Variety Trials

Performance of New Marianna Rootstocks in California for 'French' Prune

Stephen M. Southwick,¹

James T. Yeager,¹

Joseph Osgood,²

William Olson,³

Maxwell Norton,⁴ and

Richard Buchner²

ADDITIONAL INDEX WORDS. *Prunus cerasifera* x *P. munsoniana*, myrobalan, *Prunus cerasifera*, plum, prune, *Prunus domestica*, peach, *Prunus persica*

SUMMARY. Ten new marianna rootstocks [*Prunus cerasifera* Ehrh. x *P. munsoniana* Wight & Hedr. (?)] derived from open pollination of 'Marianna 2616' (M series) were planted in 1987 and evaluated at four commercial orchard locations in California (Tehama, Butte, Sutter, and

Merced counties) with 'Improved French' prune (*P. domestica* L.) as the scion. These rootstocks were compared to three standard rootstocks: 'Marianna 2624', myrobalan seedling (*P. cerasifera* Ehrh.) and 'Myrobalan 29C'. Leaf potassium (K) and nitrogen (N), tree growth, fruit production and fruit quality were measured. Selection M40 in particular had high leaf N, high leaf K (equal to 'Marianna 2624' and better than the myrobalan standards), higher yield efficiency per tree, fruit size, drying characteristics, and few root suckers when compared to the three standard rootstocks. M40 is being considered for patent and release by the Pomology Department at the University of California, Davis. Selection M58 had the highest yield efficiency of any tested rootstock. Several selections had characteristics that would make expanded planting worth considering.

French prune is produced primarily on four rootstocks in California. Myrobalan seedling (MyS), 'Myrobalan 29C' (My29C; *Prunus cerasifera*; propagated by hardwood cuttings) and 'Marianna 2624' (M2624; *P. cerasifera* x *P. munsoniana*; hardwood cuttings) are the common plum rootstocks, while peach seedling (*P. persica* L., 'Lovell' and 'Nemaguard') is used less frequently. Rootstocks are chosen, at least in part, based on their disease or pest resistance/susceptibility; which is often partially affected by the site. Characteristics of commonly used rootstocks are summarized in Tables 1 and 2, which include soil preferences as well as disease susceptibilities. Prune is commonly grown on flood-irrigated, fine-textured, poorly drained soils and often on bacterial canker (*Pseudomonas* sp.) replant sites. On these same soils K deficiency in prune trees is commonly encountered. Fine textured soils render K less available to tree roots because it is chemically and physically bound to the clay particles (Lilleland, 1946; Carlson, 1981; Carlson and Uriu 1981; Rosen and Carlson, 1984a). Consequently, even though K levels are high in the soil, K deficiency can be found in prune trees (Rosen and Carlson, 1984a) and is especially problematic with high crop loads. Rootstock can influence the uptake of K (Rosen and Carlson, 1984b). Potassium deficiency results in smaller prunes, lower yields, leaf scorch, twig death and dieback that may lead to disease problems.

The production of shoots from roots below the soil surface (commonly known as root suckers) are most numerous with the plum rootstock M2624 (Olson et al., 1991), less so with My29C and fewest with MyS. The number of root suckers is variable depending upon soil type, planting depth, and cover crop management. Because root and trunk root suckers grow into large trees when uncontrolled, mechanical sucker control contributes to management costs. Genotypes less prone to suckering would reduce costs.

While M2624 is a good rootstock, its tendency toward suckering limits its acceptability. M2624 is generally more shallow-rooted than MyS and may not be as well anchored because it is propagated by hardwood cuttings. A marianna rootstock that produced fewer suckers and was better adapted to finely textured soils that bind K would be advantageous for prune growers in California. We have evaluated the horticultural characteristics of 10 new selections of 'Marianna 2616' (M series) together with standard rootstocks M2624, MyS and My29C in replicated trials located in Tehama, Sutter, Butte and Merced counties, representing the majority of Sacramento Valley soils where prunes are grown. Several of these M series rootstocks were selected because of the possible improvement in K uptake associated with the rootstocks when compared to standards.

Materials and methods

EXPERIMENTAL SITES AND DESIGN. Cuttings of 10 new marianna rootstock selections derived from open pollination of M series, plus standards of M2624, MyS and My29C were grown at a commercial California nursery. The scion was 'Improved French' prune. Indexing for viruses by standard techniques indicated that the trees were free from commonly found viruses; the new M series selections were preserved by Foundation Plant Materials Service, Davis, Calif. All M series were easily propagated by hardwood cuttings with rooting percentages from 75% to 95%, and these percentages were consistent with controls. Trees were planted in March 1987 at four locations in California (Tehama, Butte, Sutter, and Merced counties) and grown under commercial conditions. At each location a randomized complete block design with single tree replications was used. At Tehama there were 30 single-tree replications of

Partial financial support was provided by the California Prune Board. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

¹Department of Pomology, University of California, One Shields Avenue, Davis, Calif. 95616.

²University of California Cooperative Extension, Tehama County, Red Bluff, Calif. 96080.

³University of California Cooperative Extension, Butte County, Oroville, Calif. 95965.

⁴University of California Cooperative Extension, Merced County, Merced, Calif. 95340.

each rootstock selection; at each of the other sites there were five single-tree replications of each selection used. In these experiments, all trees were pruned similarly, but not identically. Only data on root suckers was taken from the Merced site. Of the sites chosen, the Tehama County site was selected to evaluate horticultural performance. The other sites had clay soils and thus had a greater likelihood of developing K deficiency.

TEHAMA COUNTY. Trees were planted at 5.5 m (18 ft) between trees and 6.1 m (20 ft) between rows in a deep alluvial Vina loam soil. The selections planted included all rootstocks tested: M2624, M9, M16, M30, M38, M40, M58, M64, M65, M69, M75, MyS, and My29C.

SUTTER COUNTY. Trees were planted 4.9 m (16 ft) between trees and 5.5 m (18 ft) between rows in a Honcut loam soil. Selections included: M2624, M9, M16, M30, M40, M65, M69, M75, MyS and My29C.

BUTTE COUNTY. Trees were planted at 5.5 m (18 ft) between trees and 5.5 m (18 ft) between rows in a Gridley loam soil. Selections included: M2624, M9, M30, M40, M65, M69, M75.

MERCED COUNTY. Trees were planted 5.5 m (18 ft) between trees and 6.1 m

(20 ft) between rows in a Yokohl clay loam soil. Selections included: M2624, M9, M16, M30, M40, M65, M69, and M75.

LEAF NUTRIENT ANALYSES—ALL SITES. A random sample of ≈30 well-exposed mature spur leaves was taken from each tree from at least 1 m (≥36 inches) above the soil surface in late June to July of 1991 through 1993. Nitrogen and K analyses were performed by DANR Analytical Laboratory (University of California, Davis, Calif.). Leaves were washed in dilute detergent solution, dried completely, and ground prior to analyses. The Modified Dumas total N combustion method was used to determine leaf N (Sweeny, 1989). Potassium was quantified by atomic emission spectrometry or by atomic absorption spectrometry (Franson, 1985). Leaf N and K were expressed as % leaf dry weight.

HARVEST MEASUREMENTS AND VEGETATIVE GROWTH—TEHAMA COUNTY SITE. Measurements of tree growth were made annually by comparing the previous year's trunk cross-sectional area (TCSA) with that of the current year after trees had gone dormant. Yield per tree was measured by an electronic weighing load cell attached to the side of the

harvesting equipment. A random sample of 1.4 to 1.8 kg (3 to 4 lb) from each tree was commercially dried after weighing and fresh fruit mass was divided by the dry mass to obtain the fruit hydration ratio (FHR or drying ratio), which was then used to calculate dry yield per tree. Fruit size was evaluated for each tree sample by weighing out a pound of fruit, then counting the number of fruit in the sample. Dry fruit was passed over a 1.8 cm (23/32-inch) screen to remove the undersized fruit, which was weighed and used to calculate the percentage of undersized fruit, according to industry standards (no undersized fruit were sampled in 1991). Yield efficiency was calculated by dividing the dry yield by the TCSA, measured in January.

ROOT SUCKERS, DISEASE SUSCEPTIBILITY—RESISTANCE, AND TREE LOSS DUE TO BACTERIAL CANKER. Root suckers were counted on each replicate tree on an annual basis, at the end of the growing season. M series rootstocks (experimental selections) were evaluated for resistance to crown rot (*Phytophthora* sp.) by stem inoculation with *Phytophthora cambivora* (Petri) Buisman (Mircetich et al., 1990) and measurement of the length of the canker, if one developed.

Table 1. Selected characteristics of commonly used rootstocks for 'French' prune, and other prune-type plums.^z

				Resistance or susceptibility	
Rootstock	Soil type preference	Compatibility	Anchorage and suckering	Pocket gophers or meadow voles ^y	Peachtree borer <i>Sanninoidea exitiosa</i> (Say)
Plum					
Myrobalan seedlings (<i>P. cerasifera</i> Ehrh.)	Widely adapted to different soil types and moisture conditions. Will not tolerate extremely heavy soils	Good for most cultivars	Anchorage good, few crown suckers	Susceptible	Susceptible
Myrobalan 29C cuttings	Widely adapted to different soil types and moisture conditions	Good for most cultivars	Roots may be shallow the first 3 or 4 years; some crown suckers and occasional root suckers	Susceptible	Susceptible
Marianna 2624 cuttings [<i>P. cerasifera</i> Ehrh. x <i>P. munsoniana</i> Wight & Hedr. (?)]	Widely adapted to different soil types and moisture conditions	Good for most cultivars	Roots may be shallow the first 3 or 4 years; few to many root and crown suckers	Susceptible	Susceptible
Peach (<i>P. persica</i> L.)					
Lovell seedlings	Well-drained, sandy loam soils best; sensitive to wet soil conditions	Good for most cultivars	Good anchorage, low suckering	Moderately resistant	Highly susceptible
Nemaguard seedlings	Well-drained, sandy loam soils best; sensitive to wet soil conditions	Probably same as 'Lovell'	Good anchorage, low suckering	Moderately resistant	Highly susceptible

^zCatlin and Holmberg, 1981; Okie et al., 1987; Renaud et al., 1990; Ogawa and English, 1991; Olson et al., 1991; Osgood et al., 1991.

^y*Microtus californicus* Peale; *Thomomys bottae* Eyndoux and Gervais, respectively (Jameson and Peeters, 1988).

Trees were examined annually in May to June for obvious symptoms of bacterial canker, with deaths due to bacterial canker recorded.

STATISTICAL ANALYSES. Analyses of variance and mean separation by Duncan's multiple range test were conducted by using Statistical Analyses System's GLM procedure (SAS Institute, Cary, N.C.). The experimental design was a randomized complete block and in the analyses for %N and %K the design was nested; the error term for all Mean Square III tests was tree (rootstock $\times$ block). We used the following model to analyze for the variables %N and %K with repeated measures for each variable: $y_{ijkl} = \text{rootstock}_i + \text{block}_j + \text{tree}_{k(ij)} + (\text{rootstock} \times \text{block}) + \text{year}_1 + \text{year}_1 \times \text{rootstock}_j + \text{year}_1 \times \text{block}_j + \varepsilon_{ijkl}$, where y is either %N or %K (Winer, 1962).

Results and discussion

LEAF POTASSIUM. Leaf K was statistically similar in selections MyS, M2624, M16, M30, M58, M64, M69 and M75 in 1991, Tehama County (Table 3). The highest leaf K in 1992 was found in selection M30, and was higher than all standards but was not statistically differ-

ent from M58, M64 or M69. Again, selection M30 had high leaf K in 1993, but not statistically different from selection M2624. The 3-year average leaf K values suggest that selections M30 and M58 had highest leaf K concentrations. MyS and My29C had relatively low values. Adequate levels of leaf K based upon current University of California recommendations are 1.3% or above, on a dry mass basis (Carlson and Uriu, 1981; Uriu, 1981). Leaf K at the Tehama County site were well above that adequate concentration. There was a year $\times$ rootstock interaction for leaf K indicating that leaf K for the various rootstocks may change as a function of the year and the conditions associated with that season. Crop load, irrigation, rainfall and fertilizer distribution may have contributed to that significant interaction.

At the Sutter County site there were no differences in leaf K in 1991 (Table 4). However, by 1992 selection M30 was higher in leaf K than all but M9, M65, M69 and M2624. By 1993, M2624 was higher in leaf K than all rootstock selections except M30. The 3-year average for leaf K at the Sutter location indicated that both M30 and

M2624 had highest leaf K. The myrobalan selections had intermediate leaf K concentrations than the other M series selections.

At the Butte County site leaf K was highest in M30 in 1991 (Table 5). In 1992 no differences in leaf K were found among rootstock selections and by 1993 M30 was again highest in leaf K. The 3-year average indicated that M30 had the highest leaf K. At the Butte County site there was a year $\times$ rootstock interaction with regard to leaf K concentration like that found at the Tehama County location.

No site had very low concentrations of leaf K based upon University of California recommendations. Evaluations would either have to continue for many years or a site where low soil exchangeable K (normally high in clay) should be selected to help determine the utility of these rootstock selections with regard to their ability for improved uptake of K as measured by higher leaf K concentrations. It appears that M30 had consistently high leaf K across the three evaluation sites, and when considering the 3-year averages, leaf K in M30 was as good as that found in M2624 (Sutter County) or

Table 2. Disease resistance or susceptibility of commonly used rootstocks for 'French' prune, and other prune-type plums.^z

Rootstock	Disease resistance or susceptibility					Nematode resistance	
	Bacterial canker: <i>Pseudomonas syringae</i> van Hall	Crown rot <i>Phytophthora</i> sp.	Crown gall <i>Agrobacterium tumefaciens</i> (Smith and Townsend) Conn	Brown line (tomato ringspot virus)	Oak root fungus <i>Armillaria mellea</i> (Valh:Fr.) Kummer	Lesion <i>Pratylenchus vulnus</i> Allen & Jensen	Ring <i>Criconebella xenoplax</i> Raski
Plum							
Myrobalan seedlings (<i>P. cerasifera</i> Ehrh.)	Seedlings variable, generally susceptible	Moderately resistant	Seedlings variable, generally less susceptible than peach	Susceptible	Susceptible	Susceptible	Susceptible
Myrobalan 29C cuttings	Susceptible, less than 'Marianna 2624'	Moderately resistant	More resistant than seedling myrobalan	Susceptible	A little more resistant than seedling myrobalan, but less than 'Marianna 2624'	Susceptible	Susceptible
Marianna 2624 cuttings [<i>P. cerasifera</i> Ehrh. $\times$ <i>P. munsoniana</i> Wight & Hdr. (?)]	Highly susceptible	Moderately resistant	More resistant than seedling myrobalan	Resistant	Moderately resistant	Susceptible	Susceptible
Peach (<i>P. persica</i> L.)							
Lovell seedlings	Seedlings variable, generally less susceptible than plum	Susceptible	Seedlings variable, generally susceptible	Susceptible	Susceptible	Susceptible	Moderately susceptible
Nemaguard seedlings	Same as 'Lovell'	Susceptible	More than 'Lovell'	Susceptible	Susceptible	Susceptible	Moderately susceptible

^zCatlin and Holmberg, 1981; Okie et al., 1987; Renaud et al., 1990; Ogawa and English, 1991; Olson et al., 1991; Osgood et al., 1991.

better (Tehama and Butte Counties).
LEAF NITROGEN. Leaf N concentra-
tion was numerically highest in M40 in

Tehama County in 1991, but M2624,
M16, M58, M69, and M75 were statis-
tically equivalent (Table 3). MyS and

My29C selections ranked lowest. In
both 1992 and 1993 M40 had the
highest leaf N compared to all other

Table 3. Effect of rootstock on leaf N and K (% dry matter – late June to July samples) in Tehama County, Calif. 1991–93.

Rootstock ^z	1991		1992		1993		3-Year avg	
	N (%)	K (%)	N (%)	K (%)	N (%)	K (%)	N (%)	K (%)
MyS	2.22 e ^y	3.66 a	2.51 bcd	2.59 cd	2.53 bcd	3.12 ef	2.4 cde	2.92 e
My29C	2.17 e	2.84 bc	2.44 d	2.48 def	2.44 cd	3.29 cde	2.2 f	2.66 f
M2624	2.40 abc	3.10 abc	2.55 bcd	2.59 cd	2.51 bcd	3.87 a	2.4 bcd	3.11 cd
M9	2.31 d	2.94 abc	2.47 cd	2.89 abc	2.43 d	3.50 bc	2.3 e	2.95 de
M16	2.39 a–d	2.77 bc	2.60b	2.22f	2.47 cd	3.01 e	2.4 bc	2.64 f
M30	2.33 cd	3.50 ab	2.59 bc	3.14 a	2.56 b	3.92 a	2.43 bcd	3.43 a
M40	2.44 a	2.68 c	2.72 a	2.25 ef	2.72 a	3.21 def	2.53 a	2.63 f
M58	2.37 a–d	3.56 ab	2.60 b	2.92 abc	2.46 bcd	3.41 bcd	2.47 b	3.32 ab
M64	2.35 bcd	3.30 abc	2.61 ab	2.93 ab	2.53 bcd	3.44 bcd	2.47 b	3.24 bc
M65	2.33 cd	2.83 bc	2.47 cd	2.54 de	2.56 bc	3.23 cde	2.38 de	2.76 f
M69	2.38 a–d	3.18 abc	2.56 bc	2.91 abc	2.55 bcd	3.41 bcd	2.44 bc	3.04 de
M75	2.41 ab	3.31 abc	2.52 bcd	2.73 bcd	2.47 bcd	3.55 b	2.43 bcd	3.05 de
Type III mean square								
Source ^x			df			N(%)	K(%)	
Rootstock			11			0.2***	2.4***	
Block			29			0.2***	1.8***	
Tree (rootstock × block) ^y			304			0.02	0.1	
Year			2			1.3***	8.3***	
Year × block			42			0.1***	0.3	
Year × rootstock			22			0.03	0.4**	

^zStandard industry rootstocks included MyS (myrobalan seedling), My29C ('Myrobalan 29C'), M2624 ('Marianna 2624'); 10 new selections of 'Marianna 2616' (M series) include M9, M16, M30, M38, M40, M58, M64, M65, M69, and M75.

^yMeans within each column with the same letter are not significantly different using Duncan's multiple range test, $P = 0.05$.

^x $y_{ijkl} = \text{rootstock}_i + \text{block}_j + \text{tree}_{k(j)} + \text{year}_l + \text{year}_l \times \text{rootstock}_i + \text{year}_l \times \text{block}_j + \varepsilon_{ijkl}$, where y is either %N or %K.

^yError term for tests of hypothesis using Type III mean square for rootstock. The error term for all year terms is the residual sum of squares.

***Significant at $P = 0.01$ or 0.001 , respectively.

Table 4. Effect of rootstock on leaf N and K (% dry matter – late June 1993) in Sutter County, Calif. 1991–93.

Rootstock ^z	1991		1992		1993		3-Year avg	
	N (%)	K (%)	N (%)	K (%)	N (%)	K (%)	N (%)	K (%)
MyS	2.32 c ^y	2.23 a	2.41 cd	2.11 bc	2.18 a	1.89 de	2.29 bc	2.11 cd
My29C	2.45 abc	2.29 a	2.56 abc	2.16 bc	2.10 a	2.11 a–d	2.37 ab	2.19 bc
M2624	2.35 bc	2.24 a	2.40 d	2.59 a	2.05 a	2.54 a	2.27 c	2.47 a
M9	2.43 abc	1.89 a	2.54 a–d	2.23 abc	2.01 a	2.04 bcd	2.32 bc	2.05 cde
M16	2.44 abc	1.98 a	2.45 cd	2.10 bc	2.05 a	1.96 cde	2.33 bc	2.01 def
M30	2.44 abc	2.28 a	2.62 abc	2.60 a	2.05 a	2.45 ab	2.37 ab	2.44 a
M40	2.49 ab	1.89 a	2.64 a	1.97 c	2.15 a	1.88 de	2.44 a	1.91 ef
M65	2.43 abc	2.15 a	2.48 bcd	2.35 abc	2.05 a	2.00 cd	2.32 bc	2.05cde
M69	2.41 abc	2.08 a	2.45 cd	2.41 ab	2.09 a	2.37 abc	2.32 bc	2.29 b
M75	2.51 a	1.92 a	2.65 a	2.17 bc	2.12 a	1.54 e	2.44 a	1.88 f
Type III mean square								
Source ^x			df			N(%)	K(%)	
Rootstock			9			0.1**	0.1***	
Block			4			0.03	0.1	
Tree (rootstock × block) ^y			32			0.01	0.2	
Year			2			1.8***	0.5***	
Year × block			8			0.04***	0.1	
Year × rootstock			18			0.01	0.1	

^zStandard industry rootstocks included MyS (myrobalan seedling), My29C ('Myrobalan 29C'), M2624 ('Marianna 2624'); seven new selections of 'Marianna 2616' (M series) include M9, M16, M30, M40, M65, M69, and M75.

^yMeans within each column with the same letter are not significantly different using Duncan's multiple range test, $P = 0.05$.

^x $y_{ijkl} = \text{rootstock}_i + \text{block}_j + \text{tree}_{k(j)} + \text{year}_l + \text{year}_l \times \text{rootstock}_i + \text{year}_l \times \text{block}_j + \varepsilon_{ijkl}$, where y is either %N or %K.

^yError term for tests of hypothesis using Type III mean square for rootstock. The error term for all year terms is the residual sum of squares.

***Significant at $P = 0.01$ or 0.001 , respectively.

selections. The myrobalan selections ranked near the lower end of leaf N concentrations among those tested. The 3-year average indicated that selection M40 had highest leaf N concentrations and My29C the lowest. It is noteworthy that My29C had such low leaf N since it is a widely used rootstock in the California prune industry. The critical value for leaf N as recommended by the University of California for 'French' prune is 2.3% (on a dry matter basis; Uriu, 1981).

It has recently been shown that low N (below 2.3% midsummer) in young 'French' prune orchards can lead to a higher incidence of bacterial canker (Southwick et al., 1997). My29C is highly susceptible to bacterial canker (Catlin and Holmberg, 1981). The low concentrations of N found in 'French' prune leaves and the relationship between low N and bacterial canker suggest that growers should monitor the N status of prunes growing on My29C carefully,

especially in young trees, to minimize the risk of incurring bacterial canker.

At the Sutter County site M75 had numerically higher leaf N in 1991 than many other selections but was only statistically higher in leaf N than MyS and M2624 (Table 4). In 1992, selections M40 and 2624 had statistically higher leaf N than all other rootstock selections except My29C, M9, and M30. No differences in leaf N among rootstocks were observed in 1993, where leaf N

Table 5. Effect of rootstock on leaf N and K (% dry matter – late June 1993) in Butte County, Calif. 1991–93.

Rootstock ^z	1991		1992		1993		3-Year avg	
	N (%)	K (%)	N (%)	K (%)	N (%)	K (%)	N (%)	K (%)
M2624	2.65 b ^y	2.73 bc	2.62 bc	2.77 a	2.31 a	2.92 a	2.53 c	2.82 b
M9	2.48 c	2.45 c	2.59 c	2.59 a	2.16 b	2.41 b	2.41 d	2.48 d
M30	2.74 ab	3.24 a	2.76 a	3.10 a	2.34 a	2.92 a	2.61 ab	3.09 a
M40	2.77 ab	2.50 c	2.72 ab	2.77 a	2.40 a	2.41 b	2.63 a	2.56 cd
M65	2.74 ab	2.80 bc	2.63 abc	2.76 a	2.30 ab	2.32 bc	2.55 bc	2.63 bcd
M69	2.76 ab	2.87 b	2.62 bc	2.90 a	2.36 a	2.01 c	2.59 abc	2.59 cd
M75	2.83 a	2.89 b	2.73 ab	2.82 a	2.39 a	2.48 b	2.65 a	2.73 bc
Type III mean square								
Source ^x	df		N(%)		K(%)			
Rootstock	6		0.1***		0.6***			
Block	4		0.2		2.1***			
Tree (rootstock × block) ^y	24		0.01		0.1			
Year	2		1.5***		1.0***			
Year × block	8		0.02*		0.1			
Year × rootstock	12		0.01		0.2*			

^zStandard industry rootstocks included MyS (myrobalan seedling), My29C ('Myrobalan 29C'), M2624 ('Marianna 2624'); six new selections of 'Marianna 2616' (M series) include M9, M30, M40, M65, M69, and M75.

^yMeans within each column with the same letter are not significantly different using Duncan's multiple range test, $P = 0.05$.

^x $y_{ijkl} = \text{rootstock}_i + \text{block}_j + \text{tree}_{k(ij)} + \text{year}_l + \text{year}_l \times \text{rootstock}_i + \text{year}_l \times \text{block}_j + \epsilon_{ijkl}$, where y is either %N or %K.

^yError term for tests of hypothesis using Type III mean square for rootstock. The error term for all year terms is the residual sum of squares.

*,***Significant at $P = 0.01$ or 0.001 , respectively.

Table 6. Effect of rootstock on trunk cross-sectional area (TCSA.), dry yield, and yield efficiency (YE) in Tehama County, Calif. 1991–93.

Rootstock ^z	1991			1992			1993			3-Year average		
	TCSA (cm ²) ^y	Dry yield (kg) ^x	YE (kg·cm ⁻²) ^w	TCSA (cm ²)	Dry yield (kg)	YE (kg·cm ⁻²)	TCSA (cm ²)	Dry yield (kg)	YE (kg·cm ⁻²)	TCSA (cm ²)	Dry yield (kg)	YE (kg·cm ⁻²)
MyS	105 de ^v	13.7 d	0.13 de	143 cde	10.5 cde	0.07 b	163 bcd	26.3 d	0.16 b	139 g	15.3 e	0.11 d
My29C	106 de	15.0 d	0.14 de	151 bcd	9.6 d	0.06 b	172 bc	30.9 bcd	0.18 ab	143 f	16.6 de	0.12 c
M2624	120 bc	20.2 c	0.17 cd	161 b	11.5 bcd	0.07 b	181 b	34.8 b	0.19 ab	155 bc	20.1 c	0.13 bc
M9	98 e	15.8 d	0.16 cde	132 e	12.2 a–d	0.09 b	148 d	30.7 bcd	0.21 a	126 i	17.9 d	0.14 b
M16	112 cd	16.4 d	0.15 de	154 bcd	11.5 bcd	0.08 b	171 bc	29.1 bcd	0.17 ab	145 ef	17.6 d	0.12 c
M30	138 a	28.8 a	0.21 b	192 a	13.6 abc	0.07 b	215 a	41.9 a	0.19 ab	180 a	25.9 a	0.14 b
M40	114 bcd	21.9 bc	0.19 bc	153 bcd	14.6 ab	0.10 b	172 bc	33.1 bc	0.19 ab	146 e	21.7 bc	0.15 b
M58	85 f	24.5 b	0.28 a	99 f	13.7 ab	0.14 a	115 e	25.6 d	0.22 a	115 j	21.5 bc	0.19 a
M64	123 b	23.0 bc	0.19 bc	158 bc	15.1 a	0.10 b	177 b	34.5 b	0.19 ab	158 b	22.9 b	0.14 b
M65	117 bc	16.0 d	0.14 de	158 bc	12.1 a–d	0.08 b	180 b	32.8 bc	0.18 ab	152 bc	18.2 d	0.12 c
M69	119 bc	15.5 d	0.13 e	165 b	13.1 abc	0.08 b	182 b	29.8 bcd	0.16 b	155 c	17.7 d	0.11 d
M75	104 de	20.7 c	0.20 bc	140 de	15.2 a	0.11 b	156 cd	28.3 cd	0.18 ab	133 h	20.2 c	0.15 b

^zStandard industry rootstocks included MyS (myrobalan seedling), My29C ('Myrobalan 29C'), M2624 ('Marianna 2624'); seven new selections of 'Marianna 2616' (M series) include M9, M16, M30, M40, M58, M64, M65, M69, and M75.

^yTCSA measured in the dormant season after the current year's growth; 1 cm² = 0.155 inch².

^x1 kg = 2.2 lb.

^w1 kg·cm⁻² = 14.2 lb/inch².

^yMeans within each column with the same letter are not significantly different using Duncan's multiple range test, $P = 0.05$.

concentrations fell below the critical value of 2.3% N. The 3-year average showed that leaf N was numerically highest in selections M40 and M75, but not statistically higher than My29C or M30. M2624 had some of the lowest leaf N concentrations.

In Butte County in 1991, leaf N was lowest in M9, and numerically highest in M75, although not statistically different from M30, M40, M65, or M69 (Table 5). M2624 was intermediate in leaf N. In 1992 and 1993, differences among selections were similar, and the 3-year average at this site showed that M9 consistently had the lowest leaf N, followed by M2624 and M65, and that M30, M40, M69, and M75 maintained higher levels of N. None was below critical level.

TREE GROWTH (TRUNK CROSS-SECTIONAL AREA). Variation in trunk cross-sectional area (TCSA) was noticeable

in 1991 and subsequent years in Tehama County (Tables 6 and 7). Selection M30 was most vigorous and the myrobalan types and M58 were among the least vigorous. Many of the other rootstocks in the M series were intermediate in vigor compared with M30, MyS and My29C. The 3-year average indicated that selection vigor was as follows: M30 > M2624 > My29C > MyS > M58.

DRY YIELD AND YIELD EFFICIENCY. In Tehama County in the first year of fruiting (1991; Table 6), M2624, M30, M40, M58, M64, and M75 had higher dry yields than MyS, My29C, M9, M16, M65 or M69. In 1992 yields, the order of highest yielding was: M30, M40, M58, M64, M75 > M9, M16, M65, M69 > MyS, My29C, M2624. The highest dry yield per tree was measured on M30 in 1993. MyS again was among the lowest yielding and

statistically similar with My29C, M9, M16, M58, M69 and M75. M2624 had improved dry yield in 1993. The 3-year average indicated that M30 had the highest dry yield per tree, and only M30 and M64 yielded more on average than M2624. The myrobalan rootstocks were among the lowest yielding over the 3-year period.

Yield efficiency was highest with M58 in 1991 (Table 6). No other M series rootstock had a higher yield efficiency in the first bearing season than M2624. Again, in 1992 M58 had the highest numerical yield efficiency, but statistically equal to M9, M40, M64 and M75. MyS and My29C had some of the lowest yield efficiencies during the first two fruiting seasons. In 1993, M9 had a higher yield efficiency than MyS and M69, otherwise there were no other statistical differences among rootstocks. This would indi-

Table 7. Effect of rootstock on trunk cross-sectional area (TCSA), dry yield and yield efficiency (YE) in Tehama County, Calif. 1991–93; analysis of variance.

Source ^z	df	Type III mean square		
		TCSA (cm ²) ^y	Dry yield (kg) ^x	YE (kg·cm ⁻²) ^w
Rootstock	11	22763.9***	550.8***	0.022***
Block	29	667.0***	783.4***	0.041***
Tree (rootstock × block) ^u	306	423.9***	48.6***	0.003**
Year	2	314540.1***	17056.4***	0.732***
Year × block	5	216.6***	269.1***	0.021***
Year × rootstock	22	387.8***	154.5***	0.011***

^z $y_{ijkl} = \text{rootstock}_i + \text{block}_k + \text{tree}_{k(j)} + (\text{rootstock} \times \text{block}) + \text{year}_l + \text{year}_l \times \text{rootstock}_i + \text{year}_l \times \text{block}_k + e_{ijkl}$, where y is either %N or %K.

^yTCSA measured in the dormant season after the current year's growth; 1 cm² = 0.155 inch².

^x1 kg = 2.2 lb

^w1 kg·cm⁻² = 14.2 lb/inch².

^uError term for tests of hypothesis using Type III mean square for Rootstock. The error term for all Year terms is the residual sum of squares.

***Significant at $P = 0.01$ or 0.001 , respectively.

Table 8. Effect of rootstock on fruit size, undersized fruit and fruit hydration ratio (FHR), of 'French' prune in Tehama, Calif. 1991–93.

Rootstock ^z	1991 (no undersized)		1992			1993			3-Year average		
	No. fruit/kg ^y	FHR	No. fruit/kg	% Undersize	FHR	No. fruit/kg	% Undersize	FHR	No. fruit/kg	% Undersize	FHR
MyS	112.5 a ^x	1.86 a–d	108.9 ab	0.16 ab	2.60 cd	141.9 cd	1.9 d	3.04 b	118.1 abc	0.80 d	2.42 e
My29C	107.8 abc	1.89 abc	102.2 bcd	0.14 b	2.58 cd	142.4 cd	2.6 cd	3.08 ab	113.6 c	0.80 d	2.43 de
M2624	104.5 bc	1.86 a–d	95.6 d	0.17 ab	2.57 cd	136.3 d	4.6 cd	3.05 b	108.4 d	1.76 cd	2.42 e
M9	112.7 a	1.93 a	104.6 a–d	0.29 ab	2.62 bcd	160.6 ab	4.7 cd	3.16 ab	120.6 a	1.75 cd	2.48 cd
M16	111.3 ab	1.79 d	107.9 abc	0.28 ab	2.57 cd	148.3 a–d	4.3 cd	3.11 ab	119.0 ab	1.56 cd	2.41 e
M30	104.0 c	1.85 a–d	100.1 cd	0.16 ab	2.43 e	157.2 abc	11.4 a	3.19 a	114.8 bc	3.90 a	2.38 e
M40	108.3 abc	1.89 a–d	101.0 bcd	0.32 ab	2.54 d	162.7 a	8.0 b	3.12 ab	118.0 abc	3.10 ab	2.43 e
M58	112.6 a	1.80 cd	103.4 a–d	0.27 ab	2.74 a	149.6 a–d	4.7 cd	3.20 a	120.4 a	2.08 bc	2.57 a
M64	109.7 abc	1.91 ab	107.8 abc	0.09 b	2.69 abc	154.2 abc	4.3 cd	3.15 ab	120.0 a	1.62 cd	2.51 bc
M65	107.4 abc	1.82 bcd	103.0 a–d	0.49 a	2.59 cd	143.8 bcd	5.4 c	3.08 ab	114.0 c	2.08 bc	2.40 e
M69	112.4 a	1.86 a–d	110.0 ab	0.38 ab	2.58 cd	149.5 a–d	5.0 c	3.04 b	120.0 a	2.11 bc	2.41 e
M75	109.3 abc	1.94 a	111.7 a	0.27 ab	2.71 ab	150.7 a–d	3.7 cd	3.19 a	120.0 a	1.48 cd	2.53 ab

^zStandard industry rootstocks included MyS (myrobalan seedling), My29C ('Myrobalan 29C'), M2624 ('Marianna 2624'); nine new selections of 'Marianna 2616' (M series) include M9, M16, M30, M40, M58, M64, M65, M69, and M75.

^y1 fruit/kg = 0.454 fruit/lb.

^xMeans within each column with the same letter are not significantly different using Duncan's multiple range test, $P = 0.05$.

cate that the greatest differences in yield efficiency occurred early in the fruiting life of trees and with age differences became less apparent. Only M40, M64 and M75 had higher yield efficiencies than M2624. Overall, MyS had one of the lowest yield efficiencies. Most of the other M series rootstock selections had similar yield efficiencies.

INTERACTIONS. Year $\times$ rootstock interaction was significant, reflecting seasonal growth differences. As with leaf K, tree vigor may change as a function of the year and the conditions associated with that season, with impact due to crop load, irrigation, rainfall, temperature, pest pressure and fertilizer distribution. Year $\times$ rootstock interaction for yield was again significant, reflecting seasonal differences in the different rootstocks.

FRUIT SIZE AND FRUIT HYDRATION RATIO IN TEHAMA COUNTY. Fruit size is inversely related to the number of dried

fruit in a kg sample. In at least 2 out of 3 years (Table 8), large fruit were found in M2624, My29C, M30, M40, M65, M75 and small fruit were found in MyS, M9, M16, M64, and M69. By the third year of fruiting, all standard rootstocks and the following M series had caught up with the leaders in fruit size: M16, M58, M69, M75. Three-year average fruit size was larger on M2624 than other tested rootstocks and My29C had larger fruit size than most M series. In general, with the M series selections, as the dry yields per tree went up the fruit size decreased.

The percentage of dried fruit that passed a 1.8-cm (23/32-inch) sized screen (undersize) was not measured in 1991 and was relatively low in 1992 with My29C and M64 having less undersized fruit than M65 (Table 8). Otherwise, no clear trends favoring one rootstock over another were apparent with regard to undersize in

1992. The average of two seasons indicated that M30 and M40 had a higher percentage of undersized fruit than the standards and many of the other M series selections. Fruit size is a critical issue for prune growers in California. In fact, the fruit size deemed to be undersize has increased to a 1.9-cm (24/32-inch) screen size since 1996.

Fruit hydration ratio (FHR) was exceedingly low (favorable) in 1991 and M16 had one of the lowest while M9 had one of the highest FHRs (Table 8). In 1992, selection M30 had the lowest FHR, while in 1993, it was among the highest. Selection M58 had a high FHR in 1992, and was among the highest in 1993. The standard myrobalan or M2624 rootstocks had as good as or better FHRs than the M series rootstocks. The 3-year average indicated that M58 had the highest FHR (poorest) followed by M75, then by M64, and M9. The other

Table 9. Effect of rootstock on fruit size, undersized fruit and fruit hydration ratio (FHR) of 'French' prune in Tehama, Calif., 1991–93; analysis of variance.

Source ^z	df	Type III mean square		
		No. fruit/kg ^y	% Undersize	FHR
Rootstock	11	987.3*	45.9***	0.2**
Block	29	1131.0***	7.5***	2.2***
Tree (rootstock $\times$ block) ^x	306	363.1***	3.4	0.05***
Year	2	121696.1***	1968.5***	104.4***
Year $\times$ block	46	363.0***	12.4	2.4***
Year $\times$ rootstock	22	539.2***	44.8**	0.04*

^z $y_{ijkl} = \text{rootstock}_i + \text{block}_j + \text{tree}_{k(ij)} + \text{year}_l + \text{year}_l \times \text{rootstock}_i + \text{year}_l \times \text{block}_j + \epsilon_{ijkl}$ where y is either %N or %K.

^y1 fruit / kg = 0.454 fruit / lb.

^xError term for tests of hypothesis using Type III mean square for rootstock. The error term for all year terms is the residual sum of squares.

*, **, ***Significant at $P = 0.05$, 0.01 , or 0.001 , respectively.

Table 10. Effect of rootstock on 'French' prune tree root suckers in various California county locations, 1993.

Rootstock ^z	Root suckers/tree			
	Tehama	Butte	Sutter	Merced
MyS	2.4 b ^y	No data	0 b	No data
My29C	0.6 b	No data	0 b	No data
M2624	0.2 b	1.0	2.4 a	18.0 ab
M9	0.1 b	0	0.2 b	17.8 ab
M16	0.5 b	No data	0.3 b	24.0 a
M30	0.1 b	0	0.3 b	27.4 a
M38 ^x	0.5 b	No data	No data	No data
M40	0.3 b	0	0.2 b	1.6 c
M58	0 b	No data	No data	No data
M64	0.1 b	No data	No data	No data
M65	0.2 b	0.2	0 b	21.4 ab
M69	0.1 b	1.2	0 b	12.8 abc
M75	0 b	0 ^{NS}	0 b	8.5 bc

^zStandard industry rootstocks included MyS (myrobalan seedling), My29C ('Myrobalan 29C'), M2624 ('Marianna 2624'); 10 new selections of 'Marianna 2616' (M series) include M9, M16, M30, M38, M40, M58, M64, M65, M69, and M75.

^yM38 trees are at least 1 year younger than other trees.

*Means within each column with the same letter are not significantly different using Duncan's multiple range test, $P = 0.05$.

^{NS}Nonsignificant differences among rootstocks.

evaluated rootstocks were similar in their FHRs.

Significant variation in fruit size, proportion of undersized fruit and FHR existed from year-to-year (significant tree and year effects, Table 9), as were significant year $\times$ rootstock. This would indicate that in certain seasons the rootstock effect on fruit size and FHR could be altered and may not be consistent.

ROOT SUCKERS. In the Tehama, Butte and Sutter locations the production of root suckers was low in 1993 (Table 10). The number of suckers per tree at the Merced location, where rooting depth may have been limited, was high. At this site, M2624 (18 suckers/tree) = M9, M16, M30, M65, M69 > M40 (1.6 suckers/tree) = M69, M75. The production of root suckers is influenced by the site and does not always appear to be problematic. Sites where rooting depth is limited or extensive cultivation has been practiced tend toward the production of increased root suckers.

DISEASE SUSCEPTIBILITY-RESISTANCE; TREE LOSS FROM BACTERIAL CANCER. Selections M30, M38, M40, M58, M64, and M65 were equally as tolerant to infection with *Phytophthora cambivora* as MyS. At the Tehama location no trees had been lost to bacterial canker on M40, M58, or M2624 as of 1993.

Conclusion

A desirable rootstock for prunes would be easy to propagate, have good anchorage, and have resistance to all pests and diseases outlined in Tables 1 and 2. In addition, that rootstock should be free from suckering, control tree size to a degree (high yield efficiency) and produce large crops of large prunes. Such a rootstock does not currently exist and none was discovered among those tested in these experiments. Several of the tested rootstocks did have characteristics making them noteworthy. Selection M30 had high leaf K concentrations, but it was never found to have consistently higher leaf K than the standard M2624. M30 was a vigorous tree with high dry yields, but as yield went up fruit size decreased and the yield efficiency was not better than M2624. Vigorous rootstocks are generally not preferred in current and future orchard scenarios.

M58 controlled tree size and had the highest yield efficiency of any tested

rootstock. While these are good features for a rootstock, fruit size for M58 tended to be among the smallest of the tested rootstocks. This rootstock might be suitable for closely planted prune orchards.

Of the new M series rootstocks selection M40 might be the most promising. High leaf N indicated that M40 may provide some advantage in the extraction and uptake of N from soils. However, leaf K was among the lowest indicating that it may need additional K fertilization especially when grown on problematic sites with heavy cropping. Surprisingly, M40 produced few suckers at the Merced location. Even though low suckering was limited to one location, this result provides hope that a low root sucker producing rootstock may be available to replace M2624 and myrobalan types, especially if low suckering proves consistent over time and across a greater number of orchard sites. It is not clear whether M40 is resistant to oak root fungus [*Armillaria mellea* (Valh:Fr.) Kummer] or brown line virus (tomato ringspot virus; TmRSV) because it has not been evaluated for either disease. The only problem with M40 is the reduction in fruit size that comes from increased cropping. Further experimentation and field evaluation is suggested. Currently, the Pomology Department at the University of California, Davis is considering the patent and release of rootstock selection M40.

Literature cited

Carlson, R.M. 1981. Mineral nutrient availability, p. 84-89. In: D.E. Ramos (ed.). Prune orchard management. Univ. Calif. Spec. Publ. 3269.

Carlson, R.M. and K. Uriu. 1981. Potassium in prune production, p. 98-99. In: D.E. Ramos (ed.). Prune orchard management. Univ. Calif. Spec. Publ. 3269.

Catlin, P.B. and D.M. Holmberg. 1981. Root function and prune rootstocks, p. 19-22. In: D.E. Ramos (ed.). Prune orchard management. Univ. Calif. Spec. Publ. 3269.

Franson, A.H. (ed.). 1985. Determination methods 303A, p. 265-297. In: Standard method of examination of waste water. 16th ed. Amer. Publ. Health Assn.-Amer. Water Works Assn.-Water Poll. Control Fed.

Jameson, Jr., E.W. and H.J. Peeters. 1988. California mammals. Vol. 52. A. C. Smith (ed.) California Natural History Guide Se-

ries. Univ. Calif. Press, Berkeley

Lilleland, O. 1946. Present status of leaf analysis in relation to fruit tree nutrition. Blue Anchor 23:14-16, 28-31.

Mircetich, S.M., S.M. Southwick, and J. Osgood. 1990. Evaluation of prune rootstocks for resistance to phytophthora. Prune Res. Annu. Rpt. Calif. Prune Board. p. 22-27.

Ogawa, J.M. and H. English. 1991. Diseases of temperate zone tree fruit and nut crops. Univ. Calif., Div. Agr. Nat. Res. Publ. 3345.

Okie, W.R. 1987. Plum rootstocks, p. 321-360. In: C. Rom and R.M. Carlson (eds.). Rootstocks for fruit crops. Wiley, New York.

Olson, W.H., S.M. Southwick, and J.T. Yeager. 1991. French prune tree growth and yield comparisons on 'Marianna 2624', MyS and 29C rootstocks planted on a heavy, poorly-drained California soil. Acta Hort. 283:245-251.

Osgood, J.W., S.M. Southwick, J.T. Yeager, W.H. Olson, C. Weakley, and M. Norton. 1991. Evaluation of new Marianna rootstocks for French prune. Acta Hort. 283:241-244.

Renaud, R., G. Salesses, M. Roy, and A. Bonnet. 1990. Development and selection of new rootstocks of *Prunus domestica*. Acta Hort. 283:253-259.

Rosen, C.J. and R.M. Carlson. 1984a. Characterization of K⁺ and NH₄⁺ absorption by Myrobalan plum and tomato: Influence of plant potassium status and solution concentrations of K⁺ and NH₄⁺. J. Amer. Soc. Hort. Sci. 109:552-559.

Rosen, C.J. and R.M. Carlson. 1984b. Potassium uptake characteristics of Prunus rootstocks: Influence of solution Ca/Mg ratios and solution nickel. J. Plant Nutr. 7:865-885.

Southwick, S.M., B. Kirkpatrick, B. Westerdahl, M. Rupert, and K. Weis. 1997. Relationship between N fertilization and bacterial canker disease in French prune. Proc. 5th Annu. Fert. Res. Educ. Prog. Conf., Sacramento, Calif.

Sweeney, R.A. 1989. Generic combustion method for determination of crude protein in feeds: Collaborative study. J. Assn. Off. Anal. Chem. 72:770-774.

Uriu, K. 1981. Soil and plant analysis and symptomology for diagnosis of mineral deficiencies and toxicities, p. 89-97. In: D.E. Ramos (ed.). Prune orchard management. Univ. Calif. Spec. Publ. 3269.

Winer, B.J. 1962. Statistical principles in experimental design. McGraw-Hill, New York.