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Project No.: Field Evaluation of Almond Rootstocks (2000-JC-o0).

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Four Regional Rootstock Trials were established in Butte, Colusa, Kern, and San Joaquin counties. Rootstock effects to be evaluated in these ongoing trials will include rootstock influence on growth, height, bloom timing, harvest maturity, yield, and nut quality. Other continuing aspects of this project include evaluating interstocks that allow Nonpareil to grow on Marianna 2624 rootstock in trials in Colusa and Butte counties. Additional trials in Colusa county will evaluate Deep Purple plum as a rootstock for Nonpareil as well as the compatibility of newer varieties on Marianna 2624 plum.

Objectives:

1. Begin collection of data from Regional Rootstock Trials in Butte, Colusa, Kern, and San Joaquin counties.

2. Evaluate the compatibility and field performance of Nonpareil on Deep Purple plum and the compatibility of newer almond varieties on Marianna 2624 plum in a Colusa county trial.

Results:

1. Regional Rootstock Trials

Summary

Four Regional Rootstock Trials are underway in Butte, Colusa, Kern, and San Joaquin counties. Colusa and Kern county trials were planted in 1997 while Butte and San Joaquin county plantings occurred in 1998. Evaluating rootstock potential for better anchorage, bacterial canker resistance, and tolerance to shallow soils and high rainfall environments will be useful in adapting orchards to the diverse environments where California almonds are grown. In addition, the four trials are evaluating rootstock influence on growth, yield, and tree survival. Initial tree mortality was highest on 'Viking', followed by 'Atlas' possibly due to sensitivity to drying during cold storage or planting. Mortality of trees on all other rootstocks was commercially acceptable. Trees on 'Hansen 2168', 'Hansen 536', and 'Nickels' (UC 1-82) were frequently larger in trunk

circumference than trees on the other rootstocks. Tree height measurements made following the second, third, or fourth growing seasons showed some differences between rootstocks. Trees on 'Hansen 536' or 'Hansen 2168' were taller than trees on other rootstocks while trees on 'Bright's' hybrid, 'Viking', and 'Nemaguard' were often shorter than trees on other stocks. Initial harvests in the third and fourth growing seasons found that yields on 'Atlas' were often significantly greater than the yield on other rootstocks. Early in the fourth growing season in the Butte County trial substantial tree losses occurred during a windstorm especially on 'Hansen 536' but trees were also lost on 'Nemaguard', 'Bright's' and 'Atlas' rootstocks. We will continue to develop additional information as these orchards mature.

Overview

Four regional rootstock trials are established in California to develop information on rootstocks following a method previously used for cultivars (Micke *et al.*, 1998). Information developed will be useful in adapting orchards to the diverse environments where California almonds are grown. Each site was selected for a specific challenge to the rootstocks such as the need for better anchorage, bacterial canker resistance, and tolerance to shallow soils or high rainfall environments. Desirable rootstock characteristics (Felipe *et al.*, 1998) will be evaluated in these ongoing trials as the trees mature. Observations will include influence on growth, size, yield, bloom timing, harvest maturity, nut quality, and tree survival as opportunities for evaluation occur.

Although not all rootstocks are in all trials, the peach rootstocks; 'Nemaguard', 'Lovell', and 'Guardian', the peach x almond hybrids; 'Hansen 536', 'Hansen 2168' (Kester and Asay, 1986), 'Bright's' and 'Nickels' (UC 1-82), and the interspecific (peach x almond x plum x apricot) hybrids; 'Viking' and 'Atlas' are included. Several of these are commonly used in California almond orchards where plantings on heavy or shallow soils are doing well when proper irrigation and suitable rootstocks are used (Micke and Kester, 1998). Characteristics of rootstock performance are fairly well understood (Edstrom and Viveros, 1996) but side-by-side comparisons of older and newer rootstocks have not been conducted before in California regional trials.

Methods

Trees for these trials were grown by commercial nurseries and were planted bare root in cooperators fields as conditions permitted. The scion variety in the Kern trial is 'Butte' while the scions in the other three trials are 'Nonpareil'. All orchards are managed under normal commercial irrigation, fertilization, pruning, disease and pest control practices.

Due to a very wet spring, the Butte County trial was planted with dormant trees from cold storage in May 1998. 'Bright's', 'Hansen 536', 'Nickels', 'Atlas', 'Viking', 'Guardian', 'Nemaguard', and 'Lovell' rootstocks are included. The block is planted on a deep loam soil in a high rainfall area and is irrigated with solid set sprinklers. Sixty trees of each rootstock were planted in 10 replications of six trees with the exception of the 'Nickels' stock where 10 replications of 3 trees were used.

The Colusa County trial was planted in March 1997. 'Bright's', 'Hansen 536', 'Nickels', 'Atlas', 'Viking', 'Nemaguard', and 'Lovell' rootstocks are included. The block is on shallow soil with a hardpan that was slip plowed prior to planting. It is irrigated with dual microsprinklers. Sixty-four trees of each rootstock were planted in 8 replications of 8 trees each.

The Kern County orchard was established in February 1997. It includes, 'Bright's', 'Hansen 536', 'Hansen 2168', 'Nickels', 'Viking', 'Atlas', and 'Nemaguard' rootstocks. 'Nickels' was planted a year later in 1998. The orchard is irrigated with solid set sprinklers. Large plots designed to evaluate the resistance of each rootstock to "Santa Ana" windstorms were planted on very deep sandy soils a few miles north of the Tehachapi Mountains. The trial was planted at 30 trees per plot each replicated six times with the exception of 'Nemaguard' and 'Nickels' which are replicated five times and 'Hanson 2168' replicated three times.

Planted in March 1998, the San Joaquin County trial included: 'Bright's', 'Hansen 536', 'Nickels', 'Atlas', 'Viking', 'Guardian', 'Nemaguard', and 'Lovell' rootstocks. Designed to document relative rootstock tolerance to the bacterial canker complex, a second-generation peach orchard with severe bacterial canker was removed the year prior to trial establishment and the sandy soil was solid fumigated (tarped) with methyl bromide. Fifty trees of each rootstock were planted in a commercial orchard with 'Carmel' and 'Sonora' as pollinators.

Field trials in all counties were planted using a randomized complete block design. To provide uniform pollination and maximum yield potential pollenizer rows are planted on both sides of the scion cultivar used for data collection and beehives are moved into all orchards during bloom. Analyses of variance and mean separation was done by using either Duncan's multiple range test, the least significant difference test, or Fishers protected LSD.

Results

Rootstock effects evaluated so far in these ongoing trials include rootstock influence on tree establishment, growth, height, yield, and tree survival.

Tree mortality at planting, shown in Table 1, indicates significant tree losses occurred initially on 'Viking' and 'Atlas'. Mortality of trees on all other rootstocks was commercially acceptable. The 'Bright's', 'Hanson 2168' and 'Nemaguard' rootstocks had similar mortality. When replanted directly from the nursery in February 1999 and 2000 both 'Viking' and 'Atlas' established successfully.

Overall, tree trunk circumference on 'Hansen 2168', 'Hansen 536', and 'Nickels' was frequently larger than for trees on the other rootstocks. After three growing seasons in Butte County (Table 2) 'Hansen 536' was largest in circumference followed by 'Nickels' and 'Nemaguard'. There was little difference in tree size between the seven rootstocks in the Colusa trial (Table 3) with only the 'Hansen 536' significantly larger than the others. In Kern County, the 'Atlas', 'Hansen 2168', and 'Hansen 536' were significantly larger than 'Bright's' and 'Nemaguard' for the first three years (Table 4) but by the fourth season there were no significant differences in trunk growth among any rootstocks. San Joaquin trees have a significantly larger trunk circumference on 'Hansen 536' and 'Nickels' than on the other rootstocks (Table 5).

Tree height measurements (Table 6) made following the second, third, or fourth growing seasons showed significant differences between rootstocks. Trees on 'Hansen 536' or 'Hansen 2168' were taller than trees on other rootstocks in three of the four trials. Trees on 'Bright's', 'Viking', and 'Nemaguard' were often shorter than trees on other stocks.

The initial harvest of trials in the third and fourth growing seasons found that yield on 'Atlas' was often significantly greater than the yield on other rootstocks (Table 7). The yield of trees on 'Bright's' hybrid rootstock was often significantly lower than on other rootstocks. There were no significant differences between rootstocks in kernel weight or in percent open suture. Likewise, no obvious rootstock effects were observed in nut maturity or nut removal.

At the beginning of the fourth growing season, north winds blew for three days in the Butte County trial averaging 32 to 48 kilometers per hour. With the weight of the first substantial crop on the limbs, this wind resulted in splitting of primary scaffolds and loss of entire trees. Table 8 shows the percent of trees on various rootstocks that split and were lost. Substantial tree losses occurred especially on 'Hansen 536' but trees were also lost on 'Nemaguard', 'Bright's' and 'Atlas' rootstocks.

Discussion

The results on tree mortality, growth, height, yield, tree survival, and nut quality are site specific during these early years of tree development. The mortality of trees at planting was higher on 'Viking' and 'Atlas' than on any other rootstocks possibly due to sensitivity to drying during planting or cold storage. In Colusa County, trees on 'Atlas', 'Bright's' and 'Nickels' rootstocks were initially slightly delayed in flowering but there were no differences in bloom timing between any of the rootstocks by full bloom and petal fall. No measurable differences in crop maturity were found. Possibly tree vigor on all rootstocks in these young orchards has minimized differences. As observations continue, consistent trends among the four sites may become more apparent.

The functions of root systems include anchorage, absorption of water and nutrients, synthesis of plant hormones, and storage (Catlin, 1996). Some rootstocks perform certain of these functions better than others. Peach seedling rootstocks have been found to be less tolerant to drought than peach x almond hybrids and yields were lower (Godini and Palasciano, 1998). Under California irrigated conditions yield on peach seedling rootstocks has been intermediate but anchorage remains to be tested. If water supply is limited, soil conditions marginal, or nematodes present then the rootstock choice becomes especially important (Caboni and Monastra, 1998). Over time, differences among the rootstocks in these trials in criteria that count towards an orchards economic viability will no doubt begin to emerge.

Yield is often the horticultural characteristic that determines commercial rootstock selection. Perhaps a more important evaluation is tree loss after establishment. This factor is especially significant since tree attrition can reduce or eliminate the profitability of an entire orchard. Rootstocks that contribute to this problem may not be commercially viable even if other factors such as yield per tree appear positive.

According to Southwick *et al.*, 1999, a desirable rootstock is easy to propagate, has good anchorage, has resistance to all major pests and diseases, is free from suckering, controls tree size to a degree (high yield efficiency), and produces large crops. He concluded that such a rootstock does not currently exist. Whether one will be discovered among the rootstocks in these regional trials remains to be seen.

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Table 1. Percent mortality: tree losses at planting in various locations.

Rootstock	Planted in Butte Co. May 1998	Planted in San Joaquin Co. March 1998	Planted in Kern Co. February 1997	Planted in Colusa Co. March 1997
Bright's Hybrid	0	0	6.1	1.6
Hansen 536	0	0	0	0
Hansen 2168	***	***	4.5	***
Nickels (1-82)	3.3	0	*	0
Viking	58.3	42.0	13.3	3.1
Atlas	25.0	0	0	0
Guardian	0	0	***	***
Nemaguard	0	0	5.6	0
Lovell	1.7	0	***	1.6

* Planted one year later. *** Rootstock not in the trial.

Table 2. Butte County mean trunk circumference in centimeters.

Rootstock	At Planting June 1998	After 1 Season April 1999	After 2 Seasons October 1999	After 3 Seasons October 2000
Bright's Hybrid	4.07 bc*	9.77 bc	20.75 c	35.88 c
Hansen 536	4.34 b	11.31 a	24.25 a	41.32 a
Nickels (1-82)	5.22 a	10.79 ab	23.17 ab	38.79 b
Viking	4.50 b	9.11 c	21.24 c	36.35 c
Atlas	4.33 b	10.06 bc	21.98 bc	36.16 c
Guardian	3.52 c	10.01 bc	22.02 bc	36.42 c
Nemaguard	3.74 c	10.79 ab	23.17 ab	38.45 b
Lovell	3.94 bc	9.67 bc	21.33 c	35.86 c
LSD P< 0.01	0.53	1.11	1.33	1.79

* Values followed by the same letters are not statistically different as measured by Duncan's Multiple Range test.

Table 3. Colusa County mean trunk circumference in centimeters.

Rootstock	After 2 Seasons August 1998	After 3 Seasons Fall 1999	After 4 Seasons Fall 2000
Bright's Hybrid	19.7	32.4	45.3 ab*
Hansen 536	21.2	35.1	47.9 a
Nickels (1-82)	20.4	33.9	44.6 b
Viking	20.7	33.4	42.8 b
Atlas	20	32.4	42.2 b
Nemaguard	19.9	33.5	42.2 b
Lovell	20.5 ns	33.6 ns	42.2 b

* Values followed by the same letters are not statistically different as measured by Fishers Protected LSD at $P < 0.05$.
ns - Not significantly different

Table 4. Kern County mean trunk circumference in centimeters.

Rootstock	After 1 Season Fall 1997	After 2 Seasons Fall 1998	After 3 Seasons Fall 1999	After 4 Seasons Fall 2000
Bright's Hybrid	9.34 c*	22.24 b	34.57 d	48.91
Hansen 536	12.71 a	27.73 a	41.85 a	48.10
Hansen 2168	12.41 a	27.61 a	41.65 ab	51.41
Nickels (1-82)	**	12.79 c	26.17 e	46.36
Viking	11.08 b	25.50 a	37.72 c	51.35
Atlas	12.38 a	26.11 a	38.85 bc	52.47
Nemaguard	8.95 c	21.81 b	34.10 d	48.01 ns

* Values followed by the same letters are not statistically different as measured by the least significant difference test at $P< 0.05$ or are ns, not significantly different.

** This rootstock was planted in 1998, one year later than the others.

Table 5. San Joaquin County mean trunk circumference in centimeters.

Rootstock	After 2 Seasons October 1999	After 3 Seasons October 2000
Bright's Hybrid	25.7 b^x	36.1 c^y
Hansen 536	29.0 a	38.9 ab
Nickels (1-82)	28.9 a	39.8 a
Viking	25.4 b	35.3 c
Atlas	26.2 b	36.0 c
Guardian	25.2 b	35.1 c
Nemaguard	25.3 b	35.8 c
Lovell	26.4 b	36.9 bc

Values followed by the same letters are not statistically different as measured by:

^{x} the least significant difference test at $P< 0.05$.

^{y} Duncan's Multiple Range test at $P< 0.05$.

Table 6. Mean tree height (meters) at various ages and locations.

Rootstock	After 2 Seasons San Joaquin Co. October 1999	After 3 Seasons Butte Co. February 2001	After 4 Seasons Colusa Co. Fall 2000	After 4 Seasons Kern Co. Fall 2000
Bright's Hybrid	3.1 d[x]	4.56 c[y]	5.18 ab[z]	4.76 abc[x]
Hansen 536	3.4 ab	5.05 a	5.27 a	4.93 a
Hansen 2168	***	***	***	5.06 a
Nickels (1-82)	3.5 a	4.63 bc	5.06 bc	4.47 c
Viking	3.1 d	4.49 c	5.09 bc	4.83 ab
Atlas	3.3 bc	4.61 bc	5.06 bc	4.94 a
Guardian	3.3 bc	4.55 c	***	***
Nemaguard	3.2 cd	4.75 b	5.03 c	4.57 bc
Lovell	3.3 bc	4.60 bc	5.18 ab	***

Values followed by the same letters are not statistically different as measured by:

[x] the least significant difference test at P< 0.05.

[y] Duncan's Multiple Range test, P< 0.05.

[z] Fishers Protected LSD at P < 0.05.

*** Rootstock not in the trial.

Table 7. Mean yield (Kg kernel/tree) at various ages and locations.

Rootstock	3rd Season Butte Co.	3rd Season Kern Co.	4th Season Kern Co.	4th Season Colusa Co.
Bright's Hybrid	0.33 c[y]	1.18 c[x]	3.01 b[x]	2.16 cd[z]
Hansen 536	0.56 ab	2.28 ab	4.35 b	2.69 ab
Hansen 2168	***	2.52 [xx]	4.79 [xx]	***
Nickels (1-82)	0.45 b	[yy]	1.67 [yy]	2.56 bc
Viking	0.56 ab	1.38 c	3.61 b	2.93 ab
Atlas	0.66 a	2.75 a	5.69 a	3.16 a
Guardian	0.57 ab	***	***	***
Nemaguard	0.53 ab	1.72 bc	3.91 b	2.06 cd
Lovell	0.49 b	***	***	2.95 ab

Values followed by the same letters are not statistically different as measured by:

[x] the least significant difference test at P< 0.05.

[y] Duncan's Multiple Range test, P< 0.05.

[z] Fishers Protected LSD at P < 0.05.

[xx] not included in analysis, only two replicates.

[yy] not included in analysis, trees one year younger.

*** Rootstock not in the trial.

Table 8. Percent tree loss in Butte County trial during May 2001 due to splitting at primary scaffolds during high winds while carrying the first significant crop*.

Rootstock	% Split & Lost May 2001
Bright's Hybrid	10.17
Hansen 536	21.66
Nickels (1-82)	3.45
Viking	0
Atlas	6.25
Guardian	3.33
Nemaguard	11.66
Lovell	0

* Trees are in their 4th growing season, north winds blew for three days, averaging 32 to 48 kilometers per hour.

2. Deep Purple Plum and other Rootstocks for Almonds

John Edstrom, UC Farm Advisor, & Stan Cutter, Nickels Soils Lab

The USDA Agricultural Research Service has identified various plum type rootstocks, which show varying degrees of compatibility with Nonpareil. One of these, Deep Purple (DP) (*Prunus besseyi x p.salicina*) has shown resistance to root knot and root lesion nematodes in field trials. The tolerance of this rootstock to Oak Root Fungus is unknown. Another candidate is Hiawatha, also a plum type rootstock with similar parentage and characteristics. Researchers in France (INRA) have developed numerous peach/almond hybrid rootstocks with desirable characteristics, such as tolerance to drought, high pH soils and nematodes, and which also impart vigor to the scion. The most successful one of these, GF 677, is planted widely in Europe. Many newer almond cultivars have not been fully evaluated on M2624.

The objectives of this trial are to: 1) find plum type rootstocks compatible with Nonpareil and evaluate their field performance. 2) Evaluate the alternative rootstock GF 677 for Nonpareil and Butte. 3) Evaluate new almond cultivars for compatibility on M2624. 4) Retest older almond cultivars on M2624, which show erratic field trial performance. 5) Evaluate double grafted trees with interstems of Padre between Nonpareil and M2624

Nonpareils directly onto Deep Purple have been planted from two sources, Fowler (Non F) and Burchell (Non B). Nonpareil directly on M2624 has also been included as well as Butte and Nonpareil on 'Hiawatha'. Extra items included are the newly developed cultivars, 'Durango' (Fowler) and 'Kochi' (Sierra Gold), which are on Lovell. The new almond varieties for M2624 include, 'Plateau', UC 13-1 and 'Avalon'. Varieties planted as standards on M2624 are 'Sonora' and 'Mission'.

Results:

Trees were evaluated on 8-8-00, five months after planting to determine survivability and to rate tree size. Table 1 shows that most scion rootstock combinations performed satisfactorily except for Nonpareil on Deep Purple. Eight of nine Nonpareils on Deep Purple (Fowler source) died midseason, while 1 tree of 9 from the Burchell source perished. Most other Non (B) trees on DP were rated very poor. Similar poor performance was found in the first field evaluation in 1998 of Deep Purple rootstock with Nonpareil.

Other combinations grew quite well with Nonpareil and Butte on Hiawatha rating the highest. Surprisingly, Nonpareil directly on M2624 also rated high this first season.

Table 2 shows tree ratings for the selected varieties on Lovell and peach/almond hybrid rootstocks. In general, all combinations grew well except for Nonpareil/Hansens 536. Two of nine trees died in this treatment while the remaining 7 grew well. The most consistent performers in this section of the test were Nonpareil and Butte on GF 677.

Table 1

Plum Type Rootstocks
Tree Ratings

	Rep 1	Rep 2	Rep 3	Mean
Mission M2624	2.33	3.00	1.33	2.22
Sonora M2624	2.00	2.33	2.00	2.11
Avalon M2624	2.33	2.66	1.66	2.22
Plateau M2624	2.00	2.00	1.00	1.67
13-I M2624	2.00	2.33	2.33	2.22
Nonpareil/F M2624	3.00	3.00	2.66	2.88
Mission DP	2.33	2.00 *	2.33	2.22 *
Nonpareil/F DP	1.00 *	0.00 **	0.00 **	0.33 *
Nonpareil/B DP	2.00	2.33	1.00	1.77
Nonpareil/Padre M2624	2.00	2.66	2.00	2.22
Butte Hiawatha	3.00	2.66	3.00	2.88
Nonpareil/F Hiawatha	2.66	3.00	3.00	2.88

1 = small inferior tree
2 = moderate growth, healthy
3 = vigorous, healthy

* Indicates dead tree in plot
** All trees dead in plot

Table 2

Alternative Rootstocks
Growth Ratings

	Rep 1	Rep 2	Rep 3	Mean
Non- GF 677	3.00	3.00	3.00	3.00
Non- Hansens 536	2.33	2.66	0.66 *	1.88 *
Non- Lovell	3.00	2.33	3.00	2.77
Butte- GF 677	3.00	3.00	3.00	3.00
Butte -Hansens 536	3.00	2.66	2.33	2.66
Butte- Lovell	2.33	2.66	2.66	2.55
Kochi- Lovell	2.33	3.00	2.66	2.66
Durango- Lovell	2.66	2.66	3.00	2.77

1 = weak
2 = fair
3 = good

* Indicates dead tree in plot

Ratings conducted after bloom 2001 showed that Plateau was showing increased stunting on M2624 and 2 trees out of 9 had died since ratings were made last summer. Nonpareil double grafted onto Padre as an interstem on top of M2624 continues to do well, but initial vigor this spring (2001) appears less than other compatible M2624 combinations.