Petroleum Oils as Navel Orange Fruit Thinning Agents

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SUMMARY. The potential of petroleum sprays to thin navel orange (*Citrus sinensis*) crops in the San Joaquin Valley of California was examined in 1996, 1997 and 1998. Petroleum oils had not been used within the experimental site as adjuvants in other sprays or as pesticides in the previous year or during the experiment. 'Bonanza' navel oranges trees were treated annually or in alternate years with a light narrow-range petroleum oil [distillation midpoint of 415 °F (213 °C)], a medium narrow-range oil [distillation midpoint of 440 °F (227 °C)] and/or heavier oil [distillation midpoint 470 °F (247 °C)] in a range of applications from 5 to 15% by volume in a total spray volume of 200 gal/acre (1870 L·ha⁻¹). Trees treated with oil in 1996, 1997 and 1998 had 38% and 27% fewer fruit per tree in 1997 and 1998, respectively compared to trees not treated with oil indicating that crop thinning had occurred. In 1998, yield was lower in the trees that had been treated with oil annually for three consecutive years. Consecutive, annual applications of petroleum oil applied 1 to 3 weeks after petal fall produced a shift from smaller fruit sizes to larger fruit sizes beginning the second year.

Orange trees frequently set more fruit than can attain profitable size. Large oranges are usually worth more when

sold as fresh fruit. Small fruit often do not return the cost of picking, transporting and packing. The desired outcome of fruit thinning in the current marketplace is a reduction in fruit numbers with a concomitant increase in fruit size without a decrease in yield by weight. Growers do not have an inexpensive and reliable method of thinning citrus. Hand thinning is expensive, requiring removal of 25% to 50% of the fruit of the tree by late spring before fruit size increases substantially, (Morales et al., 2000; Parker, 1934). Pruning affects on fruit size of citrus have been variable (Phillips, 1972; Wheaton et al., 1984; Zaragoza and Alonso, 1981).

Naphthaleneacetic acid (NAA) will thin navel fruit but the degree of response varies and is temperature dependent (Hield et al., 1964; C.W. Coggin, personal communication). Temperatures in the San Joaquin Valley of California are often too cool [i.e., less than 80 °F (27 °C)] to thin fruit with NAA during the recommended postpetalfall application period.

Petroleum spray oils are commonly identified by their median distillation temperatures in a vacuum (Riehl, 1969, 1983). Moss (1976) reported petroleum oil applied to navel or 'Valencia' oranges during flower induction reduced flowering. Previous experimentation (Furness, 1981c, 1981d; Grafton-Cardwell and Pehrson, 1992; Knapp, 1990; Lee and Knapp, 1992) has shown narrow-range petroleum oils may induce varying degrees of leaf or fruit drop. The orange peel may also be scarred or discolored by oil when applications are made to trees under environmental stress such as those produced by drought, low humidity or wind (Davidson et al., 1991; Retzlaff et al., 1996). Orange color may also be delayed as a result of oil sprays (Furness, 1981b; Riehl, 1969). Reduction in soluble solids and acid in orange and mandarin juice have been reported at harvest after treatment with dilute oil sprays but results have been variable (Beattie, et al., 1989; Furness, 1981b; Lee and Knapp, 1994; Ohkubo, 1981; Riehl, 1969). The ratio of soluble solids to percent acid in the juice of sweet oranges at harvest generally shows little difference between untreated fruit and fruit treated with a single seasonal oil spray in spring, summer or fall (Knapp, 1990; Lee and Knapp, 1992, 1994).

Beattie et al. (1989), in Australia, found that a 2% by volume application of a medium weight narrow-range oil reduced 'Valencia' orange fruit weight and number at some locations when sprayed in autumn (April) as opposed to late spring or summer (November or February). However, Dean et al. (1978) in Texas on 'Hamlin', 'Valencia', 'Pineapple' and 'Marrs' orange trees; Lee and Knapp (1994) in Florida on 'Hamlin' orange trees, and Furness (1981b) in Australia on 'Valencia' orange trees noted that increased fruit size or individual fruit weight resulted from some applications of dilute oil sprays. These increases in fruit size or weight were associated with fewer fruit per tree and, at least in one instance (Furness, 1981a), a decrease in yield. Petroleum oil sprays can also encourage alternate bearing in some orange varieties (Dean et al., 1978; Furness, 1981a).

The effects of spray oil, as noted above, were variable. Generally, the tree response to oil was accentuated with heavier weight oils, with oils sprayed later in the season, increased rates of oil, multiple oil sprays within a season, and with consecutive annual oil sprays.

Based on the apparent ability of petroleum oils to affect fruit bearing, the objective of this research was to determine if concentrated sprays of narrow-range oil could be used as fruit thinning agents for navel oranges in California.

Materials and methods

PLANT MATERIAL: The experiment was conducted in the southern San Joaquin Valley near Bakersfield, Calif. Mature 'Bonanza' navel orange trees grafted on Carrizo rootstock [*Citrus sinensis* × *Poncirus trifoliata*] were sprayed with three weights of petroleum oils in 1996, 1997, and 1998. These navel orange trees were spaced 22 ft (6.7 m) between rows and 11 ft (3.4 m) between trees within row and were about 9 ft (2.7 m) in height.

PETROLEUM OIL SPRAYS: Petroleum oils evaluated in this research are identified by their narrow range median distillation temperatures and other chemical characteristics (Table 1). The three petroleum oils are identified as light (415), medium (440) and heavy (470). Oil was sprayed on the trees in concentrations from 5% to 15% in a total spray volume of 200 gal/acre. Oil applica-

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tions were made with an air-blast orchard sprayer.

Rates and types of petroleum oils, timing, and temperature at time of application and other thinning methodologies used in this experiment are summarized in Table 2.

The sprays applied in April 1996 and 1997 occurred about 7 to 10 d after petal fall while those in May 1998 about 21 d after petal fall. These sprays

are referred to in this report as postpetalfall sprays. Oil applications were made when the soil water status was higher than 50% available water and the wind calm. Three oil treatments were applied to trees over the 3-year period and evaluated for effects on fruit number, fruit mass and fruit quality characteristics as compared to untreated control trees. A treatment refers to the sequence of oil sprays that

was applied in the plots over the 3-year period (Table 2). Oil treatments consisted of trees that were annually sprayed only with supreme oil or narrow-range medium oil and a third treatment in which trees were sprayed with oil in alternating years (1996 and 1998, but not 1997).

EXPERIMENTAL DESIGN: A treatment was applied to an experimental unit (i.e., plot) that consisted of six adja-

Table 1. Chemical properties of oils used in this experiment with ‘Bonanza’ navel orange, Bakersfield, Calif. 1996-98.

Petroleum oils ^z	Min UR ^y (%)	Distillation				Min Cp ^y (%)	Pour point ^u		Viscosity ^t (s)	Mol wt ^s (g·mol ⁻¹)	API gravity ^r
		50% point ^x		10%-90% range							
		(°F)	(°C)	(°F)	(°C)		(°F)	(°C)			
Light	92	415	213	80	27	59	0	-18	75	212-297	33
Medium	93	440	227	80	27	59	0	-18	85	254-330	32-35
Heavy	99	470	246	84	29	68	7	-14	74	352	35

^zLight = Clean Crop Citrus Spray Oil NR 415 (United Agri Products, Fresno, Calif.); medium = Super 94 440 Spray Oil (United Agri Products); heavy = Volck Supreme Spray (Valent Corp., Walnut Creek, Calif.). The manufacturer of the base oils used by United Agri Products for the light and medium oils varied according to cost and availability. The manufacturer of the heavy oil used by Valent Corp. was Chevron Chemical Co. (San Ramon, Calif.).

^yUnulfonated residue (UR) is the percentage of oil reacting with sulfuric acid.

^xThe temperature at which half of the oil distills at a vacuum of 0.093 lb/inch² (1.33 kPa).

^uThe range of temperature measured from the point at which 10% of the oil is distilled and ending when 90% of the oil is distilled under a vacuum of 0.093 lb/inch².

^vThe percent of paraffin based molecules in the oil.

^tThe minimum temperature at which the oil remains flowable.

^rThe time required for 2 fl oz (60 mL) of oil at 100°F (37.8°C) to flow through a standard opening.

^sThe average mass of all molecules in the compound.

^rA measure of hydrocarbon composition.

Table 2. The volume and type of oil applied and the average diameter of the fruit when the oil was applied for the years 1996, 1997, and 1998.

Treatment description ^w	1996 ^z				1997 ^y				1998 ^x			
	Vol of oil in spray		Oil type ^w	Avg fruit diam (mm) ^u	Vol of oil in spray		Oil type ^w	Avg fruit diam (mm)	Vol of oil in spray		Oil type ^w	Avg fruit diam (mm)
	(gal/acre ^v)	(%)			(gal/acre)	(%)			(gal/acre)	(%)		
Heavy only	20	10	Heavy	8	30	15	Heavy	8	20	10	Heavy	10
Medium only	24	12	Medium	8	30	15	Medium	8	20	10	Medium	10
Alternating year	10	5	Heavy	8	0	---	No oil	---	12	6	Light	10
No oil	0	---	No oil	---	0	---	No oil	---	0	---	No oil	---

^zIn 1996, all oil applied in 200 gal/acre (1870 L·ha⁻¹) spray solution 23 April. Maximum temperature, 85 °F (29.5 °C).

^yIn 1997, annual oil treatments applied in 200 gal/acre spray solution 11 April. Maximum temperature was 75 °F (24.0 °C). Alternating year treatment received no oil application.

^xIn 1998, all oils applied in 200 gal/acre spray solution on 20 May. Maximum temperature was 70 °F (21 °C).

^wSee Table 1 for a description of the oils used in the experiment.

^v1 gal/acre = 3.8 L·ha⁻¹.

^u25.4 mm = 1.0 inch.

Table 3. Effect of petroleum oil treatments on fruit weight, number, and grade at harvest of ‘Bonanza’ navel orange, Bakersfield, Calif., 1997 and 1998.

Treatment	1997				1998				1997-98	
	Yield/tree (lb)	(kg)	Fruit/tree (no.)	Fancy ^w grade (%)	Yield/tree (lb)	(kg)	Fruit/tree (no.)	Fancy grade (%)	Cumulative Yield/tree (lb)	(kg)
Annual oil ^z	180	(82) a ^y	456 a	75 a ^x	130	(59) a	471 a	45 a	310	(141) a
Alternating years	195	(88) a	523 ab	75 a	146	(66) ab	706 b	54 b	341	(155) a
No oil	232	(105) a	739 b	71 a	152	(69) b	644 b	53 ab	384	(174) a

^zTreatments are more fully described in Table 1.

^yDifferent letters following values within the same column denote significant differences by Fisher's LSD at ($P_{[X|t_{(n-1)}]}$ 0.05).

^xPercentage values were transformed using $\sin^{-1} [X/\sqrt{100}]$ for statistical analysis.

^wFancy refers to the highest grade of fruit packed.

Table 4. The average number of fruit per tree in the various fruit size categories at harvest in 1997 and 1998, Bakersfield, Calif.

Treatment	1997					1998			
	>113 ^z (<66 mm ^y)	113 (66 mm)	88 (72 mm)	72+56 (77-84 mm)	<56 (>84 mm)	>113 (<66 mm ^y)	113 (66 mm)	88 (72 mm)	72+56 (77-84 mm)
Annual oil	51 a ^x	99 a	166 a	120 b	10 a	229 a	198 b	46 b	18 b
Alternating year	91 a	135 ab	179 a	96 ab	16 a	611 c	87 a	7 a	3 a
No oil	231 b	250 b	211 a	45 a	2 a	471 b	145 b	21 a	8 ab

^zFruit size classification based on the number of fruit of this size required to fill a standard California 37.5-lb (17-kg) packing carton.

^yMaximum fruit diameter in size classification; 25.4 mm = 1.0 inch.

^xDifferent letters following values within the same column denote significant differences by Fisher's LSD at ($P_{(X|equalX)} 0.05$).

Table 5. Effect of petroleum oil sprays on abscission of leaves (dry weight) of 'Bonanza' navel oranges, Bakersfield, CA 1996 and 1997.

Treatment	Leaf tissue ^z dry wt (g)	
	1996	1997
annual oil	38 b ^y	56 a
alternating oil	35 b	21 a
no oil	15 a	53 a

^zEach value is a measure of the amount of dry matter collected on a screen covering 16 ft² (1.5 m²) of ground area; 28.4 g = 1.0 oz.

^yDifferent letters following values within the same column denote significant differences by Fisher's LSD at ($P_{(X|equalX)} 0.05$).

cent trees in a row. A plot was separated from adjacent plots by two border rows and two border trees within the row. Data was collected from the largest four trees in the plot. Each treatment was replicated three times and was applied to the same plots during the three years of the experiment. The experimental plots were established and replicated in a randomized complete block design.

EVALUATING LEAF DROP AFTER TREATMENT

Leaf drop was estimated by sampling with collection screens in 1996 and 1997. A single square of wire mesh measuring 4 ft (1.2 m) on a side was placed on the berm under a single tree in each plot receiving an oil treatment. Leaves that fell on the screen were collected weekly, dried at 158 °F (70 °C) for 3 d and then weighed. Collection was from 29 Apr. to 3 June 1996 and from 23 Apr. to 9 June 1997.

EVALUATING FRUIT SIZE AND YIELD AT HARVEST. The diameter of hanging fruit was measured with an electronic caliper at harvest on 16 Oct. 1996. Sampling consisted of encircling the tree with a rope about 3 to 7 ft (1 to 2 m) from the ground around the periphery of the two largest yielding trees of each plot. The diameter of every fruit within 4 inches (10 cm) of the rope was mea-

sured with an electronic caliper. About 75 fruit from each tree were sampled.

In 1997 and 1998, fruit size, grade and yield was determined by processing all of the fruit from the largest four trees in each plot, through the experimental pack line at the University of California Citrus Research Center at Lindcove on 25 Nov. 1997 and 10 Dec. 1998. Fruit size is reported as the number of fruit required to fill a 37.5 lb (17 kg) standard carton. Treatment effects were determined by analysis of variance (Manugistics, Inc., 1997a) with mean separation using Fisher's least significant difference (LSD) at $P_{(X|equalX)} 0.05$.

Results and discussion

The effects of annual applications of heavy (470) and medium (440) oil on fruit number, grade, yield and fruit size distributions were not different from each other over the three years of the experiment (data not shown). Accordingly, data from plots treated annually with these two oils in 1996, 1997 and 1998 were analyzed as a single treatment identified as the annual oil treatment in the text and tables.

Oil treatments made postpetalfall in 1996 had no effect on fruit diameter or the most common fruit size based on rounding the diameter to the nearest integer value (data not shown). Fruit weight harvested per tree and the percentage of fruit that were graded as fancy were not significantly different among treatments in 1997 (Table 3). Fruit yield by weight in 1998 was different between trees treated with oil 3 consecutive years and those not treated with oil (Table 3). However, cumulative yield by weight for 1997 and 1998 were not different among treatments. In 1997 and 1998, the trees treated annually with oil had fewer fruit per tree than did the trees not treated with oil (Table 3) indicating that fruit thinning had occurred. In

1997, in response to this thinning, significantly more fruit of sizes 72 and 56 fruit per carton were produced on the trees treated annually with oil than the trees not treated with oil (Table 4). Fewer fruit of size 113 and smaller were harvested in the annual oil treatment than on the trees not treated with oil.

Fruit size, overall, was smaller in 1998 than in 1997 (Table 4). As in 1997, however, fruit size was larger in the trees treated annually with oil. In 1998, more fruit size 88 and fewer fruit smaller than size 113 were harvested from trees treated annually with oil as compared to the trees receiving no oil during the experiment. In 1997 the most common fruit size increased from size 113 on the untreated trees to size 88 on the annually oil treated trees, and in 1998 from size 163 on the control trees to size 113 on the annually oil-treated trees.

Even though the trees in the alternating years treatment were not sprayed with oil in 1997 as they had been in 1996, the fruit size distribution at harvest in 1997 was more similar to that of the annual oil treatment with production of fewer smaller fruit than from trees in the 'no oil' treatment. Conversely, trees in the alternating years treatment in 1998 produced fruit in all size categories (Table 4) similarly to untreated trees even though treated with oil after petal fall. These results, in addition to the absence of a thinning response in 1996 to all of the 1996 postpetalfall oil sprays suggests that fruit was thinned the season following the season oil was applied. This finding agrees with that of Furness (1981b) who found that fruit weight was not affected by oil in the first spraying season, but average individual fruit weight increased the second season, regardless of whether a spray was applied in the second season or not. The mechanism for a possible

Table 6. Market comparison between trees thinned with oil and untreated trees, Bakersfield, Calif., 1997-98.

Treatment	Year	Marketable fruit sizes no.	Fruit no.		Carton no.		Price/ carton ²	Fruit value by size	
		fruit/carton ³	(no./acre)	(no./ha)	(no./acre)	(no./ha)		(\$/acre)	(\$/ha)
No oil	1997	138	24120	59576	174	430	7	1223	3021
		113	45000	111150	398	983	7	2788	6886
		88	37980	93811	432	1066	10	4316	10661
		72	6120	15116	85	210	12	1020	2519
		56	1080	2668	19	48	14	<u>270</u>	<u>667</u>
								9617	23754
Annual oil	1997	138	5760	14227	42	103	7	292	722
		113	17820	44015	158	390	7	1104	2727
		88	29880	73803	340	839	10	3395	8387
		72	15300	37791	213	525	12	2550	6299
		56	6300	15561	113	278	14	<u>1575</u>	<u>3890</u>
								8917	22025
No oil	1998	138	22680	56020	164	406	8	1315	3248
		113	26100	64467	231	571	11	2541	6276
		88	3780	9337	43	106	18	773	1909
		72	1080	2668	15	37	20	300	741
		56	360	889	6	16	22	<u>141</u>	<u>349</u>
								5070	12523
Annual oil	1998	138	19260	47572	140	345	8	1117	2758
		113	35640	88030	315	779	11	3469	8569
		88	8460	20896	96	237	18	1730	4274
		72	2520	6224	35	86	20	700	1729
		56	720	1778	13	32	22	<u>283</u>	<u>699</u>
								7299	18029

²Fruit value obtained from sales of 31 fruit handlers obtained from Citrus Mutual Market Memo (see Literature cited) for the week that the orchard was commercially picked. Fruit value was calculated based on 100% fancy (first) grade and 180 trees/acre (445 trees/ha).

³Fruit size classification based on the number of fruit of this size required to fill a standard California 37.5-lb (17-kg) packing carton.

delayed thinning response is unknown but stress-induced effects of oil are not well understood. For example, petroleum oil has been demonstrated to advance the flowering date in pistachios (*Pistacia vera*) by as much as 2 weeks if sprayed during the dormant season (Beede et al., 1998).

The larger volumes of oil applied, regardless of weight, generally, caused some immediate water spotting on the fruit, but this symptom disappeared in a few weeks.

Phytotoxic effects of the oil, such as burning of plant tissue, occurred only for the light (415) oil spray applied after petal fall in the alternating oil treatment in 1998 and only on leaf tissue. This oil caused some necrotic lesions on outside-canopy leaves. The collection screens in most of the oil-treated plots captured more leaf tissue than in the untreated plots in 1996 but not in 1997 (Table 5). In 1996, measured differences in leaf losses were minor among treatments and differences were not readily detectable by tree appearance. Most of the leaf tissue caught in the collection screens

dropped within 20 d of the oil application regardless of whether oil was applied or not.

The percentage of fancy (first grade) fruit (Table 3) was lower than what would have occurred at a commercial packinghouse because the fruit were not washed prior to evaluation. Observation of the fruit at harvest indicated that the fruit was not physically damaged by contact with the concentrated oil sprays. The reduction in grade was largely attributable to increased feeding damage of citrus thrips, (*Scirtothrips citri*), after petal fall.

The value of the fruit, as determined by existing market prices (California Citrus Mutual, 1997b, 1998) when it was commercially picked from the orchard in which this experiment was located, was compared between oil-treated and untreated trees (Table 6). The price growers received was calculated as the best-case scenario in which all of the fruit was assumed to be fancy. Only the most marketable grades (sizes 138 through 56) were included in the calculation. In 1997 fruit from the annually oil-treated trees would

have been worth \$8917/acre (\$22025/ha) and from the untreated trees \$9617/acre (\$23754/ha). In 1998, fruit from the oil treated trees would have been worth \$7229/acre (\$18029/ha) and from the untreated trees \$5070/acre (\$12523/ha). The price differential between smaller and larger sizes was less in 1997 than in 1998 (Table 6), which made thinning less profitable than not thinning in 1997. Large fruit was worth correspondingly more than smaller fruit in 1998, which made oil thinning more profitable compared to not thinning. Not having to pick and transport the fruit less than size 138 would further reduce harvest costs in an oil-treated orchard by about \$0.85 for every carton not picked and transported. In 1997, about 120 additional cartons/acre (296 cartons/ha) of small fruit of less than size 138 were produced from trees that were not treated with oil compared to those treated annually with oil (data not shown), which increased picking and transporting costs by about \$100/acre (\$247/ha). This additional cost approximated the cost

of the oil application in 1997.

Further experimentation is necessary to determine if reduced volumes of oil or if oil applied at other times during the season may be as effective in initiating thinning as the rates and timing of oil applications made in this study. Concentrated prebloom oil sprays (data not shown) were found to be excessively phytotoxic. The possibility that the response to oil occurs the season following application also warrants further investigation. Results obtained in this experiment were in response to concentrated oil sprays. Some caution should be exercised in transferring the results obtained with these concentrated sprays to the performance of dilute, high volume oil sprays applied as insecticidal treatments. However, results from this research and the research of others (Furness, 1981a; Lee and Knapp, 1994) pose the possibility that when consecutive annual dilute insecticidal oil sprays are made, fruit size and number may be affected as well as insect populations. In two experiments similar to that reported here, oil thinning could not be demonstrated using concentrated oil sprays where cooperating growers had used dilute, high-volume oil sprays to control scale or mite populations in their orchards the previous and current year. These growers may have already promoted the maximum thinning response with these dilute, high volume insecticidal oil sprays.

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