southeasterly wind has been noted at 11,000 feet above sea level with northwesterly gales below and aloft. An explanation of this phenomenon is offered herewith. The extreme velocity at 8,000 feet represents an increase in kinetic energy with a corresponding decrease in pressure energy according to the Law of Conservation of Energy.[4] The extreme velocity or kinetic energy is reduced after passing over the mountain range with a corresponding increase in pressure energy which acts similarly to a pressure head in a body of water when a rapidly moving stream enters it. There is a return flow on each side of the fast-moving stream, but in the case of the air moving rapidly over a mountain barrier the return flow is manifest only above and below the rapidly moving air stream. The return flow near the surface on the leeward side of a mountain barrier has often been noted. The return flow aloft is superimposed upon the velocity of the air mass moving over the mountain barrier which corresponds to a marked decrease in velocity. In the case of Lebec, the phenomenon has its maximum effect at 11,000 feet above sea level.

The phenomenon of increased pressure on the windward side and decreased pressure on the leeward side of mountain barriers should be kept in mind during the preparation of weather charts. It will often solve the question of apparent discrepancies in barometer readings and it is an important clue to direction and velocity of upper air winds when the latter data are missing on synoptic charts.

[4] For the mathematics of this phenomenon see page 206, second edition, Physics of the Air, by W. J. Humphreys.

DESERT WINDS IN SOUTHERN CALIFORNIA

By FLOYD D. YOUNG

[Weather Bureau office, Pomona, Calif., July 20, 1931]

The southern California coastal plain, one of the richest agricultural sections in the world, depends to a great extent on the mountain barriers on the immediate north and east for its comparative freedom from continental climatic influences. The mountains are effective for the most part in shutting out the desert climatic extremes, but there are times when they fail to afford complete protection.

Whenever a strong area of high barometric pressure moves in or develops over the Plateau region, the barometric gradient calls for northeast or east winds in southern California. Winds from either of these directions bring air from the elevated land areas of Nevada and nothern Arizona. The descent of this air to sea level along the southern California coast causes a warming by compression in the neighborhood of 27° F. When we consider that these desert air masses usually are relatively dry before this mechanical warming takes place, it is easy to account for the extremely low humidities sometimes registered during the progress of a desert wind in southern California.

Desert winds may occur in southern California almost any month in the year, but those which come during the summer months are usually light, and of minor importance from the standpoint of damage to crops. They do, however, cause exceptionally high temperatures and low humidity, with consequent acute fire hazard.

The most destructive desert winds occur during the fall and winter months, when temperatures are likely to be close to zero in Nevada. During the progress of these winter winds, temperatures usually are not unseasonably high in southern California, but the relative humidity is sometimes extremely low. Readings of the sling psychrometer at Pomona, made with the utmost care, have indicated relative humidities of 3 per cent. Psychrometer readings at such low humidities are, of course, subject to error, but it is probable that the relative humidity falls about as low in this region as anywhere in the world.

The air moving outward from the Plateau high-pressure area is blocked on the south by the San Gabriel and San Bernardino Mountains. Wherever there is a break in these southern chains, such as Cajon Pass, the desert air streams through it and out onto the Great Valley of southern California. If the pressure difference between Neavada and southern California is only moderate (0.16 to 0.40 inch) the desert winds usually are confined to rather narrow belts extending from the mouths of the passes to the ocean by the lowest and least obstructed routes. The air stream which issues from Cajon Pass under these circumstances probably is of greater interest and importance than any of the others.

Cajon Pass lies between the San Gabriel and San Bernardino Mountain ranges, extending roughly north and south, turning toward the southeast near its southern extremity. It is a V-shaped notch about 17 miles long and quite narrow, extending from the Mojave Desert on the north to the Great Valley of southern California on the south. The slope from the summit of the pass northeastward to the Mojave Desert is gradual, the summit being only slightly higher than the general level of the desert. The fall from the summit toward the south is more abrupt, averaging about 115 feet to the mile. The approach to the pass from the desert side is shaped like a great horizontal "V," with the sides formed by the mountains, which converge at the entrance.

Desert winds are seldom felt on the floor of the pass, but appear to remain at some elevation above the ground. Looking down from the San Bernardino Mountains during the progress of a moderate wind, the first clouds of dust appear about a half mile south of the southern gate.

These air streams from Cajon Pass usually maintain their identity in a remarkable manner. They move out over the valley floor (almost level to the eye, but actually sloping towards the south and west), swing toward the southwest, and either follow the canyon of the Santa Ana River through the Santa Ana Mountains or move directly over the low mountains south of the canyon and then follow a well-defined path over the almost level plains of Orange County and reach the ocean in the vicinity of Newport. On going eastward in the open country some 7 miles south of Cajon Pass, with light to gentle variable winds, one often passes abruptly into an air stream moving from the north-northeast at a velocity of 30 to 35 miles per hour. The easterly limits of the stream usually are just as well marked, and one passes from a near gale into a region of relative calm within the space of half a mile. The width of the air stream under these conditions probably will average about 5 miles. The same air current often is encountered in the perfectly open plains 15 miles or so to the southwestward, with its velocity and width substantially unchanged, and relatively calm air on either side. The stream may shift its position slightly from time to time, but appears to change but little in width or velocity. Sometimes it spreads out somewhat after passing the Santa Ana Mountains, but usually it follows a well-defined path to the ocean. It often comes over the south foothills at the western entrance to the Santa Ana Canyon, appearing in such cases to come down the hillsides in strong gusts directly along the ground.

WINDS CAUSED BY STEEPER PRESSURE GRADIENTS

The winds which have been described above are the result of moderate pressure gradients over Nevada and southern California. When the pressure difference is greater, from 0.45 to 0.70 inch, and especially when a

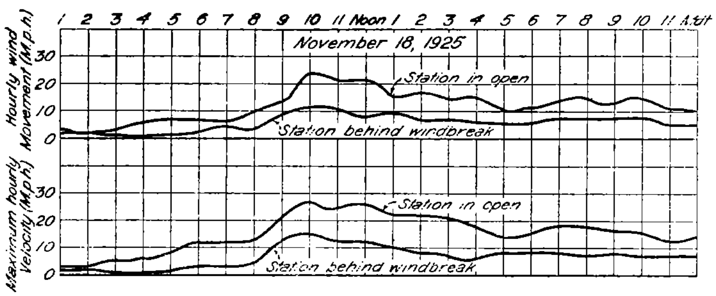


FIGURE 1.—Wind velocities 165 feet behind windbreak and at check station on November 18, 1925. (Four-cup anemometer)

low-pressure area is present over Lower California, the desert winds sometimes come directly over the mountain ranges. If the gradient winds are north, the sections directly south of the San Gabriel Mountains, which extend east and west, usually are not affected, but the wind is likely to appear at the surface about 10 miles south of the mountains. Under such conditions slow eddy currents carry heavy dust into the districts near the mountains, which make it appear locally that a west wind of 6 miles per hour or less is causing a dust which blots out the sun and limits visibility to about 500 feet.

If the gradient is northeast, strong desert winds often occur in sections almost immediately south of the range. Unusually low temperatures over the Plateau region

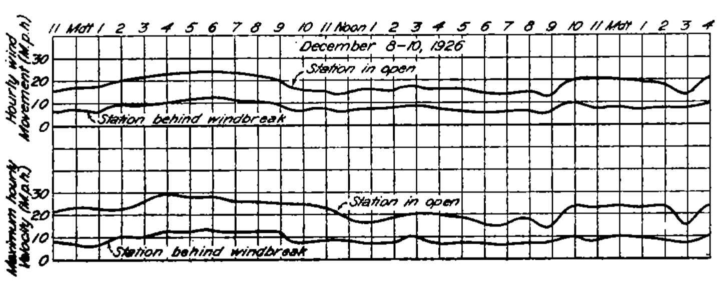


FIGURE 2.—Wind velocities 310 feet behind windbreak and at check station on December 8-10, 1926. (Four-cup anemometer)

commonly increase the severity of desert winds in southern California. When temperatures are relatively high over the Plateau, the winds blowing over the mountains normally remain at higher levels and do not reach the ground.

While these winds still cause heavy damage to citrus groves every few years, there is no doubt that the same pressure gradients produce surface winds of considerably less severity now than they did in the days when southern California was given over almost entirely to grazing. Windbreaks, orchard and shade trees, and buildings have moderated the fury of the gales which occurred in earlier times. Pioneer citrus growers tell of the terrific force of the desert winds of 50 years ago; of the unroofing of houses and barns, of crawling on hands and knees from house to barn to water the stock, and of the trunks of young trees almost severed by the cutting action of flying gravel and sand.

ELECTRICAL PHENOMENA

The extreme dryness of a desert wind causes charges of frictional electricity to build up on objects insulated from the ground. Heavy charges develop on the body varnish of automobiles, and when the driver reaches to

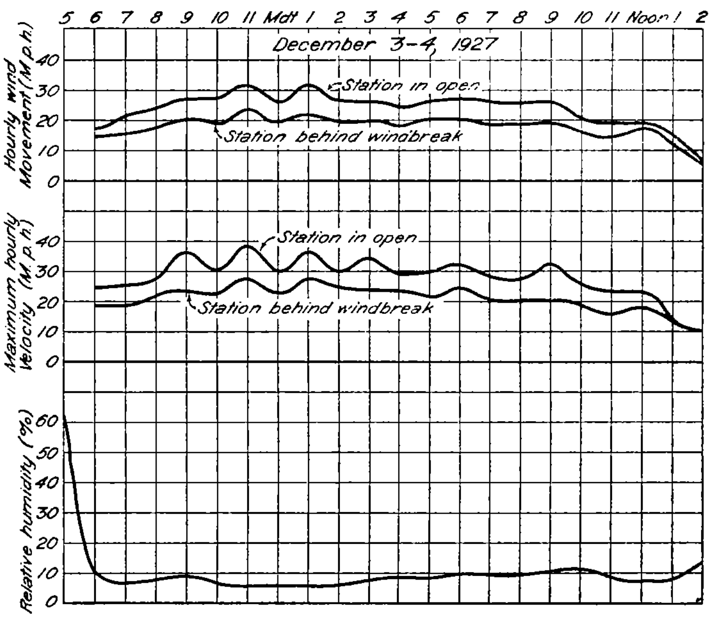


FIGURE 3.—Wind velocities 500 feet behind windbreak and at check station, and hourly relative humidity on December 3-4, 1927. (Four-cup anemometer)

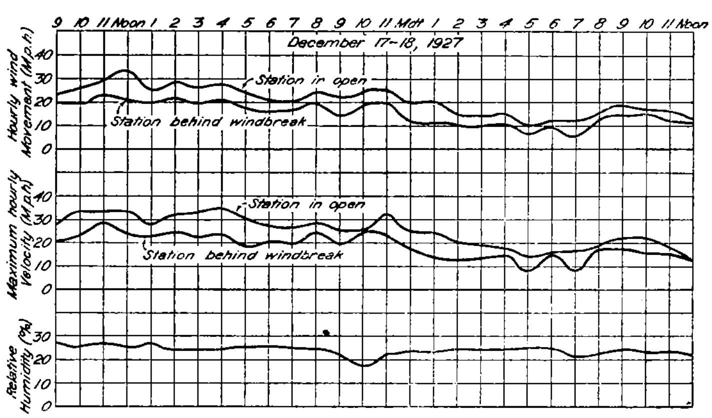


FIGURE 4.—Wind velocities 500 feet behind windbreak and at check station, and hourly relative humidity on December 17–18, 1927. (Four-cup anemometer)

open the door there often is an audible snap and an unpleasant sensation in the hand and arm as the discharge takes place. Reports have been made of the flashing luminosity of large pieces of bounding gravel carried by the wind at night, whenever they touched the ground. These electrical manifestations which are an accompaniment of desert winds with extremely low humidity, are erroneously believed by a large proportion of southern California residents to be the principal cause of damage to vegetation. In many sections the winds are known almost exclusively as "electrical storms."

DAMAGE TO CROPS

Damage to crops, especially citrus fruits, due to desert winds, is sometimes enormous. Citrus damage is of two kinds, the mechanical injury to the trees and fruits owing to the high velocity of the wind, and the desiccating effects of the extremely dry air on the foliage. When the wind velocity is high, 30 to 40 miles per hour, much fruit is blown to the ground and a great deal of that left on the trees is badly scarred through limb rubbing. Two desert winds which occurred in Orange County, Calif., during December, 1927, caused an estimated loss of 1,500 carloads of oranges through blowing the fruit from the trees. The manager of the cooperative marketing association in one district estimated that 35 per cent of the entire orange crop on the trees in his district was blown to the ground. In the most exposed portions of some orange groves, as many as 500 oranges were counted under individual trees after the wind. Fruit scratched or bruised through contact with limbs during a storm is much more subject to decay than sound fruit. If a period of rain or nights with heavy fog follows a strong desert wind within a few days, the injured fruits often decay on the trees.

Foliage injury, or "wind burn," as it is called locally, is due entirely to excessive dehydration of the leaves and small twigs in the extremely dry atmosphere. It is confined almost entirely to orange trees. Lemon and grapefruit trees seldom are damaged seriously. Partial defoliation of lemon trees sometimes results from desert winds, but it is due principally to the actual whipping off of the leaves by the wind rather than desiccation. Probably few fruits are grown under climatic conditions more unlike their natural environment than the citrus. The cultivated varieties of citrus originated in hot, humid climates, with heavy rainfall, and grew for the most part under partial shade.

It is not surprising, therefore, that they have difficulty in adjusting themselves to the extremely low humidity and relatively high velocity of the desert winds.

In December, 1927, orange trees in an area of about 35 square miles in Orange County, Calif., suffered about 20 per cent defoliation in two desert winds. (See figs. 3 and 4.) Most of this damage occurred in a period of less than 24 hours during the first storm. The more exposed orange groves suffered more than 50 per cent defoliation, and some individual trees were almost completely denuded of leaves. The shock to the trees materially reduced the size of the crop during the following season.

In the fall of 1924 defoliation due to desert winds in the same district was even greater than in 1927. Trees left in a weakened condition from loss of foliage were damaged much more severely by low temperatures in late December of the same year than those which had suffered no foliage injury.

Investigations made by the University of California and others have shown that defoliation by desert winds can be reduced through maintaining the trees in a thrifty condition and developing vigorous root systems, and by having adequate supply of moisture available to the trees immediately prior to the onset of the wind.

EFFECTIVENESS OF WIND BREAKS

Following the damaging desert winds in the fall of 1924, a study of the effect of windbreaks on the wind velocity and relative humidity was undertaken by the fruit-frost service of the Weather Bureau, in cooperation with the Villa Park Orchards Association and the Orange County Fruit Exchange. Records of wind velocity, relative humidity, and temperature were obtained at two stations in a citrus district subject to desert winds, one in an area without windbreaks and the other at varying distances behind a windbreak about a mile to the westward in the same general location. The windbreak was 1,280 feet long and extended north and south. Approximately one-half its length was made up of eucalyptus (blue gum) trees, about 95 feet high, and one-half Montrey cypress, about 70 feet high. (See fig. 5.) The windbreak trees were 30 years old. The orange trees, set 24 feet apart on the square, were 28 years old. Anemometers at both stations were placed 18 feet above the ground, or about two feet above the tops of the trees. Thermometers and hydrographs were exposed in fruit-region instrument shelters in the orange groves, 4.5 feet above the ground. The wind-break station was set 165 feet to the leeward of the windbreak the first season, 310 feet the second season, and 500 feet the third season. Wind velocities in the open (check station) and behind the windbreak during the progress of desert winds, are shown in the table below.

Smoothed records of hourly wind velocity during the progress of desert winds, at distances of 165 feet and 310 feet, respectively, behind the windbreak, and at the check station, are shown in Figures 1 and 2.

	Average hourly wind velocity [1]	Average hourly maximum velocity (5 minutes) [1]	Maximum velocity period of wind [1]
Nov. 18, 1925:			
Check station	12.0	15.0	27.0
165 feet behind windbreak	5.5	6.5	15.0
Decrease due to windbreak ....per cent	54	57	44
Dec. 8–10, 1926:			
Check station	18.0	22.0	29.0
310 feet behind windbreak	8.0	9.0	13.0
Decrease due to windbreak ....per cent	56	59	55
Dec. 3–4, 1927:			
Check station	23.1	27.6	38.0
500 feet behind windbreak	17.3	20.3	27.0
Decrease due to windbreak ....per cent	25	26	29
Dec. 17–18, 1927:			
Check station	20.4	25.7	34.0
500 feet behind windbreak	14.8	18.1	28.0
Decrease due to windbreak ....per cent	27	30	18

[1] Four-cup anemometers used.

The records indicate that the effectiveness of the windbreak is as great at 310 feet as at 165 feet, and that its effectiveness decreases by approximately 50 per cent at a distance of 500 feet. The openings between the trunks of the wind-break trees were large enough near the ground to permit considerable air movement through them, while higher up the heavy foliage of adjoining trees was interlaced, leaving few open spaces. It is believed that the wind entering the orchard near the ground increased the velocities shown at the 165-foot station and accounted for the lack of difference between the velocities at 165 feet and 310 feet. This breeze coming in between the tree trunks very close to the ground undoubtedly was spread and dissipated to a large extent by the resistance of the orange trees before it had traveled far into the orchard.

The two winds which occurred in December, 1927, noted in the table, caused considerably more damage to citrus trees and fruits than any others experienced during the time the wind-break study was carried on. Smoothed records of hourly wind movement and maximum hourly velocity at the check station and the station 500 feet behind the windbreak are shown in Figures 3

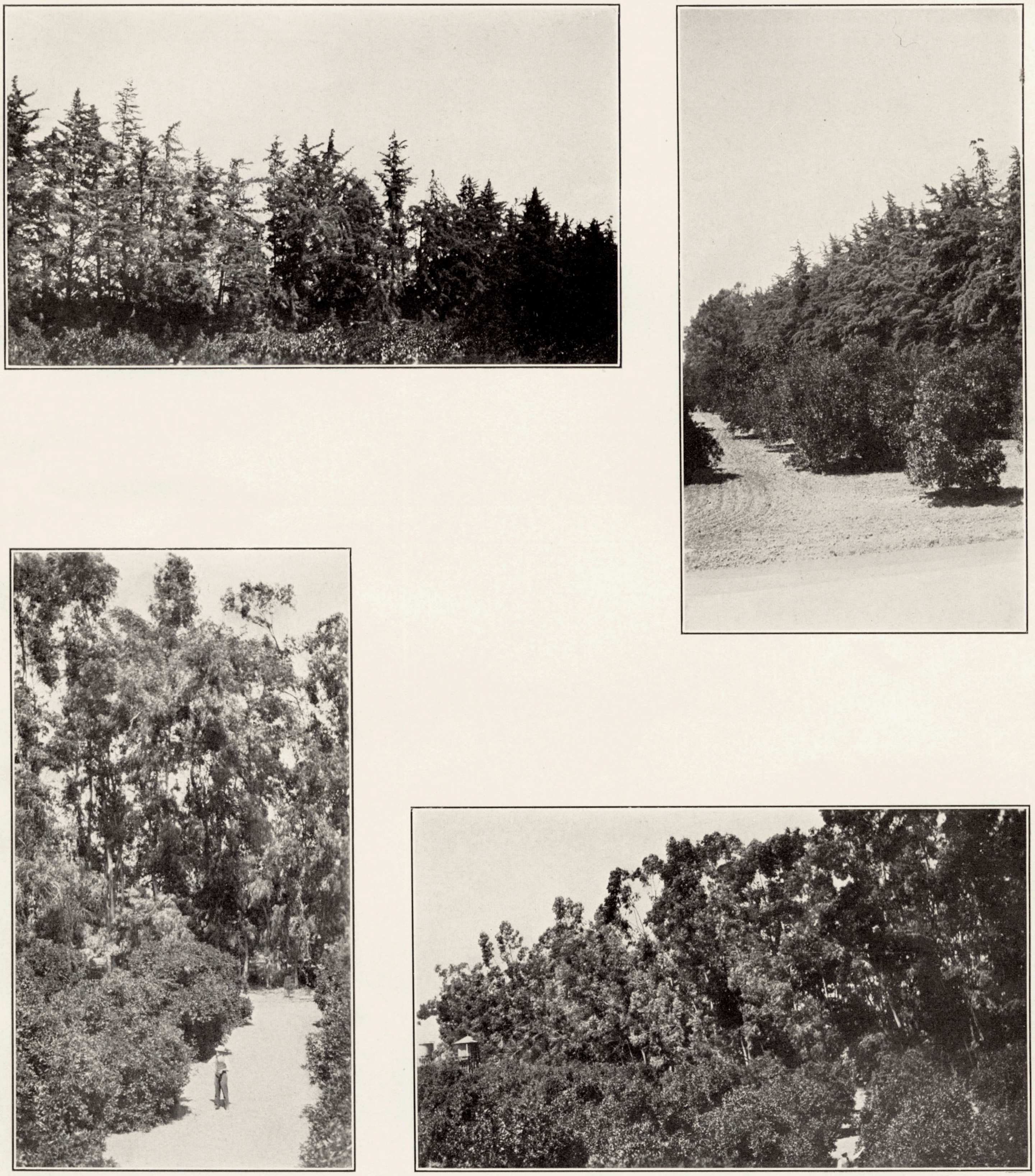
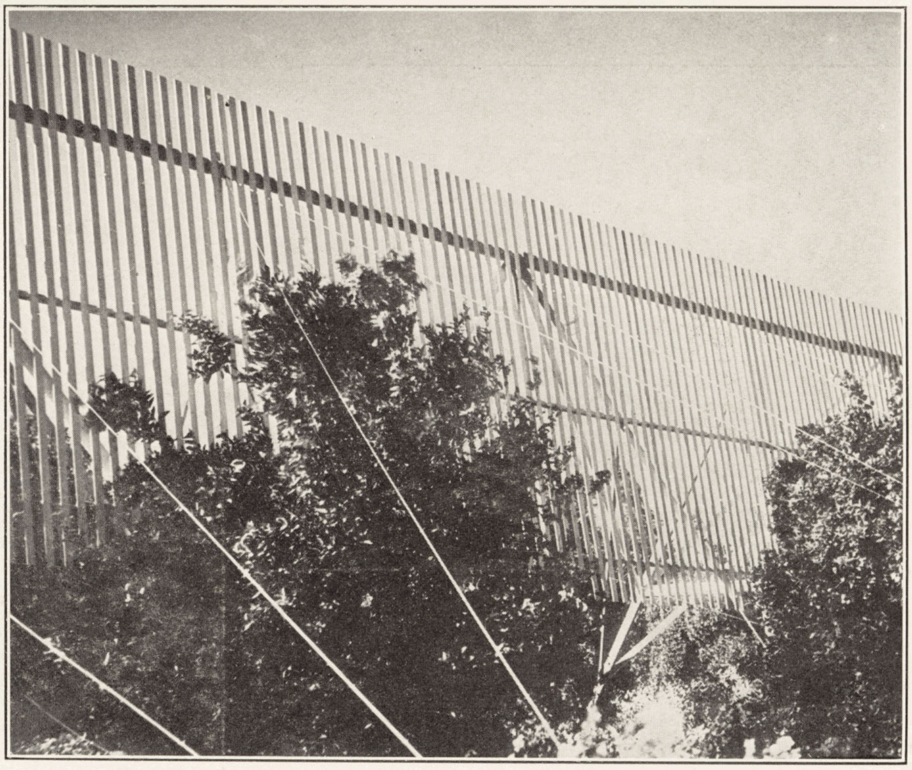


FIGURE 5.—Views of Eucalyptus and Cypress windbreak used in experiment



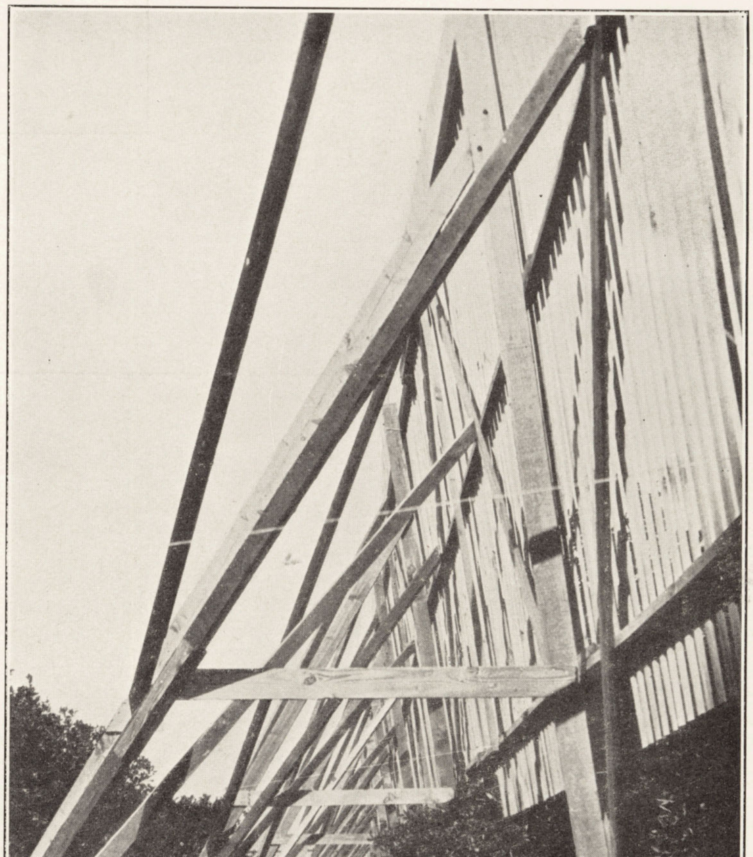


FIGURE 6.—Views of artificial windbreak 28 feet high in orange grove near El Modena, Calif. Many different types of artificial windbreaks have been developed, but none has been very successful in protecting mature citrus trees. Photos by H. A. Rathbone

and 4. Smoothed records of hourly relative humidity, taken from a carefully checked and regulated hair hygrograph, are included.

The records obtained during these two wind storms as well as the records of many lighter and less destructive desert winds, indicate quite definitely that "wind burning" of citrus trees occurs only when the relative humidity is unusually low. Heavy winds without excessively low relative humidity have caused no burning whatever, while relatively light winds with low humidity have never failed to cause some damage to foliage. While the dividing point on the relative humidity scale between burning and no burning varies slightly with different wind velocities and different conditions of the trees, all the records obtained in this study indicate that foliage burn is suffered only when the relative humidity falls to 10 per cent or lower. So far as could be determined, all the foliage burn which occurred during December, 1927, was caused by the first desert wind, on the 3d and 4th. The second wind, on the 17th and 18th, blew off many leaves which had been damaged in the earlier storm, but apparently caused no new burning. The second wind blew considerably more fruit from the trees than the first one, but this was owing to the fact that the loss of foliage during the first wind left the fruit on the inside of the trees without protection.

A careful inspection of the two orange groves in which the wind-break studies were carried on was made immediately after the desert winds of December, 1927. At the check station the average loss of foliage caused by "wind burning" was 30 per cent over the entire orchard. In the orchard behind the windbreak there were very slight indications of burning in the tops of the trees for a distance of 72 feet therefrom, probably caused by the wind which came through the lower part of the break. Soil moisture condition, due to the proximity of the wind-break trees, also probably was a factor. From 72 feet to 288 feet from the break there was no burning whatever. From 288 feet to 500 feet the amount of burn slowly increased from zero to about 2 per cent. From 500 feet to the western boundary of the orchard, 784 feet from the break, the damage increased more rapidly, the heaviest burn appearing in the last 250 feet. In the last row the foliage burn was estimated to be approximately 10 per cent.

In the orchard protected by the windbreak no fruit was blow off the trees for a distance of 288 feet. From this point to the 500-foot line fruits on the ground averaged four to the tree. From 500 feet to the western border of the orchard, 784 feet from the windbreak, the number of fruits per tree on the ground increased rapidly. A count of oranges under 10 trees in the last row showed an average of 30 per tree.

The number of oranges per tree on the ground in the check orchard varied from 98 to 452, with an average for all parts of the grove of 163.

The relative humidity was always somewhat higher behind the windbreak during relatively light desert winds, but there was little difference between the two stations during the heaviest winds.

These studies indicate that a windbreak such as the one for the orchard in which the records were obtained, affords practically complete protection from desert winds, both as to loss of fruit and damage to foliage, up to a distance of about 500 feet, and partial protection up to at least 800 feet from the break. Data on wind damage show the necessity for an adequate system of windbreaks throughout the sections visited most frequently by desert winds. The disastrous effects of desert winds in 1924 and 1927 resulted in the planting of many miles of new windbreaks in portions of Orange County, but lack of severe winds in recent years has resulted in many of them being removed. Large windbreak trees compete for food and moisture with citrus trees in adjoining rows, and cause some reduction in the crop of fruit. Also the planting of windbreaks throughout a large area increases the frost hazard to some extent. However, the protection from desert wind damage far outweight either of these factors in the districts most subject to wind damage.

Many different types of windbreaks have been devised in addition to the familiar lines of growing trees. Views of artificial windbreaks erected in an orange grove near El Modena, Calif., are shown in Figure 6. They are placed in every fourth tree row north and south, or about 96 feet apart, extend to a height of about 23 feet and are anchored firmly to heavy stakes driven into the ground. Their cost, when constructed with secondhand lumber, was slightly more than 75 cents per running foot.

Studies to determine the effectiveness of these windbreaks were carried on during the winter of 1930–31. Unfortunately the wind direction at the chosen location was subject to change from north to east, or vice versa, during the progress of desert winds, so that the wind direction was sometimes parallel to the windbreaks. When the wind was in the east its velocity midway between two breaks was reduced by approximately 50 per cent, but when the wind direction changed to north, the velocity was sometimes stronger between the breaks than at the check station. The windbreak structures withstood velocities as high as 20 miles per hour without any indication of weakness.

Acknowledgment is due Mr. Harold A. Rathbone, junior meteorologist in the Weather Bureau, for installing and caring for meteorological equipment at the two wind stations, and for keeping records of wind damage. The writer is grateful for his assistance.

SNOW COVER IN SOUTHERN CANADA AS RELATED TO TEMPERATURES IN THE NORTH ATLANTIC STATES AND THE LAKE REGION

By R. H. Weightman

[Weather Bureau, Washington, D. C., September 25, 1931]

It has been stated frequently, and apparently with reason, that a snow cover of more than normal amount over central and eastern Canada in the late winter should retard the usual rapid rise of spring temperatures in the Lake Region and the north Atlantic States, with resultant low temperatures over those regions during the spring months, particularly the month of April. Similarly snow cover greater than normal over northwestern Canada and northeastern Alaska in the late winter should be followed by low spring temperatures in the Plains States and Upper Mississippi Valley.

Amount of snowfall for the month is available at a number of stations in Canada and northeastern Alaska but the amount of snowfall during one month is not the information that will have the most direct bearing on temperatures in our northern border States in the follow-