Wind Machine Tests in Citrus

frost protection studies in 1954 confirmed earlier findings next to be investigated in deciduous trees

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Tests of wind machines made in January and February, 1954, at the University of California Citrus Experiment Station, Riverside, confirmed and extended previous tests of multiple machines.

During investigations of wind machines started in 1947, three kinds of tests have been made: *1.* Off-on-off tests which compared operating conditions with natural conditions within the orchard in a time sense. *2.* The inside operating conditions compared with conditions observed outside the test area at the same time. *3.* Comparison of heater system with wind-machine system on the same night and reversing the order of tests the following night.

There was further confirmation by interpreting responses on a heat-transfer basis, using direct measurements of sky radiation and of heat conduction into the ground, and the measured change of the temperature profile in the airdrift due to mixing induced by the air jet.

Although the field tests are too variable to treat statistically to show the degree of reliability of interpretations, the results are averages of two to six tests each and well fortified by using the several test techniques and repeated comparison with commercial experience:

Firstly, tests were limited to calm, clear sky radiation conditions usually ending with light frost. Tests were not started until the temperature at tree level was 40°F or less and unless there was a typical cold airdrift from an easterly direction.

Secondly, the instrumentation was extensive with the automatic recording of 65 temperatures, four heat-flow rates, 10 air velocities, and seven directions.

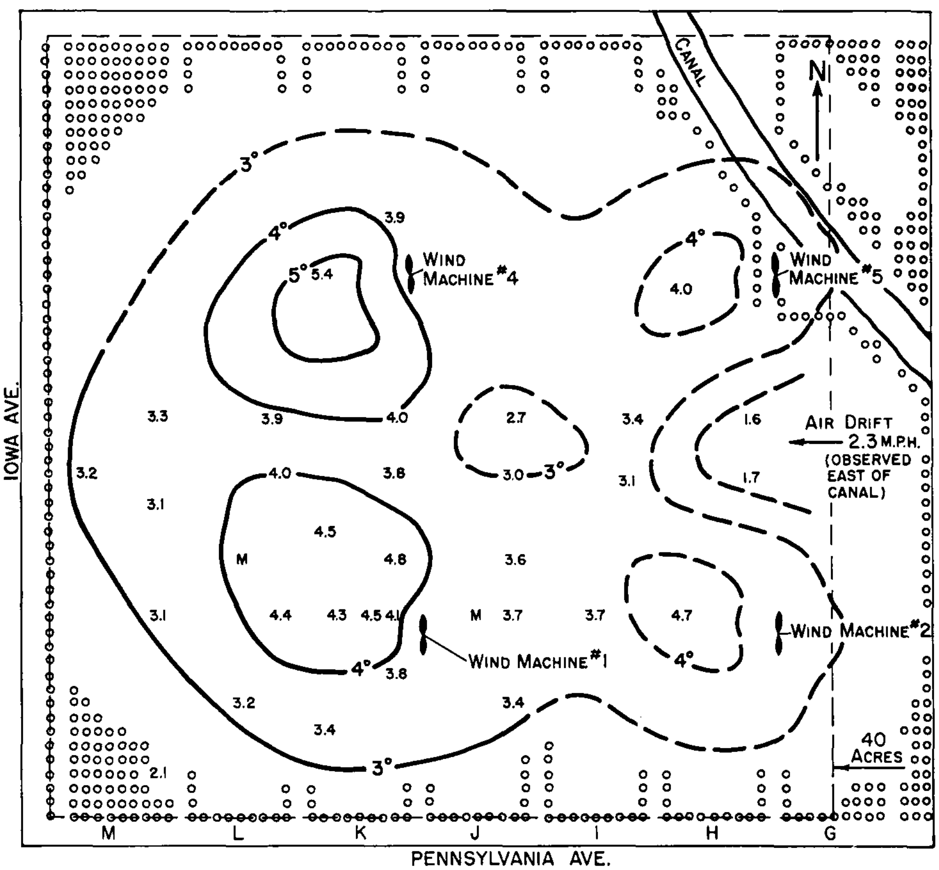
Thirdly, from a half to one hour was always allowed for transitions from an operating period to natural period. Then the readings taken about every four minutes were averaged—usually over one-hour periods—for each of the elements recorded.

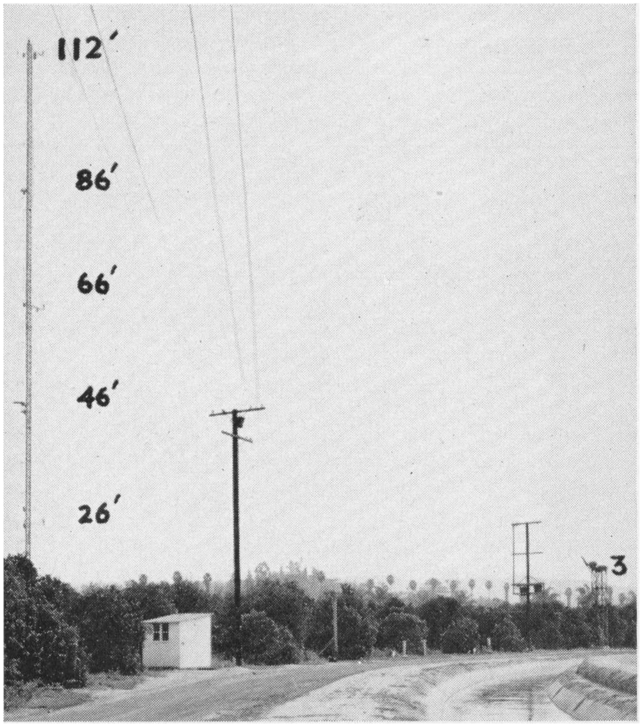
The most important finding of 1954 resulted from the comparison of four small machines with four large machines, all on a 600′ rectangular setting.

The diagram on this page is a plan view of 40 acres of mature citrus showing the distribution of the averaged response of six tests on four large machines, each with a thrust of 830 pounds using 70 bhp—brake horsepower. The result is very satisfactory and confirms last year's report that the two machines first receiving the cold airdrift—averaging about 2.3 miles an hour—act nearly as isolated, single machines, but the pair 600′ farther downdrift affect each other strongly and maintain a belt between them of more than 3°F temperature rise when the air at 40′ is 10° warmer than that at 7′.

With each of the four machines reduced to 300 pounds thrust—corresponding to 19 bhp each—the average response of three tests, adjusted to 10°F inversion, is shown in the diagram on the next page. Even though the response of the two machines farthest updrift is nearly what is expected of independent single machines, the two machines downdrift are positively influenced by the first two. This is evident in nearly 3° response. In this location, the first two machines should have been closer together transversely to the drift. The observed protection area for 2°F is about 5½ acres per machine in multiple installation and figures 3½ bhp per acre, but this should be considered less than a minimum multiple installation for the orchard and location conditions at the Citrus Experiment Station. This confirms the minimum estimate made last year that 15 bhp machines may be spaced 400′ apart transversely to the cold airdrift and 550′ apart in the line of drift.

Plot diagram of the average temperature response for four 830-pound thrust—70 bhp—wind machines in an inversion with the temperature at 40′ 10°F warmer than at 7′ above ground. This shows strong interaction between the two machines, No. 1 and No. 4, farthest downdrift. All the machines were turning 180° in four minutes in the downdrift direction and 180° in 1⅓ minutes against the drift. The machines are spaced 600′ apart.

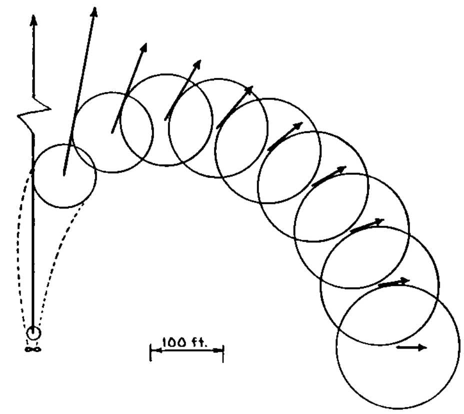




Photograph showing the 114′ mast at the outside station used to determine air velocities, directions, and temperatures of the airdrift entering the test area. In the distance is seen wind machine No. 3 not used in this winter's tests except for frost protection.

By similar reasoning, the four 70 bhp machines could have been spread farther apart for a minimum installation in this area. Possibly 700′ × 900′ could have been used if 2°F protection is considered adequate, as mentioned for the four 19 bhp machines. With 70 bhp machines, this would figure nearly five bhp per acre or up to nine rated horsepower for a gasoline engine.

Most growers need more than 2°F protection and wish to minimize the use of supplementary heaters in colder weather. Whether more horsepower, per machine and per acre, is cheaper than firing heaters more often, in support of small-powered wind machines, depends on the frequency and severity of frosts. Frosts naturally vary with each orchard—primarily because of location, age, velocity of cold airdrift, and ground condition.



Plan view diagram of direction and velocity of successive sections of an air blast for each 10° turning of the propeller axis—approximately every 14 seconds. The sizes of the circles indicate the normal increase in volume due to the progressive entrainment of surrounding air. The first arrow should represent the maximum velocity at the propeller which is about 15 times greater than the velocity arrow 10° later. The length of the arrow for each circle indicates the magnitude of the radial velocity and outward direction of movement in an idealized case—calculated for 800-pound thrust, neglecting drift and orchard roughness.

The Turning Jet

To move a jet of air transversely to its axis—like smoke from a moving locomotive—introduces a shearing effect that greatly retards the outward flow. In such a case, instead of jet velocities decreasing in direct proportion to distance—as is true of stationary jets—the velocities in moving jets utimately decrease approximately as the arithmetical square of the distance. Furthermore—if instead of moving transversely—the jet is turning, the retardation increases with distance so that the velocity decrease of the ultimate expanding ring would be as the cube of the distance.

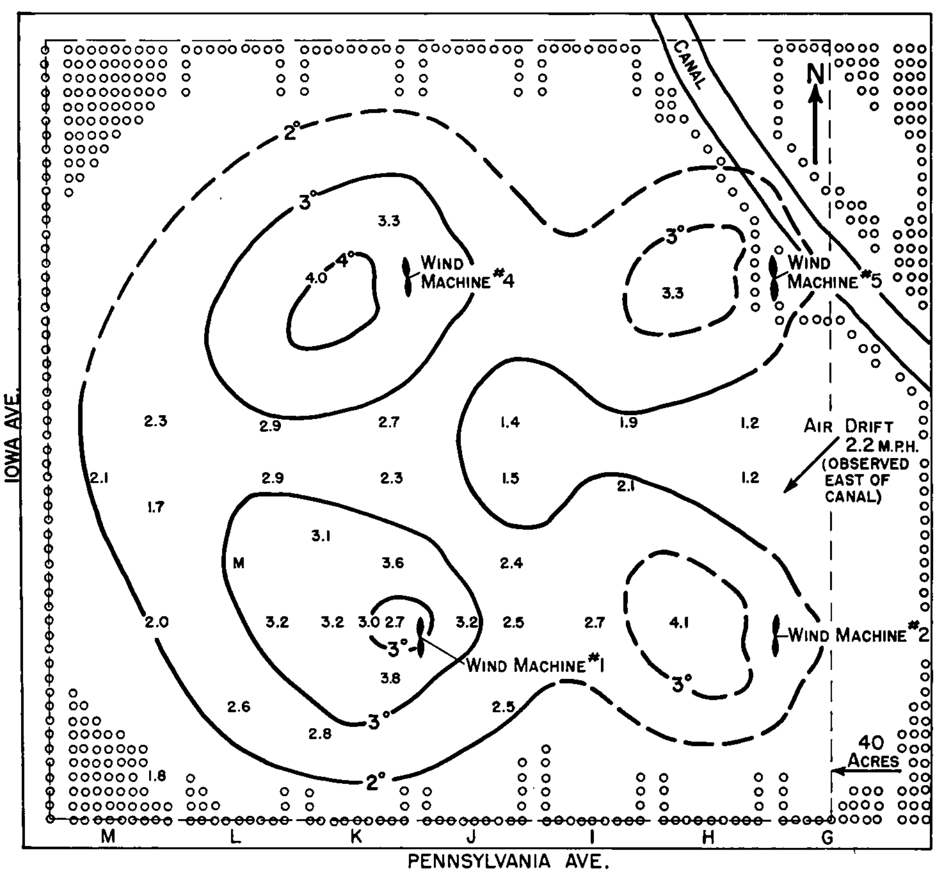
The transition from a simple jet near the source to the slowly expanding ring at considerable distance is not known precisely, but photographs of air-stream models indicate the pattern as shown in the diagrammatic drawing at the top of this column.

To apply this theoretical study to actual orchards, a group of special tests were carried out with high-speed instruments. An additional portable tower, equipped with five anemometers—wind gauges—from 16′ to 65′, was installed at the test location.

If there were no irregularities in airdrift, the air blast from a 70 bhp machine turning 45° a minute would reach a station 400′ from the tower in about 54 seconds. Time measurements in the orchard, however, showed large variations and a shortening of the time obvi-

Concluded on next page

Plot diagram of the average temperature response for four 300-pound thrust wind machines—19 bhp—in a 10°F inversion showing virtually independent action of the two updrift machines but positive interaction of the two downdrift machines and bigger individual response areas. The machines are placed and operating as in the diagram on page 8.



WIND MACHINES

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ously caused by crossdrift. The extent of this erratic behavior in airdrift—March 5, 1954—is shown most clearly in the tables on this page, especially by the highly variable times of arrival of the blast at the 400′ station. Sometimes the crossdrift bent the jet centerline so far that the jet appeared even before the machine directly faced the station—negative time values—and occasionally the blast was not felt at all.

A previous assumption was that a miss meant that the air jet passed by overhead, but the five anemometers up to 65′ above the ground failed to show any velocity spurt whenever there was a miss at 26′. This shows that occasional air eddies at Riverside may be strong enough to telescope a turning jet so that, for instance, only the weakest segment of the jet reaches the station with its velocity indistinguishable from natural airdrift. Because of the uncontrollable variability in natural conditions, model studies are to be undertaken next year to determine the relationships between temperature response in an orchard and the idealized jet pattern represented in the drawing on page 9.

The tests on frost protection by wind machine completed in 1954 pretty well define the results to be expected in citrus orchards near Riverside from single machine and from multiple installations of various power. The desirable variation of spacing distance with power is also fairly evident, so the main lack in the test data is now in variation of cold airdrift velocity and in variation of tree form and spacing. Therefore, next year's tests are planned for deciduous orchards.

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Natural drift velocities—½ minute average—before arrival of blast at 33-foot level, and times of arrival of the peak velocity of successive blasts at each level 200 feet from the machine. Times were measured relative to when the propeller axis pointed directly at the anemometers. The machine was operating at 830 pounds thrust, set at 2° down-pitch and turning 45° per minute.

Blast	Time	Drift velocity (mph) at 33′	Arrival time of blast (seconds) 16′	25′	33′	45′	65′
1	10:49 P	2.17	10	15	11	11	26
2	10:55	2.62	3	7	8	12	21
3	11:00	2.06	10	11	11	7	26
4	11:05½	1.30	4	8	9	8	None
5	11:10½	2.39	3	0	6	5	None
6	11:16	1.72	5	3	5	3	None
7	11:21½	1.67	4	2	4	3	None
8	11:27	1.67	7	6	6	6	None
9	11:32	2.39	4	1	3	2	None
10	11:37	2.06	1	0	0	1	None
Ave. for 10		2.00	5.1	5.3	6.3	5.8	. .
11	11:42½	2.39	2	2	0	–5	None
12	11:48	2.73	3	3	3	–2	None
13	11:53	2.95	–16	–20	–8	–7	–17
14	11:58	2.84	–6	–2	–2	–3	None
15	12:03½ A	3.23	3	–1	1	1	None
16	12:09	2.95	4	0	–1	0	None
17	12:14½	2.73	4	–2	–1	–3	None
18	12:20	2.28	–2	–2	–4	–4	None
19	12:25	2.68	2	–2	–1	–2	None
20	12:30½	2.57	3	3	3	8	None
Ave. for 10		2.74	–0.3	–2.1	–1.0	–1.7	. .

Natural velocities and jet velocities at 33-foot level 400 feet from wind machine, and times of arrival of peak velocities at five levels with the machine operating at 830 pounds thrust, set at 2° down-pitch and turning 45° per minute.

Blast	Time	Drift velocity at 33′ (mph)	Max. blast velocity mph	Arrival time of blast (seconds) 16′	25′	33′	45′	65′
1	10:36½ P	2.45	9.9	29	21	22	16	7
2	10:42	1.90	. .	51	50	62	50	54
3	10:47½	1.78	. .		Blast Missing			
4	10:53	3.12	. .	43	44	43	43	45
5	10:57½	2.39	8.2	23	22	20	18	35
6	11:03	2.35	8.5	12	12	9	16	21
7	11:08	3.70	7.6	7	3	–3	2	4
8	11:13	3.81	8.8	–2	–2	–3	0	1
9	11:19	4.34	. .		Blast Missing			
10	11:24	4.85	8.6	–17	–3	–4	–5	None
11	11:29½	4.40	6.3	33	32	9	10	None
12	11:35	3.81	7.9	37	35	37	36	None
13	11:40	2.00	7.8	34	33	33	40	53
14	11:45½	2.68	5.9	53	54	55	53	42
15	11:51	2.28	9.3	24	21	24	25	35
16	11:57	3.47	9.6	27	26	24	23	26
17	12:01½ A	2.73	6.3	22	28	29	27	31
18	12:07	1.19	5.9	44	49	47	44	52
19	12:12	3.06	. .		Blast Missing			
20	12:17	2.11	. .		Blast Missing			

LADINO

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After about six to eight weeks the mature larva drops to the ground, closes the open end of the case, and completes its development. Those larvae which overwinter may feed again in the spring before pupating.

There are very few natural enemies of the clover case bearer. It is inferred that the hymenopterous wasp—*Bracon pygmaeus* (Prov.)—will attack it, but none have been reared in California. Chemical control will also be very difficult because the materials which can be applied to the blooming crop without harming pollinators do not seem to be effective against the case bearer.

Cultural practices seem to be the most important controls. Seed fields should be pastured close in the spring, and the start of the seed crop delayed until May 15. In harvesting, the chaff should not be blown back into the field but should be carried away to be fed or burned. The trash and cleanings at the seed mills do not seem to create any hazard.

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