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EFFECT OF CERTAIN HYDROCARBON OILS ON THE TRANSPIRATION RATE OF SOME DECIDUOUS TREE FRUITS

By VICTOR W. KELLEY

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EFFECT OF CERTAIN HYDROCARBON OILS ON THE TRANSPIRATION RATE OF SOME DECIDUOUS TREE FRUITS¹

By VICTOR W. KELLEY, Associate in Pomology²

MOST SPRAYS, under some conditions, have a deleterious effect upon the plants which they are designed to protect, but perhaps no spray material has been so universally accused of injuring plants as has oil. Because of this uncertainty in regard to its physiological effect, many fruit growers have been reluctant to follow the recommendations to use oil sprays. The revival of the use of unsaturated oils (chemically active, colored) in the dormant season for the control of scale insects and the more recent use of saturated oils (chemically inert, highly refined, white) as insecticides or ovicides during the growing season, has made the physiological reaction of deciduous fruits to oil a subject of general interest. It was with the hope of assisting in the solution of this problem that this work was started in 1923. Because of its vital association with photosynthesis, any significant change in transpiration rate should at least suggest an effect upon metabolism.

REVIEW OF LITERATURE

The literature records a considerable number of observations in which oil sprays were reported as the cause of various manifestations of abnormal behavior. These include earlier blooming, retardation in the opening of blossom and leaf buds, killing of buds and twigs, yellow stunted foliage, premature abscission of leaves and fruit, and small, sour, late-maturing fruit. For a review of these observations the reader is referred to the author's publication, "Effect of Certain Hydrocarbon Oils on Respiration of Foliage and Dormant Twigs of the Apple,"^{12*} or to the original references as follows: Ballard and Volck,^{1*} Burroughs,^{3*} deOng,^{5*} deOng, Knight, and Chamberlain,^{6*} English,^{7*} Felt,^{8*} Newcomer,^{21*} Overley and Spuler,^{22*} Pickering,^{24*} Volck,^{27*} Woglum,^{28*} and Yothers.^{29*}

Only a few investigators have studied the physiological effect of oils in experiments designed especially for that purpose. Burroughs,^{4*}

¹A preliminary report of these experiments was published in the 1926 Proceedings of the American Society for Horticultural Science, pages 321-325.

²The advice and assistance of Dr. W. A. RUTH, Chief in Pomological Physiology, who suggested the problem, and who has been in close touch with the work thruout, is gratefully acknowledged.

in 1921-1922, found that the respiration of ripe Wealthy, Baldwin, and Wagener was reduced as much as 50 percent after dipping in "crystal-aronite," but that with immature fruits the evolution of carbon dioxide was increased. In preliminary experiments reported in 1923^{3*} he found that apple leaves which had been burned with an oil spray had no starch in the portions which were still alive, and that leaves which were stunted by the oil contained no starch. Magness and Burroughs,^{19*} in 1923, reported that Winesap apples dipped in a nondrying oil had a lower oxygen content than the control lots. Magness and Diehl,^{18*} in 1924, studied the effect of oils upon the respiration rate of apple fruits. They found that at temperatures ranging from 32° to 80° F. the respiration rate was decreased. Heavier oils caused a greater decrease than oils of lower viscosity. At all the temperatures there seemed to be an apparent increase in the concentration of carbon dioxide within the tissues of the oil-coated fruits, and at the higher temperatures there appeared to be a limitation of the oxygen supply which retarded ripening and induced anaerobic respiration. Neller,^{20*} in 1928, found that untreated Winesap respired about 40 percent faster than dry-brushed, oil-coated specimens after four months in storage, and 17 percent faster after a storage period of eight months. At a temperature of 20° C. and a relative humidity of 30 percent untreated fruits of Delicious and Winesap lost weight more rapidly than oil-coated specimens. The moisture content of the oil-coated fruits was slightly higher.

Knight, Chamberlain, and Samuels,^{16*} in 1929, reported on the physiological effects of saturated oils on citrus. By microscopical methods they observed the penetration of oil into the leaf and traced it thru the vascular system to the pith and xylem parenchyma where it was stored. They found that penetration was always most rapid in those areas where the stomata are located, but in their opinion penetration was not necessarily confined to those areas. Unfortunately, in most of their experiments the application of oil was made to both surfaces of the leaf, making the exact point of penetration difficult to determine. In their opinion saturated oils on citrus are the cause of more or less profound metabolic disturbances which may ultimately become seriously deleterious. Observed changes were reduced transpiration, increased respiration, and interference with photosynthesis. They considered these changes to be due to physical rather than chemical reactions. It is the judgment of these investigators that "heavy white oils (of a viscosity exceeding 60 seconds Saybolt) must be used sparingly and with a great degree of caution if, in the future, serious ultimate injury is to be avoided."

The author,^{12*} in 1928 and 1929, studied the effect of oils of different viscosities and degrees of unsaturation on the respiration of dormant twigs and foliage of the apple. The effect of the emulsions on dormant

twigs depended largely upon the developmental stage of the buds at the time of application. Before the separation of the bud scales, termed in spraying the "dormant season," all the oils accelerated respiration, but when applied immediately after this stage but before the first leaves had unfolded, known as the "delayed-dormant season," they retarded respiration. The buds of the cuttings treated with any of the oils during the dormant season failed to grow; treated at delayed dormancy, growth was only retarded. The light oils, however, retarded growth much less than the heavier oils. Viscosity was important in respiration during the dormant period, only with unsaturated oils; at delayed dormancy it was a factor with both saturated and unsaturated oils. On foliage the heavier oils affected respiration only at high humidity; the greater effect of the light oils was produced at this humidity. Younger, unsprayed leaves respired more rapidly than older leaves; their respiration was more affected and they were more easily injured by oil sprays.

The author also found that the relative humidity during and following the application was the most important single factor to be considered in avoiding injury. The greatest damage to twigs was always produced at high humidity; visible injury to foliage occurred only at high humidity and when the spray was applied to the lower surface. It occurred as translucent areas on the lower side three to four hours after spraying. The severity of the injury depended on the age of the leaf and the length of the exposure to high humidity. When removed after a short exposure, the translucent areas gradually disappeared; by longer exposure, they extended thru the mesophyll to the upper epidermis and caused the tissue to turn brown. Microscopic examination showed that the oils penetrated the leaf as an emulsion thru the stomata. The emulsion apparently starts to enter thru the stomata immediately after application. High humidity was thought to facilitate the entrance of the emulsion. Saturation of the heavier oils comparable to those used in commercial spraying was not important in either the dormant or delayed-dormant periods. It was relatively unimportant in foliage applications.

METHODS OF EXPERIMENTATION

Spray Materials. The oils from which the emulsions were made were supplied by the Standard Oil Company of Indiana. Table 1 gives the technical description furnished by H. J. Saladin, Assistant Manager of the Technical Division, Lubricating Department.

No. 3619 is a saturated oil, a representative of the group of oils used for summer spraying, and is more highly refined than the ordinary lubricating oil. It has been treated with concentrated sulfuric acid to remove the unsaturated hydrocarbons, is lighter in color than an un-

saturated oil, and is inert chemically. No. 3614 is a less highly refined oil of the same body or viscosity as 3619. It is an unsaturated oil and is chemically active.

Boiled emulsions were made from the above oils; 500 cubic centimeters of oil, 125 cubic centimeters of distilled water, and 115 grams of 40 percent potash fish-oil soap being used. These materials were thoroly mixed, brought to the boiling point, and then pumped while hot, using one hundred strokes of a bucket pump equipped with a bordeaux nozzle. Most of the sprays were made from the boiled emulsions, but a few series were sprayed with cold-mix emulsions, using bordeaux or casein-lime as the emulsifying agent. "Volek," a prepared emulsion manufactured by the California Spray Chemical Company, was also used.

TABLE 1.—TECHNICAL DESCRIPTION OF OILS USED IN THE TRANSPIRATION STUDIES

Product	Specific gravity at 60° F.	Flash point 0° F.	Fire test 0° F.	Viscosity (Saybolt test) at 100° F.	H ₂ SO ₄ absorption	Evaporation test	Acidity milligrams KOH
					<i>perct.</i>	<i>perct.</i>	<i>grams</i>
No. 3614.....	.883	335	385	83	9	1.07	.023
No. 3619.....	.853	350	400	83	0	.24	.006

The concentrations of the sprays varied from one-half of 1 percent to 3 percent on the basis of the number of cubic centimeters of the stock emulsion used per hundred cubic centimeters of water. The actual concentration of the oil was thus slightly less than the above percentages. Sprays containing only the emulsifying agents (casein-lime, bordeaux, and soap) were also included. The checks were sprayed with water.

Plant Materials. Cuttings of the current season's growth of apple, pear, peach, plum, and sour cherry were used. The varieties were Jonathan, Grimes, Delicious, Elberta, Kieffer, Wild Goose, and Early Richmond. Terminal shoots of moderate vigor from the outside of the tree were selected, approximately the distal eight inches being used for the experiments. All shoots for any series of comparisons were selected from a single tree. The bases of the cuttings were put in water in the orchard immediately after separation from the plant; they were then taken to the laboratory and cut under water before being placed in the potometers.

Application of Sprays. As a thoro covering of the foliage was desired, the shoots were in most cases dipped in the spray material. When the conditions of the experiment would not permit dipping, the spray was applied with an atomizer. Comparisons have been made of the effect of spraying the upper surface only, the lower surface only,

and both surfaces. The effect on old and young leaves has also been compared. Applications have been made at different times during the day and under the varying conditions of temperature and humidity usually found in the latitude of Urbana-Champaign, Illinois, during the growing season from June to October.

Transpiration Apparatus. In the earlier experiments the shoots were sealed in Ehrlenmeyer flasks and the transpiration determined by successive weighings. In the greater part of the work, however, potometers were used, making it possible to read the amount of water taken up by the cutting directly on a burette. This apparatus has been described and illustrated by the author in a former publication.^{11*} Readings were generally made twice each day, in early morning and late afternoon. In some of the series, readings were made at half-hour intervals; in others, the day and night transpiration was determined separately. The transpiration rate of each shoot was secured preliminary to treatment, and the effect of the spray was determined by the change in the transpiration rate as compared with the change in the rate of the checks under identical conditions. The leaf area was determined with a planimeter and the records are on the square-inch-hour basis.

Environmental Conditions. Most of the preliminary experiments were carried on in a greenhouse, altho a few series were run outdoors. The greater part of the work (all for which data are published), however, was done in a large, well-ventilated laboratory in which the light, temperature, and air circulation were quite uniform for all the shoots in any series. Such an environment is considered better for transpiration experiments than a greenhouse with its varying conditions of light and air currents. Temperature and humidity determinations were made at the time of spraying and at the intervals when readings were made.

EXPERIMENTAL RESULTS

Comparison of Saturated and Unsaturated Oils

Until a few years ago all spraying oils were unsaturated. Such oils are of a rather low degree of refinement, are colored, and because of their composition are chemically active. Saturated oils are more highly refined, are colorless, and are considered chemically inert. Because of their chemical composition, theoretically saturated oils should injure the plant less than unsaturated oils. For this reason they have practically supplanted unsaturated oils for foliage sprays; in fact, it was not until the advent of these more highly refined, saturated spraying oils that foliage application of oil sprays became common.

The data for five series of tests with three varieties of apple, the spray material having been applied by dipping, are shown in Table 2.

TABLE 2.—EFFECT OF SATURATED AND UNSATURATED OILS ON TRANSPIRATION RATE OF APPLE SHOOTS WHEN APPLIED TO BOTH SURFACES OF THE LEAF BY DIPPING

(The checks were dipped in water)

Series No.	Time and date of application	Environmental conditions when sprayed		Range of preliminary period	Transpiration period after spraying	Number of shoots	Concentration of spray	Variety	Rate after treatment, expressed in percentage of preliminary rate		
		Temperature ° F.	Relative humidity						Saturated oil	Unsaturated oil	Check
	1926				hours		perct.				
1.....	5 p.m., July 21	84	49	10:15 a.m.—4 p.m.	39	2	2	Grimes Jonathan	10.3 18.2	9.4 14.5	30.9 35.8
2.....	2 p.m., July 22	81	65	9:45 a.m.—2 p.m.	42	2	2	Grimes Delicious	15.5 16.5	13.2 13.9	40.6 46.9
3.....	2 p.m., July 23	79	48	10 a.m.—1:30 p.m.	65	2	1½	Grimes Jonathan	21.5 27.6	13.6 29.2	52.0 64.6
7.....	7 a.m., Sept. 17	72	86	3:30 p.m.—6:30 a.m.	23	2	2	Grimes	37.5	41.8	161.1
8.....	3 p.m., Sept. 18	78	78	9:30 a.m.—2:30 p.m.	39	3	2	Grimes	27.2	24.7	77.1

Three of the series were run in July and two in September, 1926. The applications were made at various times during the day from seven o'clock in the morning to five o'clock in the afternoon and under diverse conditions of relative humidity and temperature.

The most striking fact shown by the data is that both the saturated and unsaturated oils under all the conditions encountered reduced the rate of water loss, the oil-sprayed shoots transpiring only from one-fourth to one-half as much water per square inch of leaf surface as the checks which were sprayed with water. In six of the eight tests the unsaturated oils reduced the transpiration rate slightly more, but the differences do not appear to be significant.

In a former paper the author^{13*} has shown that the three varieties of apple included in Table 2 differ in rate of transpiration. Grimes transpires most rapidly, followed closely by Delicious, and then by Jonathan. These varieties also seem to respond differently to the oil sprays. Grimes, which transpires most rapidly, is affected more by the oil than Jonathan, which has a lower rate of transpiration. This may indicate a difference in susceptibility to oil injury.

Effect of Oils on Transpiration Rates of Different Species

It has been shown by the author^{11*} that deciduous fruits vary widely in their rates of transpiration. Series 9 and 10 show the effect of oils upon the transpiration of the apple, pear, sour cherry, peach, and plum, the first three species belonging to the class which transpires rapidly and the last two to the low-transpiring group. Series 9 was sprayed with Volck, a prepared foliage insecticide, and Series 10 with a homemade, cold-mix emulsion. The humidity was quite high in both cases.

In both Series 9 and 10 (Table 3) the oil spray retarded the transpiration rate of all five species, the rate of the sprayed shoots ranging from approximately one-fourth to two-thirds that of the checks. The data are perhaps not sufficient to draw definite conclusions regarding the comparative effect upon these species, but the oil seems to reduce the rate of the low-transpiring group (peach and plum) the more. In both series, however, the sour cherry, which transpires less rapidly than either the apple or the pear,^{11*} was affected least by the oil. On the other hand, the apple, which transpires more rapidly than the pear,^{11*} was affected more by the oil.

Effect of Bordeaux Oil Emulsions

Cold-mix oil emulsions are less stable than those prepared after heating the oil and emulsifying agent together. Most of the emulsions used in these experiments are of the boiled, stable type. Table 4 gives the data secured in two tests with a quick-breaking emulsion in which bordeaux was the emulsifying agent.

TABLE 3.—EFFECT OF OIL SPRAYS ON TRANSPARATION RATE OF APPLE, PEAR, CHERRY, PEACH AND PLUM, WHEN APPLIED BY DIPPING
(Series 9 was sprayed at 7 a.m., September 21, 1926; the temperature at the time was 69° F. and the relative humidity, 76 percent.
Series 10 was sprayed at 2 p.m., September 23, 1926; the temperature was 75° and the relative humidity, 86 percent.)

Series No.	Spray used	Number of shoots in each treatment	Length of period after treatment	Transpiration rate after treatment, expressed in percentage of preliminary rate							
				Grimes				Kieffer		Early Richmond	
				Sprayed	Check	Sprayed	Check	Sprayed	Check	Sprayed	Check
9.	Volck, 3 percent....	2	hours 33	31.9	66.1	37.9	59.1	40.2	55.7	27.2	57.9
10.	Casain-lime, cold-mix emulsion....	1	40½	37.0	88.2	49.1	89.1	65.7	74.8	30.3	77.8
										31.7	95.6

TABLE 4.—EFFECT OF BORDEAUX OIL EMULSION ON TRANSPARATION RATE OF GRIMES WHEN APPLIED BY DIPPING

Series No. ¹	Time and date of application	Spray used	Number of shoots in each treatment	Environmental conditions		Area of leaf surface	Preliminary transpiration rate per square inch per hour	Transpiration rate per square inch per hour after treatment	Rate after treatment as percentage of preliminary rate
				Temperature	Relative humidity				
				° F.	perct.	sq. in.	cc.	cc.	
13.	1926 7 p.m., Oct. 11	Bordeaux oil emulsion	6	77	63	129.39	.0649	.0084	12.9
		Water.....	6	77	63	133.99	.0686	.0496	72.3
14.	7 p.m., Oct. 12	Bordeaux oil emulsion	4	66	80	87.64	.0625	.0336	53.7
		Bordeaux only.....	2	66	80	48.97	.0812	.0532	65.5
		Copper sulfate.....	1	66	80	20.61	.0737	.0590	80.1
		Lime water.....	2	66	80	42.87	.0948	.0568	59.9
		Water.....	5	66	80	103.13	.0741	.0612	82.6

¹It was raining during a considerable part of the test period for both series.

The spray applied to Series 13 (Table 4) was from a very poor emulsion, the bordeaux having at least partly settled to the bottom of the stock emulsion, which necessitated its being shaken up before dilution. The diluted spray left a distinct oily residue on the foliage. The effect of such a poor emulsion was to retard the transpiration to a greater degree than usual, the oil-sprayed shoots transpiring only about one-sixth as much water per unit area of leaf surface as those sprayed with water. Series 14, sprayed with a better emulsion, showed a much smaller reduction in rate. The amount of oil actually applied to the leaf when the poor emulsion was used probably was much greater. There is a suggestion in Series 14 that the emulsifying agent caused a slight reduction in the transpiration rate; however, such a conclusion could not be definitely drawn from this particular series, but it can be conclusively stated from this and other series that by far the greater part of the reduction is due to the oil and not the emulsifying agents.

Effect of Spray on Upper and Lower Surfaces

The two surfaces of the apple leaf are quite different in their physical characteristics. The upper epidermis is rather thick but is usually almost glabrous, while the lower epidermis is thinner and is always more or less pubescent. It is also known that the stomates are located only on the lower epidermis of the apple. With such differences in the structure of the two surfaces it might be expected that the plant would react differently to sprays when applied to either one to the exclusion of the other.

Series 11 and 12 (Table 5) give a comparison of the effect of oil emulsion when applied to the upper surface, the lower surface, and to both surfaces. The data show that oil sprays retard transpiration only when they come in contact with the lower epidermis. Application to the upper side of the leaf not only did not affect the transpiration rate, but spraying both surfaces reduced the rate no more than application to the lower surface only. In these series the emulsifying agent does not seem to have affected the transpiration rate.

Leaf Age as a Factor in Effect of Oils on Transpiration

Not only is it true that the two surfaces of the apple leaf are always very different, but their structure does not always remain the same. It has been pointed out by Ruth and Kelley^{25, 26*} that these surfaces change with age and that the character of the surfaces determines to a great extent the ease of wetting and the amount of the spray material which is retained. Both surfaces of the apple leaf are pubescent when very young. The upper surface gradually becomes glabrous with an accumulation of cutin, while the lower epidermis always retains a considerable part of its pubescence. If the cuticle is difficult

TABLE 5.—EFFECT OF SURFACE COVERED BY SPRAY

(Grimes variety; spray applied with an atomizer at a concentration of 2 percent. Series 11 was sprayed at 10 a. m., September 29, 1926; the temperature was 69° F. and the relative humidity was 67 percent. Series 12 was sprayed at 2 p. m., October 5, 1926.)

Series No.	Spray used	Part of surface covered	Number of shoots in each treatment	Area of leaf surface	Preliminary transpiration rate per square inch per hour 2:30 p. m. to 9:30 a. m.	Transpiration rate per square inch per hour after treatment (46 hours)	Rate after treatment as percentage of preliminary rate
11.....	Casain-lime, cold-mix..	Upper	3	sq. in. 67.09	cc. .0327	cc. .0146	44.6
		Lower	3	69.49	.0363	.0097	26.7
	Casain-lime alone.....	Both	2	51.72	.0336	.0095	28.2
	Water.....	Both	1	25.15	.0328	.0144	43.9
		Both	3	65.72	.0357	.0161	45.1
12.....	Casain-lime, cold-mix..	Upper	3	88.40	.0391	.0391	100
		Lower	3	75.27	.0355	.0231	65.1
		Both	2	59.80	.0394	.0238	60.4
	Casain-lime alone.....	Both	1	31.40	.0379	.0379	100
	Water.....	Both	3	80.50	.0383	.0384	100.2

to wet with a particular spray, the presence of hairs usually facilitates the wetting. It has also been shown that the stomata are not fully developed and functional to the greatest degree in very young leaves.^{2, 17*} The author^{13*} also has shown that older apple leaves transpire more rapidly than younger ones from the same shoot.

The comparative effect of oil sprays on old and young leaves is shown by the data in Table 6. The tip of the shoot with eight to ten leaves was cut off and placed in one potometer, and the basal portion was placed in another potometer, the central part of each shoot being discarded in order to further increase the age differences in the leaves used. Comparisons are therefore between young leaves and older leaves from the same shoot.

All the oils retarded the transpiration of both ages of leaves but the reduction was much greater in the case of the older leaves. There did not seem to be any significant difference between the saturated and unsaturated oils in their effect upon transpiration. Casein-lime, the emulsifier used, again had little, if any, effect.

Effect of Oil Concentration

One of the important factors in oil injury is the percentage of oil in the diluted spray. Other things being equal, the higher the percentage of oil when injury occurs, the greater the damage. Unfortunately, only one series was run to determine this point; the data for this series are given in Table 7.

It should be kept in mind that the concentrations of the oil in the sprays used in these experiments were within the limits usually given for safe spraying and that no visible injury was observed on the foliage at any time. The data in Table 7 indicate that a 2-percent spray retarded transpiration more than a one-half of 1 percent dilution. This might be expected since, if the effect is due to penetration, the higher the concentration, the greater the amount of oil which would enter the leaf. A single shoot sprayed with a soap solution, the emulsifying agent used in the oil sprays, transpired only slightly less than the shoots sprayed with water, indicating again that the reduced transpiration was due mostly or entirely to the oil in the spray.

Required Interval for Effect of Oil to Become Evident

Knight *et al*.^{16*} have shown by microchemical tests that oil penetrates the leaf tissue. The author^{12*} demonstrated in 1929 not only that oil penetrates the leaf, but that it enters as an emulsion thru the stomata soon after application and before the spray dries upon the leaf. Series 2 and 3 were planned to determine how soon after application the reduction in transpiration could be measured. Readings were made at 30-minute intervals.

TABLE 6.—EFFECT OF SPRAYS ON OLD AND ON YOUNG LEAVES OF GRIMES VARIETY WHEN APPLIED BY DIPPING

Spray used	Date	Time of application	Environmental conditions when sprayed		Number of shoots in each treatment	Length of period after treatment	Rate of transpiration after treatment, expressed in percentage of preliminary rate			
			Temperature	Relative humidity			Terminal leaves		Basal leaves	
							Sprayed	Check	Sprayed	Check
	1926		° F.	perct.		hours				
Volek, 3 percent.....	Aug. 2	4 p.m.	74	68	4	17	34.05	64.58	17.66	62.18
Casein-lime.....	Aug. 2	4 p.m.	74	68	4	17	61.68	64.58	59.12	62.18
Saturated oil, 2 percent.....	July 24	6 p.m.	..	..	2	38			20.93	54.93
Unsaturated oil, 2 percent.....	July 24	6 p.m.	..	..	2	38	23.65	51.38	17.09	54.93

TABLE 7.—EFFECT OF OIL CONCENTRATION ON TRANSPIRATION OF GRIMES VARIETY WHEN SPRAY WAS APPLIED BY DIPPING

(Application of spray was made at 7 p.m., October 14, 1926; the temperature was 69° F. and the relative humidity was 46 percent. A saturated oil was used in making the emulsion.)

Spray used	Concentration	Number of shoots in each treatment	Area of leaf surface	Preliminary transpiration rate per square inch per hour	Transpiration rate after treatment per square inch per hour	Rate after treatment as percentage of preliminary rate
	perct.		sq. in.			
Oil emulsion.....	2	2	38.90	.0628	.0158	25.1
Oil emulsion.....	1/2	3	63.55	.0751	.0298	38.54
Soap.....	...	1	21.95	.0779	.0378	48.82
Water.....	...	3	59.72	.0721	.0386	53.67

The reduction in transpiration was measurable within 30 minutes after application (Table 8), indicating that the effect of the oil must have started immediately after spraying. This seems reasonable since the author^{12*} has shown that the emulsion enters the stomata before the spray dries. Grimes, Jonathan, and Delicious reacted similarly to the oil, altho there was a suggestion again that those varieties which transpired most rapidly were affected most by the oil. There did not seem to be any constant significant difference between the effects of saturated and unsaturated oils. This fact, together with the rapidity with which the reduction in transpiration starts, indicates that the effect is physical rather than chemical.

Effect on Day and Night Rates Compared

Under normal conditions the relative humidity is usually higher and the temperature lower at night. These environmental factors, therefore, together with the closure of the stomata, tend to reduce the transpiration rate during darkness. Series 5, 6, and 7 (Table 9) indicate the effects that the oils have on the day and night rates.

Several deductions may be made from the data in Table 9. As has been true in former series, the oil invariably reduced the transpiration rate. In all three series the night rate of the checks was considerably lower, the range being from 67 to 82 percent of the day rate. This was true in spite of the fact that in Series 5 and 6 the night rate was determined first, and it has been shown by the author^{11*} that the transpiration rate of cuttings decreases as the interval of their separation from the plant increases. Since the humidity and temperature were recorded only at those periods when potometer readings were made, these data are not adequate to evaluate fully the effect of these factors on the rate of transpiration. The temperature was uniformly moderate, however, and the humidity was rather high in all three series during both the day and night periods. The younger oil-sprayed leaves also transpired more slowly during darkness than in the daytime, but the older oil-sprayed leaves in Series 6 transpired at practically the same rate both day and night and in Series 5 and 7 at a considerably higher rate during darkness than in the daytime. It does not seem possible to explain the higher rate of the oil-sprayed older leaves during darkness. The difference cannot be accounted for on the basis of environmental facts because the checks transpired more slowly at night. The fact that only the older leaves were thus affected suggests that the higher rate was a stomatal phenomenon, and that the stomata on these leaves did not entirely close during darkness. Observations in early morning, however, showed that the stomata on both sprayed and unsprayed leaves were closed.

TABLE 8.—INTERVAL AFTER SPRAYING REQUIRED FOR REDUCTION IN TRANSPIRATION TO BEGIN
(The period after treatment for Series 2 was 42 hours and for Series 3, 62½ hours. Concentration of oil was 1½ percent.)

Series No.	Variety	Spray used	Number of shoots	Transpiration rate after treatment, expressed in percentage of preliminary rate		
				First 30-minute period	Second 30-minute period	Entire period
3.....	Grimes	Saturated oil Unsaturated Water	1	18.9	12.7	21.5
			2	8.9	13.5	13.6
			2	56.0	110.2	32.0
2.....	Jonathan	Saturated oil Unsaturated Water	2	16.4	28.0	27.6
			2	16.0	34.0	29.2
			1	67.0	133.5	64.6
	Grimes	Saturated oil Unsaturated Water	2	13.4	9.5	15.5
			2	18.7	12.7	13.2
			2	96.0	64.0	40.6
	Delicious	Saturated oil Unsaturated Water	1	7.7	7.7	16.5
			2	21.1	17.5	13.9
			2	35.0	69.5	46.9

TABLE 9.—EFFECT OF OIL SPRAYS ON DAY AND ON NIGHT RATES OF TRANSPIRATION IN GRIMES VARIETY
(Series 5 and 6 were started on August 2, and Series 7 on September 16, 1926. Two shoot; were used for each treatment.)

Series No.	Spray used	Age of leaves	Average transpiration rate after spraying				Ratio of night rate to day rate	Environmental conditions			
			In percentage of preliminary rate		In cubic centimeters per square inch per hour			Relative humidity		Temperature	
			Day rate	Night rate	Day rate	Night rate		Day	Night	Day	Night
5.....	Volek	Younger	36.7	26.2	.0135	.0096	75 } 67 } 115 } 75 }	perct.	perct.	° F.	° F.
	Water.....	Younger	74.9	50.1	.0266	.0178		82 at	68-82	73 at	73-74
	Volek.....	Older	12.4	14.3	.0055	.0063		8:30 a.m.	Range from	8:30 a.m.	Range from
	Water.....	Older	66.6	50.0	.0283	.0214			8 p.m. to 4:15 a.m.	8 p.m. to 4:15 a.m.	8 p.m. to 4:15 a.m.
6.....	Volek	Younger	42.9	30.7	.0157	.0112	71 } 69 } 98 } 82 }				
	Water.....	Younger	78.1	54.0	.0275	.0190					
	Volek.....	Older	22.8	22.4	.0089	.0087		82 at	68-82	73 at	73-74
	Water.....	Older	72.1	64.2	.0274	.0226		8:30 a.m.	Range from 8 p.m. to 4:15 a.m.	8:30 a.m.	Range from 8 p.m. to 4:15 a.m.
7.....	Saturated....		24.3	54.4	.0051	.0096	189 } 203 } 82 }				
	Unsaturated..		28.5	54.8	.0038	.0087		86-83	83 at	72-79	75-80
	Water.....		176.4	143.6	.0308	.0252		Range 7 a.m. to 6:30 p.m.	6:30 p.m.		

DISCUSSION

Three questions of major importance naturally arise for solution in a discussion of these data: (1) How do oil sprays bring about a retardation in transpiration? (2) Is the effect of oils physical or chemical? (3) What effect does such a retardation in transpiration have upon the plant?

Oil Sprays Affect Stomatal Behavior of Leaf

Direct evidence shows that oil sprays affect the stomatal behavior of the apple leaf. Microscopical examinations of lower epidermal strips, according to the method of Lloyd,^{14*} show that when oil emulsion is applied to the underside of the leaf, the stomata do not open so wide as on unsprayed foliage. Differences in stomatal aperture were evident nine days after spraying.

There is also considerable indirect evidence that oils affect the stomatal behavior. In the first place they reduce the transpiration only when applied to the underside of the leaf, where the stomata are located. This also is in agreement with the evidence on oil penetration reported on by the author.^{12*} In this experiment it was found that penetration of the emulsion occurred only when the spray was applied to the underside of the leaf. Knight *et al*^{16*} also concluded that the penetration of oil in citrus was much greater when applied to the lower epidermis where the stomata were situated.

Further evidence of a stomatal effect is deduced from the fact shown by the data that oil sprays retard the transpiration of older leaves to a greater degree than when applied similarly to younger foliage. Palladin^{23*} states that the transpiration rate of very young leaves is highest because of the permeability of the epidermis to water, and that the rate then decreases but later reaches a second maximum when the stomata begin to function. Bergen^{2*} and more recently Koketsu^{17*} show that transpiration is greatest in leaves at the height of their development. This is probably true also of the apple leaf and is additional evidence that the retarding effect of the oil is a stomatal phenomenon since it is greater on older leaves in which the stomata are fully developed and functional to the highest degree.

On the theory that stomata open in response to the turgidity of the guard cells, the lessened transpiration would indicate that oils in some way lower the water content of the leaf, possibly by reducing the soluble carbohydrate. Hagen,^{9*} in a study of the influence of the contents of the guard cells on stomatal aperture, found that their opening was associated with the presence of sugar. Knight *et al*^{16*} and also Burroughs^{3*} have reported that oil sprays under some conditions materially reduce the manufacture of carbohydrates.

Effect of Oils Appears Physical, Not Chemical

The evidence from these experiments tends to show that the physiological effect of oils is due to physical and not chemical causes. This statement is based primarily on the results obtained in the comparisons with saturated and unsaturated oils. There did not seem to be any constant significant difference in their effect, the highly refined white oils reducing transpiration just as much as the ordinary unsaturated spraying oils. There was no visible injury with any of the oils. These results are in agreement with the work of the author^{12*} on the effect of saturated and unsaturated oils on the respiration and growth of the dormant twigs and foliage of the apple. The degree of refinement of the oils seemed to be a relatively unimportant factor. Viscosity was of much more importance, the lighter oils under some conditions retarding growth much less than the heavier oils. Knight *et al*^{16*} also conclude from their experiments that the effect of the oils is physical rather than chemical.

Retardation Indicates Interference With Transpiration Mechanism

The degree of retardation in transpiration when sprays containing oils are applied to the undersurface of the leaf indicates that such sprays interfere with the transpiration mechanism. Whether such an interference is detrimental to the plant, it is not possible to conclude directly from these experiments. However, if one of the principal functions of the transpiration stream is to provide an adequate water film in the cells for the absorption of carbon dioxide, it would seem that anything which would reduce the transpiration rate as much as 50 percent would interfere seriously with metabolism. It does not follow, however, that a reduction in the amount of water transpired would necessarily reduce the water content of the foliage to the point where it would interfere with metabolism. It is even conceivable that a reduced transpiration might result in an actual increase in the percentage of water in the leaf tissues provided the intake of water thru the roots continued as usual. Such an increase might result in a waterlogging of the tissues, which might interfere with metabolism more than a deficiency of moisture. Manifestations of oil injury, such as yellowing foliage, abscission of leaves, and stunting of foliage growth, which are found as observations in horticultural literature, would indicate that under some conditions at least oil sprays interfere seriously with metabolism. The experiments of Knight *et al*^{16*} and Burroughs,^{3*} which show that oils interfere with photosynthetic activity, also indicate such an interference.

SUMMARY AND CONCLUSIONS

1. Saturated oils (highly refined, white) and unsaturated oils (lower degree of refinement, colored) were tested in their effects upon the transpiration rates of the apple, pear, peach, plum, and sour cherry. Comparisons were made of different concentrations; of applications to the upper, lower, and both surfaces; and of applications to older and younger leaves. Three emulsifying agents were used.

2. All the oils retarded the transpiration rates of all the species and varieties studied, the reduction being in many cases more than 50 percent and in a few instances as high as 75 percent.

3. Spray applied to the upper surface of the leaf had no effect upon transpiration, but when applied to the lower surface a marked retardation was evident. Spraying both surfaces reduced the rate no more than spraying the lower surface only.

4. The reduction in transpiration was greater with older than with younger leaves. These comparisons were made between the terminal and basal sections of the same shoots.

5. Stomatal examinations of sprayed and unsprayed apple leaves showed that the stomata on leaves sprayed on the undersurface do not open so widely as on unsprayed leaves. Such behavior may be due to a reduction in soluble carbohydrate in the sprayed foliage, which lowers the turgidity of the guard cells.

6. The degree of retardation in transpiration rose with the increase in concentration of the oil. However, one-half of 1 percent, the lowest concentration used, caused a definite decrease in rate.

7. There was no constant significant difference between saturated and unsaturated oils in their effects upon transpiration. This suggests that the effect of the oil is physical rather than chemical.

8. The effect of the oil upon transpiration became evident soon after application, differences being measurable within thirty minutes after application. The retarding effect continued as long as it was possible to continue the transpiration studies with cuttings, which was a maximum period of about three days. Differences in stomatal aperture on leaves on the tree were noted nine days after spraying.

9. These experiments suggest that oil foliage sprays should be used with caution; that highly refined oils may not be a guarantee against injury; that the undersides of leaves should not be sprayed unless such spraying is essential for the control of insects; and that oils should not be applied when the humidity is very high.

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