this freezing of the surface soil, especially where continuing over so long a period as noted above, may injure the hair roots near the surface of the ground and thus weaken the tree.

TABLE 5.—*Effect of cover crop on amount of temperature, °F., inversion near ground.*

[Average minimum temperature on clear nights.]

SHELTERED THERMOMETERS.

	North plot.			South plot.		
	5-foot elevation.	10-inch elevation.	Difference.	5-foot elevation.	10-inch elevation.	Difference.
Both plots in cover crop	31.5	30.7	−0.8	30.9	30.1	−0.8
North plot in cover crop; south plot clean cultivation	26.9	27.0	+0.1	26.2	25.4	−0.8

UNSHELTERED THERMOMETERS.

	North plot.			South plot.		
	24-inch elevation.	7-inch elevation.	Difference.	24-inch elevation.	10-inch elevation.	Difference.
Both plots in cover crop	29.4	27.8	−1.6	28.3	27.1	−1.2
North plot in cover crop; south plot clean cultivation	25.4	25.5	+0.1	23.9	22.4	−1.5

The unsheltered thermometers show this in a somewhat greater degree. (See Tables 4 and 5.)

The bare soil probably was warmed up to a depth of 2 or 3 inches during the day, and this heat was conducted to the surface during the night, partially maintaining the temperature of the surface layer of air. On the other hand, the cover crop shaded the soil, preventing its warming up to any considerable extent during the day and also acted as an insulating agent between the surface of the soil and the surface layer of the air during the night.

It is not possible to draw a definite conclusion from observations covering only one frost season, but all the evidence obtained thus far indicates that a cover crop has little effect on the temperature a few feet above the ground. If this conclusion is borne out by experiments, which it is hoped to carry out in later seasons, any increased damage to fruit by frost in a cover-cropped citrus grove must be attributed to some other agency than a depression of the air temperature by the cover crop. If the greater damage found in cover-cropped groves can not be explained by natural differences in temperature, due to difference in elevation or other such cause, the answer may be found in a physiological effect of the cover crop on the tree.

One of the principal effects of the cover crop on the temperature is due to its shading the ground and thus preventing the warming of the soil during the day. This effect is discounted, however, in a citrus grove of old trees, because the trees themselves shade a large proportion of the ground and prevent the sun's rays from warming the soil to the extent that would be the case if there were no trees present. It readily can be seen that the effect of a cover crop in depressing the temperature on a clear, calm night would be greater in a grove of young trees, and still greater in an alfalfa field, without trees.

An interesting point brought out in this work was the fact that there was no temperature inversion within 5 feet of the ground over the clean cultivated area. There was a difference of nearly a degree between the 5-foot shelter and the ground shelter while the cover crop remained, but this difference disappeared entirely when the cover crop was removed. This is brought out in Table 5.

A SECOND EXPERIMENT ON COVER CROPS.

A second experiment with the object of determining the influence of a cover crop on the frost hazard was carries on by Mr. Eckley S. Ellison, observer, U. S. Weather Bureau, on the property of the Fontana Farms Co., near Fontana, Calif. That settlement is situated in extreme southern San Bernardino County about 45 miles due east of the town of San Bernardino.

Mr. Ellison's observations were made at the 5-foot level above the ground on a clean cultivated area and on one that was covered with grass and clover. A portion of the experimental plot was plowed under and the observations continued. His conclusions as given in his own words follow:

> Results obtained in this experiment tend to show that a cover crop increases the frost hazard, although the amount of the increase is so small as to be practically negligible. At a distance of 5 feet above the ground, the lowering of temperature amounts to less than half a degree F. Also the duration of critical temperatures is not affected to any practical extent regardless of the condition of the surface, whether cropped or clean.
>
> It might be that when large areas are planted to cover crops the influence on the temperature would be more marked, but it is the writer's belief that even then no considerable influence would result, due to the relatively small effect detected when a plot of 5 acres is used as a basis of comparison.
>
> Since the effect of a cover crop, although small, can be noted at an elevation of 5 feet, there is reason to suppose that from that height down to the surface of the ground a greater influence would be exerted. The results of this experiment can not, therefore, be construed to fit the case of a grower who has a considerable portion of his crop below the 5-foot level. Within the cover crop itself the influence of the vegetation is probably great—two or three degrees at least * * *.

—*A. J. H.*

CALCULATING TEMPERATURE EXTREMES IN SPOKANE COUNTY, WASH.

By E. M. KEYSER, Meteorologist.

[Weather Bureau, Spokane, Wash., October 19, 1920.]

Whatever degree of success was attained in temperature calculations in Spokane County last spring came as a by-product of the survey work authorized here by the Chief of Bureau. The original stimulus for undertaking these calculations came from a personal knowledge of the work being done in southern Oregon and California by Meteorologist Floyd D. Young. This stimulus was intensified by the various inspirational and very practical articles in MONTHLY WEATHER REVIEW SUPPLEMENT No. 16 (Predicting Minimum Temperatures From Hygrometric Data). The scope was greatly augmented by the willing and accurate clerical work done by Observer Frank B. Whitney, specially assigned to aid in the survey.

SCOPE OF 1922 TEMPERATURE SURVEY.

Spokane County, 54 miles long and 36 miles broad, touching Idaho on the east, reaches within 66 miles of the Canadian border. In the survey lasting from April 9 to June 13 temperature records were obtained from nine stations outside of Spokane, which is near the center of the county. Five of these were in Spokane Valley east of

the city and the other four in what is called the Deer Park section north of the city. Stations were all equipped with maximum and minimum thermometers in charge of orchardists. Six of the stations had thermographs and one key station in each district a sling psychrometer.

From these stations a body of valuable temperature data was obtained. Comparison of the records of the different stations brought out most interesting results. Particular attention was given to minimum temperature. It was found that the minima at the outside stations showed a range on some nights of as much as 11° among themselves and in a number of cases of between 10° and 20° as compared with the Spokane minimum. Report was made to the Central Office of the daily minima at each station and a detailed comparison of each minimum with the Spokane minima.

SPOKANE RECORDS IN CALCULATION CURVES.

Early in the season work was begun on graph making, which resulted eventually in a large number of useful station and field graphs by means of which, without use of formula, any assistant or cooperative observer, after having obtained the evening relative humidity and dewpoint, could easily calculate the approximate minimum temperature the following morning. The first graphs made were 5-year graphs based on all April and May Spokane records from 1917 to 1921, inclusive. It was immediately seen that in many cases these curves gave very close approximations to the Spokane minima 12 hours in advance. A little later similar dot charts were made for the April and May records for 1912 to 1916, inclusive. The deductions for the two sets were so nearly alike that we were greatly encouraged. Also, for variation, formulæ were worked out for the two sets and a table of corrections prepared for each possible humidity, to be applied to the dewpoint. This table required only simple addition and was used by the man on evening duty.

While deductions from these graphs gave next morning's minimum within 2° practically 50 per cent of the time and within 4° 75 per cent of the time, it was noted that the miss was at times as great as 8° or 10°. Different investigational plots were made and different researches gone into in an effort to solve the "miss" problem. While individual causes were discovered for poor approximations, the limited investigations we were able to make did not furnish us a clue to a principle worthy of general application. We had to content ourselves with the uncorrected approximations, which were, of course, for the Spokane station. Due to the probable wide divergence of the orchard minima from the Spokane minima the graphs were used with great hesitancy in trying to apply their results to orchard conditions.

GRAPHS FROM THE NEW FIELD DATA.

When the hygrometric data from the orchard key stations began coming in we soon started the construction of our field graphs. As the dots were entered from week to week we were astonished to find that they were falling along a usable curve. A final checking up on these field graphs showed that by the close of the frost season much more accurate approximations of the following morning orchard minima could be made by them than by the detailed 5-year Spokane graphs. These gave minima that were accurate more than 15 per cent of the time; within 1°, about 33 per cent of the time; 2°, 50 per cent; 3°, 60 per cent; and 4°, 70 per cent of the time. The other 30 per cent of the time the approximations ranged from 5° to 9° in error, except one case, which was 13° off. The graphs of the two stations were not equally accurate and the figures given are the means of the two stations.

ALL GRAPHS TO A PRACTICAL TEST.

The very practical value of these field curves was brought out on one or two mornings of the survey. The San Francisco district forecasts on the mornings referred to, based wholly of course on the daily weather charts, called for light to heavy frost in this vicinity. The local forecaster at Spokane confirmed the predictions and light to heavy frost was heralded through the usual cards and daily weather maps. The district evening forecasts, based on the 5 p. m. (local time) weather charts, repeated the warnings. On the two days referred to, the 5 p. m. field graphs gave deductions for minima well above freezing. Also the Spokane graph gave its rather questionable confirmation of the field calculations. The actual minima following these forecasts and calculations were well above the danger line, the freezing point not having been reached at any station. It was surprising what confidence in the mathematical curves was instilled in the local forecaster by these two occurrences.

5 P. M. GRAPHS FOR EVERY MONTH.

The possibilities of useful deductions from the use of parabolic curves made from hygrometric data by this time appeared as a great stimulus for extending the work to cover other portions of the year than the spring frost season. The fruit crop is subject to injury from low temperature in the autumn while on the trees, in storage, or in transit, and a foreknowledge of sudden temperature falls in the autumn or early winter might be as much protection to the orchardist as a frost warning in the months of April, May, and June. Similar dot curves were accordingly constructed for one of the fall months covering 10 years of Spokane records.

These charts, one each for clear, partly cloudy, and cloudy observations of the 5 p. m. readings, gave as accurate results for Spokane minima as did the spring charts. So we continued the making of these afternoon charts for other fall months, then the winter months, and finally we had three of the 10-year minimum temperature charts for each month of the year, all based on the 5 p. m. observations recorded in form No. 1001 and morning minima as recorded in form No. 1014. The late spring, summer, and early fall curves give the closest approximations and the winter curves the farthest. All are not only usable but very desirable in ascertaining the next morning's minima. The boundary lines of the dots mark the area within which the minima may be expected to be indicated almost 100 per cent of the time. In the great majority of cases the necessary factors will fall much closer to the curve, of course, than they do to the boundary line.

NOON MINIMUM GRAPHS MORE ACCURATE.

Success with the 5 o'clock graphs gave additional interest to charting. If 5 o'clock calculations give close estimates, possibly noon calculations might also. Graphs were accordingly made for one month of noon observations, using all of the 4 years' hygrometric and weather observations. The results were quite startling. The noon graphs in many cases gave more accurate deductions than did the evening. Convinced of this all,

the available noon data in the Spokane records were compiled and three graphs for each remaining month constructed. Application of the proper graphs to the 61 days of the 1922 survey gave approximations within 4° of accuracy 77 per cent of the time.

MAXIMUM GRAPHS MOST ACCURATE OF ALL.

These unexpected and astonishing results obtainable every day by the noon graphs in connection with minimum temperatures raised the query as to whether maximum graphs might not be practicable. Graph momentum was high now and but little additional work was needed to try out their accuracy. The data of dew point and humidity had already been compiled and checked and it remained only to copy them and work out the departures of the afternoon maxima from the noon dew points and plot them. The first set of these graphs gave remarkably close approximations which encouraged us to complete the 36 noon maximum graphs, 3 for each month. They were afterwards applied to all the Spokane maxima occurring during the 61 days of the temperature survey with the following percentages of accuracy: Within 1°, 52 per cent; 2°, 78 per cent; 3°, 89 per cent; and 6°, 100 per cent. It is admitted that a foreknowledge of the maximum is of less advantage than of the minimum, but it is conceivable that at times this advance information would be of value. At any rate it was of great interest to discover a clue to calculating it. When opportunity permits it is desired to apply the early morning or a mid-forenoon humidity data in an effort to arrive at an earlier determination of the afternoon maxima. A preliminary try out by use of the 5 a. m. hygrometric data was not particularly encouraging, but the matter is only in abeyance. During one or two heated periods this summer these graphs were found quite useful in informing the afternoon newspaper in time for publication whether previous records were likely to be equaled or exceeded.

GRAPHS ALWAYS USABLE, BUT STILL IN THE ROUGH.

It is realized that various observers who have used parabolic curves for estimating minimum temperatures have segregated the so-called "radiation" nights from the cloudy or rainy nights, but it is believed that these graphs have a universal practical application. In making the Spokane curves no nights were eliminated. The completed curves take into consideration every 5 p. m. reading and every morning minimum available. The deductions from them are therefore applicable for any kind of a night, within the range of accuracy represented by the dots. Some experimentation was entered into by segregating the radiation nights or nights with minima near freezing or below and plotting the corresponding 5 p. m. hygrometric observations. The graphs thus obtained gave practically the same results as did the all-inclusive graphs. It is not claimed for these comprehensive graphs that they are the last word in approximation. It is only held that they are of immense usefulness and are dependable guides for the local forecaster every day in the year. Moreover, they may act as emergency aids in the late afternoon when the local and district forecasters (using the weather map only) have overlooked an imminent sudden temperature drop or cold wave, such as may sometimes occur overnight.

Plans are in progress and in contemplation for working out usable corrections to be applied to the graph deductions. It is believed that they have already greatly

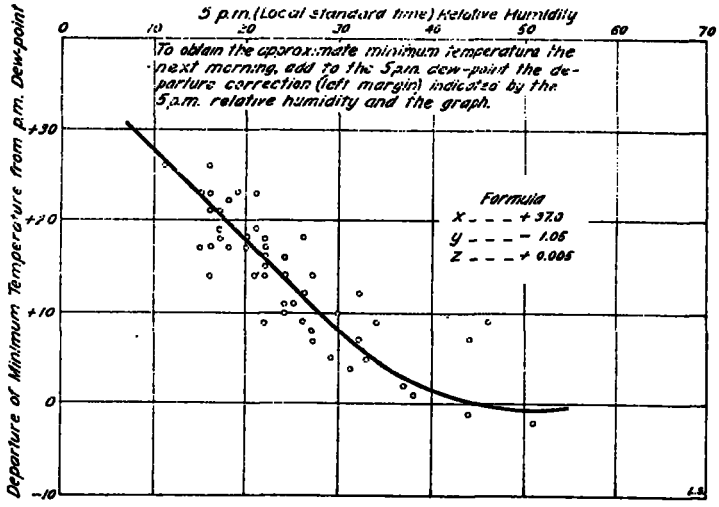

FIG. 1.—Minimum-temperature prediction graph for the months of April and May, 1917–1921, inclusive, at Spokane, Wash., based on all of the 5 p. m. *clear* observations for the period.

enhanced the Weather Bureau's usefulness not only to the apple industry but to many others as well.

Figures 1 and 2 show the minimum temperature forecast curves as calculated from the Spokane 5 p. m. hygrometric data for the months of April and May for 1917–1921. No. 1 covers all clear, and No. 2 partly

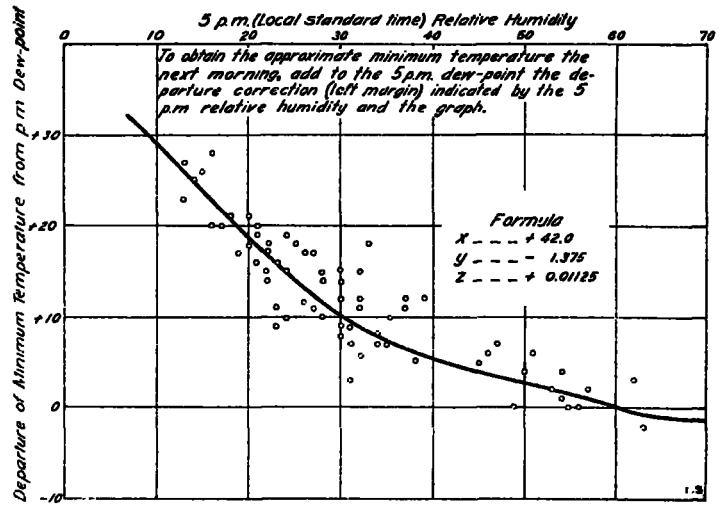

FIG. 2.—Minimum-temperature prediction graph for the months of April and May 1917–1921, inclusive, at Spokane, Wash., based on all of the 5 p. m. *partly cloudy* observations for the period.

cloudy nights. The curves are parabolic and based on the equation

$$v = x + by + b^2z.$$

in which b equals the evening relative humidity and v the variation of the minimum temperature the following morning from the 5 p. m. dew point. The values of the unknown quantities, x, y, and z, are shown on the charts.