36	63	141	668	39	6.6	5.1	3.1	22.6	64.9	6	3.3
3	Loamy Sand	0.4	55	56	73	366	16	6.7	2.8	5.2	21.8	66	4.5	2.6
4	Loamy Sand	0.4	72	52	62	290	25	6	2.6	5.2	19.7	55.9	15	4.2
5	Loamy Sand	0.5	33	58	81	377	25	6.5	3	4.9	62.1	62.1	7.5	3.6
6	Loamy Sand	0.7	82	64	207	845	82	6.6	6.8	2.4	24.8	61.5	6	5.2

Table 3: Water analyses (2011-2014) from well supplying water for the trial. Blue indicates values are below normal, red indicates values are above normal.

Sampling Period	pH	EC dS/m	SAR	Ca meq/L	Mg meq/L	Na meq/L	Cl meq/L	B mg/L	HCO_3 meq/L	NO_3-N mg/L	N lbs/acre in.
2014 Late season	7.6	0.31	0.90	1.47	1.05	1.00	0.30	0.05	1.80	10.3	2.3
2013 Mid-season	7.2	0.43	0.90	1.82	1.36	1.10	0.50	0.10	1.50	18.5	4.2
2012 Late season	7.4	0.48	1.30	1.69	1.20	1.50	0.80	0.10	1.60	13.9	3.2
2011 Late season	7.9	0.52	0.8	2.44	1.47	1.18	0.42	0.03	2.1	17.2	3.9
2011 Mid-season	7.9	0.52	0.9	2.50	1.50	1.23	0.42	0.03	2.1	19.6	4.5

Table 4: 'Nonpareil' hull boron nutrient analysis of among 14 rootstocks. Different letters indicate statistically significant differences (log10 normalized one-way ANOVA, Tukey-Kramer HSD or Steel-Dwass All pairs, $p < 0.05$). Blue indicates nutrient concentrations are deficient, red indicates nutrient concentrations are excessive.

Rootstock	Hull Boron (PPM)	Tukey Grouping HSD
Atlas	80.4	AB
BB106	71.4	ABC
BH5	69.8	ABC
Cadamen	78.6	AB
Cornerstone	63	BC
Empyrean-1	71	ABC
FloridaguardxAlnem	70.4	ABC
Hanson 536	76.2	ABC
Krymsk-86	71.2	ABC
Nemaguard	84	A
RootPacR	56	C
TemproPac	77.6	AB
Viking	68.4	ABC

Table 5: Mean 2013, 2014, 2015, and cumulative yields for 'Nonpareil' scion grafted to 14 different rootstocks. Measurements with different letters indicate statistically significant differences at p<0.05 (ANOVA and Tukey-Kramer HSD). Asterisk denotes treatments planted as potted trees in mid-April. These rootstocks were excluded from the analysis.

	2013		2014		2015		Cumulative	
Rootstock	Kernal Yield/acre (lbs)	Tukey HSD	Kernal Yield/acre (lbs)	Tukey HSD	Kernal Yield/acre (lbs)	Tukey HSD	Kernal Yield/acre (lbs)	Tukey HSD
Atlas	536.4	A	1262	ABC	1721	A	3519	ABC
Empyrean-1	503.4	AB	1494	AB	1958	A	3956	A
Viking	477.7	ABC	1151	BCD	1739	A	3368	ABC
Hansen 536	442.8	ABC	1280	ABC	1532	AB	3254	ABC
BB #106	398.9	ABC	1165	BCD	1492	AB	3057	ABCD
Nemaguard	398.3	ABC	814	D	685	D	1897	E
FXA	375.4	ABC	1605	A	1800	A	3780	A
RootpacR	369.9	ABC	1041	CD	847	CD	2244	DE
TemproPac	361.3	ABC	1366	ABC	1863	A	3590	ABC
BH #5	349.1	BC	1168	BCD	1382	ABC	2898	BCD
Cadamen*	329.9		1018		1408		2756	
Krymsk-86	321.7	C	1257	ABC	1090	BCD	2668	CDE
Cornerstone*	228.4		1012		1021		2261	

Table 6: Mean 2013, 2014, 2015, and cumulative yields for 'Fritz' scion grafted to 7 different rootstocks. Measurements with different letters indicate statistically significant differences at p<0.05 (ANOVA and Tukey-Kramer HSD).

Rootstock (Fritz)	Yield (lbs/acre)			
	2013	2014	2015	Cumulative
Atlas	435 A	1420 A	1925	3773 A
BH #5	223 A	1137 A	1489	2850 AB
Empyrean-1	377 A	1402 A	1679	3458 AB
Hansen 536	418 A	1420 A	1642	3479 AB
Nemaguard	317 A	1182 A	1091	2550 B
Viking	428 A	1414 A	1887	3730 A

Table 7: Mean 2013, 2014, 2015, and cumulative yields 'Monterey' scion grafted to 7 different rootstocks. Measurements with different letters indicate statistically significant differences at p<0.05 (ANOVA and Tukey-Kramer HSD).

Rootstock (Monterey)	Yield (lbs/acre)			
	2013	2014	2015	Cumulative
Atlas	753 AB	1841 A	1763 AB	4358 AB
BH #5	563 B	1709 A	1893 AB	4164 AB
Empyrean-1	829 A	1850 A	1791 AB	4476 AB
Hansen 536	626 AB	1759 A	2096 A	4481 A
Nemaguard	631 AB	1516 A	1360 B	3507 B
Viking	593 B	1603 A	1809 AB	4004 AB

Table 8: Mean estimated percent bloom for four seasons among rootstocks grafted to 'Nonpareil'. Bloom period in 2013 was too compact to reliably determine % bloom differences among rootstocks. Measurements with different letters indicate statistically significant differences at $p<0.05$ (ANOVA and Tukey-Kramer HSD of arcsin transformed bloom percentages).

Rootstock, cv 'Nonpareil'	2012	2013	2014	2015	2016
Atlas	43% DEF	100%	34% ABC	74% BC	92%
BB #106	63% BCD	100%	25% C	88% A	100%
BH #5	43% DEFG	100%	32% ABC	88% A	100%
Cadamen	22% GHI	100%	29% ABC	82% AB	100%
Cornerstone	11% I	100%	30% ABC	80% ABC	100%
Empyrean-1	76% A	100%	53% AB	84% AB	100%
Flor x Alnem	38% DEFGH	100%	35% ABC	86% A	100%
Hansen 536	63% ABC	100%	56% A	86% A	100%
Krymsk-86	7% I	100%	33% ABC	83% AB	100%
Nemaguard	54% CDE	100%	23% C	83% AB	100%
Red Titan	28% FGHI	100%	28% ABC	83% AB	100%
RootPac(R)	23% HI	100%	28% BC	89% A	100%
TemproPac	35% EFGH	100%	31% BC	83% AB	100%
Viking	74% AB	100%	28% ABC	71% C	88%

Table 9: Mean estimated percent bloom for four seasons among rootstocks grafted to 'Fritz'. Bloom period in 2013 was too compact to reliably determine % bloom differences among rootstocks. Measurements with different letters indicate statistically significant differences at $p<0.05$ (ANOVA and Tukey-Kramer HSD of arcsin transformed bloom percentages).

Rootstock, cv	2012	2013	2014	2015	2016
Atlas	31% B	100%	6% A	94% A	92%
BH5	12% C	100%	5% A	92% A	95%
Empyrean-1	66% A	100%	11% A	92% A	94%
Hansen 536	55% A	100%	12% A	91% A	91%
Nemaguard	28% BC	100%	3% A	94% A	95%
Red Titan III	26% BC	100%	5% A	90% A	90%
Viking	36% B	100%	4% A	92% A	92%

Table 10: Mean estimated percent bloom for four seasons among rootstocks grafted to 'Monterey'. Bloom period in 2013 was too compact to reliably determine % bloom differences among rootstocks. Measurements with different letters indicate statistically significant differences at $p<0.05$ (ANOVA and Tukey-Kramer HSD of arcsin transformed bloom percentages).

Rootstock, cv 'Monterey'	2012	2013	2014	2015	2016
Atlas	42% BC	100%	36% AB	93% AB	94%
BH5	21% D	100%	28% AB	89% B	92%
Empyrean-1	71% A	100%	48% A	94% A	92%
Hansen 536	64% AB	100%	53% A	91% B	92%
Nemaguard	27% D	100%	18% B	89% B	92%
Red Titan III	33% CD	100%	31% AB	94% A	93%
Viking	53% AB	100%	27% AB	90% B	93%

Table 11: Average nematode counts among blocks per 500g of soil. Soil samples were taken at 12-18 in depths from within the dripline of rootstocks grafted to 'Nonpareil'. No significant differences were observed among rootstocks at $p<0.05$ (Steel-Dwass All Pairs ln count +1).

Nematode Species	Root Knot	Ring	Root Lesion	Stubby Root	Pin	Free Composite
Rootstock	----- nematodes/500g soil -----					
Atlas	0	0	0	0.4	0	7785.2
BB #106	0	45.6	0	20.4	0	2660.8
BH #5	0	122.8	37.6	1.2	0	3863.2
Cadamen	0	0	0	4.8	0	1330.8
Cornerstone	0	0	0	2.4	0	3497.2
Empyrean-1	0	0	0	0.8	0	7777.2
Flor x Alnem	0	12.4	0	29.2	0	1604.8
Hansen 536	0	1832.0	0	0	0	3329.2
Krymsk-86	131.2	247.2	546.8	5.6	0	1374.4
Nemaguard	0	0	0	0	0	5232.8
RootPac(R)	0	0	8.8	22.4	326.8	2402.0
TemproPac	0	0	33.6	4.8	0	3713.2
Viking	0	0	0	0	0	3661.6

D. Exploring Alternative Rootstocks for Butte County

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Objectives:

Evaluate Nonpareil vigor and compatibility with rootstocks for almond and assess tree field performance. Evaluate rootstock effects on tree nutrition.

Materials and Methods:

Working with Brouwer Orchards in Durham and Fowler Nursery a participant in the P2G Rootstock consortium, a rootstock trial was planted on March 15, 2010 following the removal of a previous 'Lovell' peach rooted orchard containing some plum rooted replants. This replicated randomized trial evaluates 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 were measured in 2012 (3rd leaf), 2013 (4th leaf), 2014 (5th leaf), and 2015 (6th leaf). Mortality and anchorage will be noted as opportunities arise. Conduct a nutritional assessment by rootstock with replicated sampling and July leaf analysis when trees are mature.

Results and Discussion:

In this Six Rootstocks trial, four of the 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). After six growing seasons, trees on the 'Empyrean 1' rootstock are largest in circumference followed by trees on 'Nickels'. Trees growing on 'Atlas' and 'Lovell' are similar in trunk circumference as are trees on 'Lovell' and 'Krymsk 86'. 'Rootpac-R' rooted trees are the smallest.

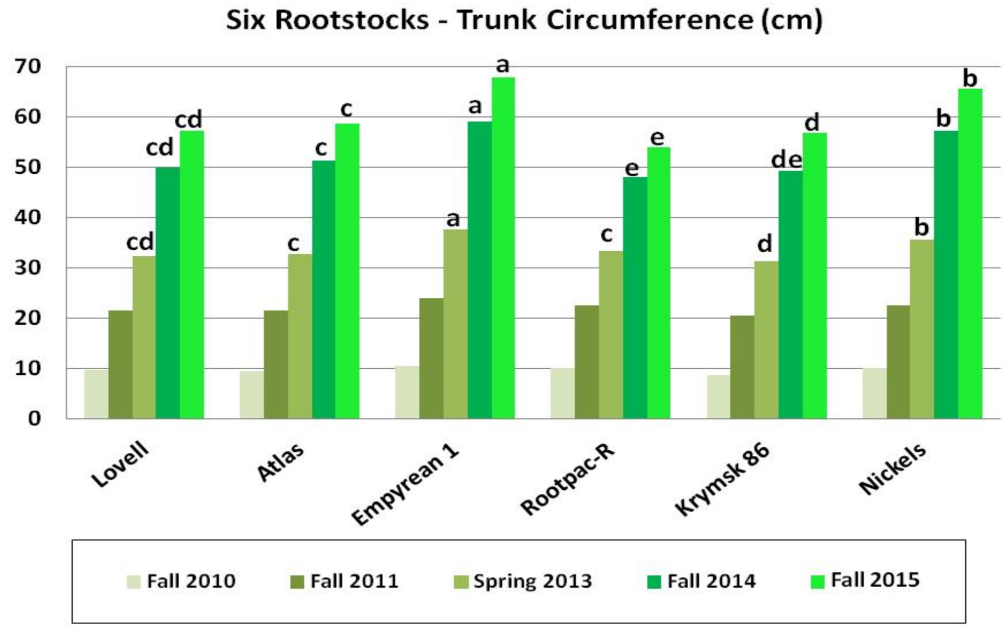

Figure 1. Trunk circumference of 'Nonpareil' almond after six growing seasons.

Tree spacing in this orchard is 24 feet across x 16 feet down the row giving a tree population of 113 trees per acre. Yield data was collected beginning in the third leaf (**Table 1**). 6th leaf yield closely follows tree canopy size related to rootstock vigor. 'Nonpareil' yields are heaviest on the largest trees; those on 'Empyrean 1' and 'Nickels', followed by 'Atlas'. Trees on 'Krymsk 86', and 'Lovell' are smaller and have lighter yields. Trees on 'Rootpac-R' are the least vigorous and have the lightest yield.

Table 1. Yield of 'Nonpareil' almond on six rootstocks planted in Durham, California.

Six Rootstocks Yield -- Durham, California

Pounds of kernel per tree

Rootstock	3rd Leaf	4th Leaf	5th Leaf	6th Leaf
Lovell	0.65 cd	9.22 cd	12.62 b	19.54 c
Atlas	1.00 a	10.53 ab	18.23 a	25.01 b
Empyrean 1	0.61 d	11.69 a	19.32 a	29.89 a
Rootpac-R	0.79 bcd	9.07 d	13.74 b	15.17 d
Krymsk 86	0.93 ab	9.00 d	13.49 b	21.55 c
Nickels Hybrid	0.85 abc	10.28 bc	19.08 a	29.48 a

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.

Research Publications or References Cited:

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