RESISTANCE OF SMALL PLATES IN A STREAM OF FLUID.[1]

By LORD RAYLEIGH.

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In a recent paper on æolian tones [see preceding abstract] the author had occasion to determine the velocity of wind from its action upon a narrow strip of mirror, the incidence being normal. But there was some doubt as to the coefficient to be employed in deducing the velocity from the density of the air and the force per unit area. Observations both by Eiffel and by Stanton had indicated that the resultant pressure (force per unit area) is less on small plane areas than on larger ones; and although the author used provisionally a diminished value of C in the equation $P = C\rho V^2$ in view of the narrowness of the strip, it was not without hesitation; in fact, experiments had already been commenced which appeared to show that no variation in C was to be detected. Subsequently the matter was carried a little further, and the method is here described.

According to the principle of similitude a departure from the simple law would be most apparent when the kinematic viscosity is large and the stream velocity small. Thus, if the delicacy can be made adequate the use of *air* resistance and such low speeds as can be reached by walking through a still atmosphere should be favorable. The principle of the method consists in balancing the two areas to be compared by mounting them upon a vertical axis, situated in their common plane and capable of turning with the minimum of friction. If the areas are equal, their centers must be at the same distance (on opposite sides) from the axis. When the apparatus is carried forward through the air, equality of mean pressures is witnessed by the plane of the obstacles assuming a position of perpendicularity to the line of motion. If in this position the mean pressure on one side is somewhat deficient, the plane on that side advances against the relative stream until a stable balance is attained in an oblique position, in virtue of the displacement (forward) of the centers of pressure from the centers of figure.

Several arrangements were tested, viz, rectangular strips of equal area, one three times the breadth of the other; circular disks of area 2:1, one disk and two others of total area equal to the first. No deviation from the simple law was detected.—*E. H. B*[*arton*].

SELECTED BIBLIOGRAPHY OF FROST IN THE UNITED STATES.

By WILLIAM GARDNER REED and CORA L. FELDKAMP.

[Dated Office of Farm Management, Washington, Nov. 1, 1915.]

INTRODUCTION.

This bibliography has been selected[2] from all the material on frost and frost prevention under American conditions which has come to the attention of the writers. This includes all the material in the classed bibliographies of the John Crerar Library (Chicago), the Library of Congress, the Library of the United States Department of Agriculture, the Weather Bureau Library, and the Library of the Bureau of Plant Industry, as well as references in the MONTHLY WEATHER REVIEW, the Experiment Station Record, and various other agricultural and meteorological publications.

It is believed to cover the subject adequately, but is in no sense a complete bibliography of the published material on frost. It is arranged with the later papers first as most of the work is very recent. Earlier papers have usually not been included when later papers cover substantially the same ground.

The papers marked with asterisks (*) form a group which will give a more or less complete idea of the frost problem and the methods of protecting against frost damage. A series of papers[3] on frost appears in the MONTHLY WEATHER REVIEW, October, 1914; there is also a more popular series in Better Fruit (Hood River, Oreg.), volume 5, number 4, October, 1910.

The State index is an attempt to show the work which has been done in the different States; it includes only papers listed in the bibliography.

FROST DATA (General).

United States Weather Bureau, Climatological Division.
Summaries of climatological data of the United States by sections (tables). Various dates.[4]

Frost data for 106 "sections" of the United States are given. These summaries are continually brought down to date as the issue for each section is exhausted. In the summaries printed before 1914 the summaries give the average and latest date of last killing frost in spring, and the average and earliest date of first killing frost in autumn for numerous stations in each section. In the summaries printed since 1914 the dates for each year of record are given.

1915.

Coit, J. Eliot.
Citrus Fruits (New York: Macmillan) xx+520 p., 151 fig. "Frost and orchard heating." Chap. **14:** 230–276, fig. 72–95.

The more important cold periods are described. Frost forecasting and the factors affecting frost are explained. The phenomena of frosting of citrus fruits are discussed. Methods of preventing frost injury are considered under the following heads: Selection of a relatively frostless locality, using a resistant stock, breeding new resistant stocks, use of mechanical devices to conserve heat, raising the dew point, and slow thawing. Heating with oil heaters is described in detail, with descriptions of various oil pots. The necessity of cooperation is emphasized.

***McAdie, Alexander G.**
Temperature inversions in relation to frosts. Annals, Harvard College Observ. **73:** 168–177, 4 pl.

The physics of frost formation in connection with local air drainage and inversions of temperature is discussed, especially with regard to water vapor relations. The physical bases of the methods of protection are explained.

Malone, R. E.
Smudging an orchard with native material in Alabama. Alabama Tuskegee agr. exp. sta. Bul. **28,** 13 p., tables.

The value of smudging in Alabama is briefly discussed. The experiment-station orchard and the methods of frost protection are described. Smudging material was wet peach prunings and tar. Loblolly pine makes excellent smudging material.

Smith, J. Warren.
Predicting minimum temperatures for frost protection. Ohio naturalist, **15:** 405–408, 1 fig.

Temperature forecasting is explained and a method of obtaining minimum temperatures from the similarity during conditions favorable to frost is suggested.

1914.

Beals, Edward A.
Frost forecasts and frost protection in Oregon, Washington, and Idaho. Mo. weather rev. 1914, **42:** 587.

Frost warnings are issued mainly for the benefit of commercial orchards in which protection is used. Forecasts have saved many crops. Orchard heating is generally practiced.

Briggs, Robert R.
Frost protection in Arizona. Mo. weather rev., 1914, **42:**589–590.

Frost has been little studied in this State, but the possibilities of protection in irrigated areas is becoming of increasing importance.

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[1] *See* Phil. mag., July, 1915, p. 179–181.
[2] Thanks are due to Prof. C. F. Talman, of the Weather Bureau, for valuable suggestions and advice.—Authors.

[3] Reprinted as W. B. No. 542, "Papers on frost and frost protection in the United States." Washington, 1915.
[4] These section summaries were collected as Bulletin W of the Weather Bureau in 1912. *See* "1912 United States Weather Bureau."
* The papers marked with an asterisk (*) form a group which gives a general idea of the frost problem.

***Carpenter, Ford A.**
Utilization of frost warnings in the citrus region near Los Angeles, California. Mo. weather rev., 1914, **42**:569–571, 12 pl. (incl. maps, tables, diagr.).

The character of the region and the influence of location upon frost occurrence and the weather types causing frosts are discussed. Frost forecasts are issued by 11 a. m. Methods of protection and utilization of frost warnings are discussed. Protection, generally by oil pots, is expensive but profitable.

Carpenter, Ford A. & Garthwaite, J. W.
Memorandum on air drainage in the vicinity of the Corona district, California. Mo. weather rev., 1914, **42**:572–573, 5 fig.

The effect of a small arroyo on local temperature conditions is discussed.

Cline, Joseph L.
Frost protection by irrigation in southern Texas. Mo. weather rev., 1914, **42**:591–592, incl. tables.

Protection of early vegetables by covering or flooding is the most successful practice in Texas. Low temperatures frequently occurring with high winds make smudging and heating impracticable.

Culbertson, J. D.
Frost protection in the Limoneira lemon orchards. California State Com. Hort., Mo. Bul. **3**:1–8.

Early fighting was with coal baskets, but oil pots have proved much more effective and less expensive. Fruit is badly sooted, but expense of cleaning is more than covered by the saving due to heating. Adequate equipment is essential. Detailed accounts of cost of equipment are given; the first cost is about $183 per acre, and maintenance, aside from operating expense, is $33.34 annually per acre. This is small compared to other expenses of fruit growing.

Fassig, Oliver L.
The period of safe plant growth in Maryland and Delaware. Mo. weather rev., 1914, **42**:152–158, table, 10 fig. (incl. maps).

Frost records for Maryland have been tabulated for 20 years, 1890–1913. Air temperatures of 32°F. have been considered killing frost. Frost data for Maryland and Delaware are shown by tables and maps.

Frazer, Calvin.
The frost problem up to date. Country gentleman, **79**:360, 392, illus.

A popular discussion of the nature of frost damage and the temperatures dangerous to fruit. The methods of protection and the services of the Weather Bureau in issuing frost warnings are described.

Garcia, Fabian & Rigney, J. W.
Hardiness of fruit buds and flowers to frost. New Mexico agr. exp. sta., Bul. **89**, 52 p., 9 figs.

Degree of cold necessary to kill fruit buds and blossoms varies with the locality; resistance varies also with different stages of development. The bloom is not the most delicate stage. Damage is greater with greater degree and longer duration of cold, and when the low temperature is nearer sunrise.

Garthwaite, J. W.
Letter on frost and frost prevention. Mo. weather rev., 1914, **42**: 571–572.

Many general frost conditions do not seem to hold in the Corona (California) region. Trees are often damaged at the top. The necessity of being prepared for frost at any time is emphasized.

Herrmann, Charles F. von.
Protection against frost in Georgia. Mo. weather rev., 1914, **42**:585–586.

Frost protection in Georgia has kept pace with the rapid growth of horticultural interests, but efficient use is not yet made of the facilities of the Weather Bureau.

***Humphreys, W. J.**
Frost protection. Mo. weather rev., 1914, **42**:562–569, 1 fig.

The physics of frost formation and favorable location for fruit orchards are discussed: the methods of frost protection are stated and criticized, particularly ground covering, air drainage, spraying, screening, heating, irrigation. Frost cure is also discussed.

***Marvin, Charles Frederick.**
Air drainage explained. Mo. weather rev., 1914, **42**:583–585.

It is pointed out that the collection of cold air in low places is not a result of drainage down the slopes, but rather the process of building up from the bottom, in which chilled air moves away from the hillside but does not flow down the slope.

Mitchell, Alexander J.
Frost and frost protection in Florida. Mo. weather rev., 1914, **42**:588–589.

The products in Florida show varying resistance to frost. Winter frosts occasionally damage the more tender plants. Various methods of protection of fruit and truck are in use.

Nichols, Carl.
Frost fighting equipment in citrus orchards. California cultivator, **42**:259, 282, 2 fig.

The equipment for frost fighting in each of the fruit districts of California is described in detail.

Smith, J. Warren.
Frost warnings and orchard heating in Ohio. Mo. weather rev., 1914, **42**:573–583, incl. tables, 5 pl. (incl. maps, diagr.).

Frost protection in Ohio is comparatively recent. "Fruit-frost" stations of the Weather Bureau have been established and frost warnings issued. Protection is largely by heating. Temperatures dangerous to fruit buds are discussed. Studies for frost forecasting are outlined.

Sprague, Malcolm.
Frosts and frost protection in Texas. Mo. weather rev., 1914, **42**:590

Frosts in Texas occur in connection with cold waves. Smudging and heating have been successful in orchards and trucking districts in eastern Texas. Frost warnings have enabled the cutting of sugar cane in time to prevent serious damage.

Thiessen, Alfred H.
Protection from frost in Utah. Mo. weather rev., 1914, **42**:586–587.

Frost damage in Utah occurs in April and May and in the early fall. Forecasting is based on key situations. Protection is largely by heating.

Voorhees, J[ohn] F.
Notes on frost protection in the vicinity of Knoxville, Tenn. Mo. weather rev., 1914, **42**:587.

Protection in Tennessee is still in an experimental stage.

Walker, T. J.
An orange man's dream. California cultivator, **42**:69–70.

A fanciful description of future conditions of mixing the air by electric fans, but with suggestions which may become practicable.

Weldon, George P.
Apple growing in California. California State Com. Hort., Sacramento, **124**, p. 58 fig.
"Injury and protection of apples from freezing." Chap. **12**:70–74, figs. 45–47.

No part of California is free from killing frost. The bud and blossoms are the stages of greatest danger in apples. The character of fruit injury and the methods of protection are discussed. Orchard heating with oil is preferred, fires should be lighted before the temperature drops too low and should be kept burning until well after sunrise. "Orchard heating if done at all should be done rightly."

1913.

Adamson, J. E.
Fighting the big freeze [in California]. Pacific rural press, **85**:321, 328–329, 3 fig. The same reprinted in Mo. weather rev., 1913, **41**:289–291, 1 fig.

The methods used in California in the successful fight against the very serious frost condition of December-January, 1912–1913, are discussed. Protection was mainly by heating. Frequent temperature readings showed the conditions in the groves.

Ballantyne, A. B.
Blooming periods and yields of fruit in relation to minimum temperatures. Utah agr. exp. sta. Bul. **128**, p. 245–261, [10 fig.].

Frosts at blooming time sufficient to destroy the whole crop are usual. Frosts of from 5 to 9 degrees when the buds are moist are less damaging than when the buds are dry. Tables and diagrams of blooming periods, yields, and minimum temperatures are given.

***Beals, Edward A.**
Forecasting frost in the north Pacific Coast States. U. S. Weather Bur. Bul. **41**, 49 p. (incl. tables, 3 fig., 4 diagr., 6 charts).

The occurrence of frost in the fruit region of the north Pacific States is discussed. Forecasts are made by the district forecaster but applied by trained local forecasters. The weather types with which frost occurs are described.

***Chandler, W. H.**
The killing of plant tissue by low temperature. Missouri agr. exp. sta. Research Bul. 8, p. 143–309, 3 pl., chart.

The literature on the destruction of plant tissue by cold is reviewed and a series of experiments of freezing twigs and buds of various fruit trees described. Freezing to death is a specific set of phenomena in which ice forms in the intercellular spaces and death results because of the withdrawal of water from the protoplasm. With a few exceptions, rate of thawing seems to have nothing to do with death. Maturity increases the hardiness of the tissues. The effect of various other factors on hardiness is described. Killing temperatures for peach blossoms in Missouri vary from 22°F. to 26°F. Killing of buds is not common.

Henry, Alfred J.
Vertical temperature gradients between Mount Weather, Va., and valley stations. U. S. Weather Bur., Mt. Weather Observ. Bul. **6**:35–37, incl. tables.

Comparative data for monthly mean temperatures are given. This is a fundamental study of relation between valley and mountain temperatures.

Herrick, R. S.
Orchard heating and frost prevention. [Portland, Oreg., Pacific horticultural correspondence school], 11 p.

The history of orchard heating and the methods used are discussed. Frost conditions are described. The temperature at which heating is necessary at different stages of development of fruit are stated. The types, care, and use of heaters are discussed.

Kellerman, Karl F.
Suggestions for frost protection. Jour., Washington acad. sci., **3**:53–55.

The value of increased vapor content of the air is discussed and methods of increasing the humidity are suggested.

McAdie, Alexander G.
Frost studies: Determining the probable minimum temperature. Mo. weather rev., 1913, **41**:623–625.

The physics of frost is discussed and the conclusion reached that moisture studies must play an important part in the attempt to forecast the minimum temperature.

McAdie, Alexander G.
Report on recent destructive frosts in California. Mo. weather rev., 1913, **41**:120–122.

Temperatures dangerous to citrus fruits have occurred frequently in California and frost losses have been severe. Protection by organized effort by the use of oil heaters saved much of the crop during the destructive frost of December, 1912. The characteristics of this frost are described with a record of the minimum temperatures.

Merrill, G. E.
The freeze and frost fighting. California cultivator, **40**:227, 230, 231.

The results of the frosts of the winter of 1912–1913 are discussed. Smudging was successful. A central heating plant and heating by steam pipes are advocated. Conditions in Santa Barbara County, California, and in Arizona are described.

[Wood, William.]
Cost and result of frost firing. California cultivator, **40**:260–261.

The exact cost for heating a grove of 14 acres (1,000 trees) of lemons at Duarte, California, is given. The total operation expense for 16 nights was $638.76 and the cost of equipment $573.25.

Woodbridge, T. R.
Smudging costs. Pacific rural press, **85**:588–589.

Detailed schedules of cost of heating at Upland, California, for the season 1912–1913. The total cost per acre per hour was $1.24, including overhead charges and depreciation.

1912.

Alter, J. Cecil.
Does frost fighting pay in Utah? Mo. weather rev., 1912, **40**:606–608.

The cost of heating with oil to keep the temperature at 30° varies from 60 cents per hour per acre when the outside temperature is 29° to $4.20 per hour per acre when the outside temperature is 20°. Below 20° heating has arbitrarily been considered impracticable.

Brandenburg, Frederick H.
Temperatures injurious to peaches, apples, and pears in various states of development. Mo. weather rev. 1912, **40**:426.

The report of a committee of the Fruit Growers' Association of the Grand Valley (Colorado) is given. The following tables are of interest:

Table showing at what temperature smudging is necessary at the various stages of development of peach buds.

Stage.	°F.
Peaches one-fourth inch in diameter	30
Dropping the shuck	31
Setting	31
Full bloom	29 to 30
Buds in pink	22
Buds swelling	15
Buds dormant	−15

Table showing at what temperature smudging is necessary at the various stages of development of apples and pear buds.

Stage.	°F.
Calyx closed	30
Flower gone, calyx closing	30
Petals dropping	31
Fruit forming	30
Full bloom	30
Buds in the pink	25
Buds separating	20
Buds swelling	15

Church, J. E. & Fergusson, S. P.
Avoidance and prevention of frosts in the fruit belts of Nevada. Nevada agr. exp. sta. Bul. **79**, 58 p., 16 pl.

Orchard heating experiments are described. Frost phenomena, weather changes, and frost forecasting are outlined, including descriptions of apparatus. Orchard sites should be on higher ground. Orchards in Nevada can be protected when the temperature falls as low as 22° at a cost of 73 to 95 cents per tree.

***[Coit, J. Eliot.]**
The protection of citrus fruit against frost. Citrus protective league of California (Los Angeles), Cir. **6** [8 p.].

The methods of protection in use in southern California are discussed briefly but adequately.

Cox, Henry J.
The Weather Bureau and the cranberry industry. U. S. Dept. Agr. Yearbook, 1911: 211–222, pl. 6–9.

This is essentially a popular discussion of the material in Bulletin T of the United States Weather Bureau (see 1910, Cox).

Greene, Laurenz.
Orchard heating. Iowa agr. exp. sta. Bul. **129**:129–164, 16 fig.

Late spring frosts cause immense losses in Iowa. Methods of handling oil and use of oil heaters are discussed. Heater tests are described and experience of Iowa growers quoted.

Grubb, E. H.
Orchard heating. Oregon Short Line R. R. Co., Salt Lake City, Utah. 15 p., 5 fig.

An account and brief history of protection in the Grand Valley, Colorado, are given. Crude oil is the best fuel. Heat and smoke are both essential. The cost of equipment for 10 acres with oil for 8 nights is $510. The principles of orchard heating are discussed, and several appliances are described.

Henry, Alfred J.
The temperature at Mount Weather [Va.] and adjacent valley stations. Mt. Weather Observ., Bul., 1911, **4**:310–341, incl. tables, 10 fig.

The temperature relations between the summit and base stations are discussed in detail by seasons. The relation of mountain and valley to low temperatures at night is shown and the vertical temperature gradients with the free air are given.

McAdie, Alexander G.
Covering almond trees for frost protection. Pacific rural press, **83**: 241, 247, 2 fig. *Also* in Mo. weather rev., 1912, **40**: 282–283. 2 fig.

California experiments under a paper cover to prevent radiation are described. It seems probable that enough heat can be conserved by covering to prevent damage.

McAdie, Alexander G.
New heater and vaporizer for frost protection. Pacific rural press, **83**: 388, 4 fig. *Also* in Mo. weather rev., 1912, **40**: 618–619.

A method of using heat and moisture combination is described.

McAdie, Alexander G.
Studies in frost protection. Effect of mixing the air. Mo. weather rev., 1912. **40**: 122–123, 779, 2 fig.

Conditions at Kentfield, California, are described. When surface conditions seemed the same on two mornings frost occurred but not on others, a gale in the upper air prevented low temperatures.

Milham, Willis Isbister.
Meteorology (New York: Macmillan) xvi+549 p., 14 pl., 143 fig., 34 charts. Frost, pp. 213–216, charts 27–28.

Frost and the physical processes resulting in frost are defined. Methods of forecasting frost. Differences between temperatures in shelters and of vegetation. Describes methods of protection. Gives frost data for the United States.

O'Gara, P. J.
A comparative test of fuel oils and appliances used in orchard heating to prevent frost injury. Off. of Pathologist and Local U. S. Weather Bur. Sta. for Rogue River Valley. (Medford, Oregon) Bul **6**. 27 p., 4 fig.

Test of various oil pots and fuel oils under orchard conditions is described in detail. Simple types of oil pots with oil of a medium specific gravity are recommended. The cost of heating is about one cent per hour for each oil pot. The quantity of oil required to raise the temperature of full-bearing orchards 5° above that of the surrounding air is about 12¼ gallons an hour, if the wind is not more than 2 miles an hour. Young orchards with low fruiting require about twice as much oil for the same results.

United States Weather Bureau.
Summaries of climatological data by sections. U. S. Weather Bur. Bul. **W**, 2 vols., tables, maps, diagrs.[5]

Climatological data for each of 106 "sections" of the United States are given. These data include the average and latest date of last killing frost in spring and average and earliest date of first killing frost in autumn for numerous stations in each section.

Whitson, A. R., & Baker, O. E.
The climate of Wisconsin and its relation to agriculture. Wisconsin agr. exp. sta., Bul. **223**, 65 p., incl. tables, 24 fig. "Growing season," pp. 24–30, figs. 11–14.

The dates of killing frost in Wisconsin and their relation to agriculture are discussed. Maps of the average date of last killing frost in spring, of the first killing frost in autumn, and of the length of the "growing season" are presented.

***Wilson, Wilford M.**
Frosts in New York. New York Cornell agr. exp. sta., Bul. **316**: 505–544, figs. 135–151.

Conditions favorable to the formation of frost are discussed and successful methods of protection are described with especial reference to New York. Frost data and maps for New York are given.

1911.

Alter, J. Cecil.
Value of mountains to climatic safety for the fruit grower. Mo. weather rev., 1911, **39**: 1248–1249.

The advantage of the broken topography of Utah in preventing the occurrence of late spring frosts except in the very low places is emphasized. The advantage of morning shading by mountains is explained.

Cline I[saac] M.
Freezes of November 13 and 29–30, 1911, in the sugar, orange, and trucking region [of Louisiana and Texas]. Mo. weather rev., 1911, **39**: 1714–1716.

The conditions during the record cold for this time of year are described. The forecasts of cold were made in time and a great part of the crop was saved.

***Day, P. C.**
Frost data of the United States and length of the crop-growing season. U. S. Weather Bur. Bul. **V**, 5 p., 5 maps.

Maps are presented showing average dates of last killing frost in spring, first killing frost in autumn, and length of the growing season, also maps of latest date of last killing frost in spring and earliest date of first killing frost in autumn. Isochronal lines are shown east of the Rocky Mountains and figures given at stations west of the mountains.

[5] The data for each section are printed separately and continually brought down to date as the issues are exhausted. See "Frost Data" at the beginning of the bibliography.

***Garriott, E. B.**
Notes on frost. Revised August, 1911, by Alexander G. McAdie. U. S. Dept. Agr., Farmers' Bul. **104,** 35 p., 4 fig.

The formation of frost and the seasons of frost in different parts of the United States are briefly discussed. Other atmospheric conditions being favorable, frost may usually be expected when the temperature reported by Weather Bureau stations falls to 40° F. The existence and causes of "thermal belts" are considered. Local soil and moisture conditions influence frost occurrence. Frost data at Weather Bureau stations are presented. Methods of protection from frost by preventing radiation, by adding heat to the air, and by adding moisture are described. Essentials of a frost-fighting campaign are stated. Summaries are given of work in Florida, Missouri, California, Indiana, Oregon, Utah, and Massachusetts.

Gruss, E. W.
Protecting truck against frost. Mo. weather rev., 1911, **39:** 1231–1232.

Truck crops are of sufficient value in Texas to warrant protection. Protection is necessary only occasionally and danger is forecast by the Weather Bureau. Covering and smudging are successful methods of protection.

Gruss, E. W.
Protection against frost. Mo. weather rev., 1911, **39:** 581–582.

The freeze of January, 1911, in southern Texas is discussed. Smudging proved beneficial where used. Precautions necessary to receive and make use of forecasts and also methods of protection are outlined.

Henry, Alfred J.
Variations of temperature at summit and base stations in the central Rocky Mountain region. Mt. Weather Observ. Bul., 1911, **4:** 103–114, incl. tables, 1 fig.

The temperature relations between the base and summit stations in Colorado is discussed. The relations of altitude and location to temperature are described in connection with weather types and movement of air.

Howard, R. F.
Protection of orchards from frost. Better fruit, **6,** no. 5: 36–38, 4 fig.

Conditions of frost occurrence are discussed. Smudging and heating and apparatus are described. A satisfactory method of arranging and lighting heaters is explained.

Lewis, C. I. & Brown, F. R.
Preliminary frost fighting studies in the Rogue River Valley. Oregon agr. exp. sta. Bul. **110,** 62 p., 19 fig.

The work of the station from 1909 to 1911 is discussed. The average cost per acre for a four-hour period was $5.10 for oil, but $5.30 for wood under similar conditions. There is no doubt that crops can be saved by orchard heating. No arbitrary table of temperatures for frost injury has been worked out for all conditions.

McAdie, Alexander G.
Protecting the California orange crop from frost. Mo. weather rev., 1911, **39:** 1910–1912.

Statistics of the citrus fruit industry are given and the relation between this industry and frost fighting are discussed. The topography of the orange region is described. Temperatures on four actual dates from December, 1909, to 1911 are given for various points. Statements of the cost of protection and the amount of saving are quoted.

McAdie, Alexander G.
Work of the Weather Bureau in protecting fruit; especially frost protection. Mo. weather rev., 1911, **39:** 275–276.

Frost warnings, the physical processes of frost, and the methods of protection are discussed.

O'Gara, P. J.
Frost injury prevention methods in Rogue River Valley. Better fruit, **6,** no. 5: 21–30, 17 fig.

Same under title of The prevention of frost injury in the orchards of the Rogue River Valley, Oregon. Off. of Pathologist and local U. S. Weather Bur. Sta. for Rogue River Valley (Medford, Oregon) Bul. **5,** 27 p., 22 fig.

A brief history of frost protection is given. Heating is the common method in Rogue River Valley; wood and oil are burned. Various types of oil pots are discussed. Successful heating saved the fruit crops in 1911. Frost forecasting by the Weather Bureau has made successful fighting possible. Frost fighting campaign must be carefully planned. The methods of protection are described in detail.

Slataper, D. Lee.
Value of windbreaks and smoke. Gulf coast citrus fruit grower, **1,** no. 6: 18–19.

The freeze of January 2, 1911, is described and the use of wet hay and oil smudges is discussed. The necessity of windbreaks to keep the smoke from blowing away is emphasized.

Thiessen, Alfred H.
Orchard heating. Mo. weather rev., 1911, **39:** 761–762.

Methods of frost fighting in Grand Valley, Colorado, are discussed. The region is effectively organized and the campaign to the last detail planned in advance. Oil and coal heaters are used. Killing temperatures vary with the stage of development of the plant, its previous condition, etc. When the temperature is falling rapidly, fires are lighted at 34° F. Best results are obtained in orchards surrounded by other orchards.

Woodbury, C. G. & Wellington, J. W.
Orchard heating. Indiana agr. exp. sta. Bul. **154,** pp. 71–96, 16 fig.

A number of types of orchard heaters have been devised to prevent frost damage. A series of tests of different types of heaters was made at the station. The temperature was raised from 5 to 7 degrees with 80 to 100 heaters per acre. Oil heaters seem preferable to coal under Indiana conditions. To control temperatures properly requires an initial investment of about $500 for a 10-acre orchard. In most Indiana orchards heating will not pay unless the production is increased by better cultural methods.

1910.

Barney, F. E.
Practicability of orchard heating with coal. Better fruit, **5,** no. 4: 39–40, 2 fig.

The essentials of heaters are discussed and a successful coal heater is described.

Brackett, G. B.
Prevention of frost injury to fruit crops. Better fruit, **5,** no. 4: 33–36, 10 fig.

Frost injury generally occurs on clear still nights. Various methods of protection are discussed. Heating is the most practicable method. Proper preparation is urged. Heating has saved many thousands of dollars, although comparatively new.

***Brackett, G. B.**
Prevention of frost injury to fruit crops. U. S. Dept. Agr. Yearbook, **1909:**357–364, 1 fig., 1 pl.

Frost damage and protection by explosives, smudges, and heating devices are discussed. Methods of heating with coal and with oil are described, and the cost of each given. Frost injury can be prevented. Methods of procedure are suggested. Published Weather Bureau records show probability of frost occurrence in any region.

***Cox, Henry J.**
Frost and temperature conditions in the cranberry marshes of Wisconsin. U. S. Weather Bur., Bul. **T,** 121 p., incl. maps, diagr., tables, 31 fig.

Cranberry growing in Wisconsin and the necessity of protection from frost are discussed. Flooding is described as a method of protection. The occurrence of low temperatures is also discussed and the frost problem is presented. The effects of exposure, soil, vegetation, and moisture on surface temperatures are explained. Various methods of protection and the incidental disadvantages of each are discussed. For frost forecasting, soil temperatures are important. Careful and continued work is necessary for protection.

Degrees of cold which will kill fruit buds.
Better fruit, **5,** no. 4: 40, 4 fig. (Quoted from Wenatchee Republican.)

The susceptibility of peaches and apples to frost damage at different stages of development is discussed.

Henry, Alfred J.
Variations of temperature and pressure at summit and base stations in the Rocky Mountain region. Mt. Weather Observ. Bul., 1910, **3:** 201–225, 5 fig.

Data for summit and base stations in the Rocky Mountain region of Colorado are discussed by hours and months. The relation of the vertical temperature gradients to cyclones and anticyclones is considered. The relation of air movement to temperature conditions is discussed.

Herrmann, Charles F. von.
How farmers may utilize the special warnings of the Weather Bureau. U. S. Dept. Agr. Yearbook, **1909:** 387–398.

Use of frost and cold-wave warnings, pp. 390–396.

When crops are extended beyond their normal limits, or when great financial gain results from growing crops outside the normal time, artificial protection is necessary. Frost and frost regions are explained. Methods of protection for special crops are outlined.

Herrick, R. S.
Winter and frost injuries to fruit trees. Colorado agr. exp. sta. Bul. **170:** 12–19, 2 fig.

The kinds and causes of winter killing at very low temperatures, the methods of protecting the trees are discussed, and the effect of spring frost on fruit and leaves. Methods of protection are also summarized. If temperature can be kept above 29°F., damage will not result.

Meyer, Lewis.
Orchard heating in Grand Valley, Colorado. Better fruit, **5,** no. 4: 27–29, 6 fig.

Smudge pots or heaters have proved successful, but protection must be carried out in a systematic manner to be successful. Fires must be started before the temperature is too low.

Mitchell, A. J.
Effects of low temperatures on citrus trees and fruits. Mo. weather rev., 1910, **38:** 16–17, 1 fig.

The conditions of frost occurrence in Florida, and the results of the cold wave of December, 1909, are discussed. Temperatures of 25°F. will cause no harm to trees under normal conditions, but such temperatures for 4 to 6 hours will damage fruit. Temperatures of 20°F. will seriously injure trees. Heating will prevent damage.

Paddock, Wendell, & Whipple, Orville B.
Fruit growing in arid regions (New York: Macmillan), xx+395 p., 98 fig. "Frost injuries, secondary bloom, and frost protection," chap. **19**, pp. 324–354, figs. 87–96.

Frost injury occurs at variable temperatures. The characteristics of frost injuries and the value of the second-crop bloom and its fruit are discussed. Protection is regarded as insurance. Natural protection by location and its limitations are explained. Methods of artificial protection are discussed as follows: Retarding the blooming period, use of water, smudging, and heating. Coal and oil and the types of burners are compared. The necessary equipment is listed and its probable cost stated. The temperatures at which heaters should be lighted are discussed.

Rhodes, Robert H.
Graphic story of frost fighting in Colorado. Better fruit, **5**, no. 4. p. 30–32, 5 fig.

A vivid popular description of a night's work protecting peaches from damage.

Wells, Edward L.
Relation of Weather Bureau to horticulture. Better fruit, **5**, no. 4. p. 44–46.

The methods of distributing frost forecasts in various fruit districts are described.

Whipple, O. B.
Effect of freezing on buds, bloom, and fruit. Better fruit, **5**, no. 6. p. 20–22, 6 fig.

Knowledge of exact temperatures dangerous to buds, bloom, and fruit is essential to prevent waste or loss. Character of freezing damage is discussed. Dangerous temperatures at different stages of development are given.

Whipple, O. W.
Protection of fruit crops from frost injury. Better fruit, **5**, no. 4. p. 17–19, 8 fig.

Advantage of protecting against frost is now proved. Various methods of protection are discussed. Heating is the most recent and best method. Oil is usually the most satisfactory fuel. The whole community should cooperate.

1909.

Bartlett, James L.
Frosts in Wisconsin: occurrence, prediction, and methods of prevention. Univ. Wisconsin Bul. **290** (University extension series, **1**:39–82. incl. tables, 9 pl.).

The nature of frost and the conditions of its occurrence are discussed. Records of frost occurrence in Wisconsin are given. Methods of observation and forecasting are described, and frost damage and the possibilities of protection in Wisconsin are discussed.

Howard, W. L.
Protecting orchards against frosts and freezes. Missouri agr. exp. sta., Circ. of inform. **35**. 10 p.

Smudging has been successful in Europe in preventing loss of heat by radiation, but heating has met with more favor in the United States. Experiments in Missouri are described and directions given for the use of heaters. Heating is necessary after peach and apple buds open, whenever the temperature falls below the danger point which varies with the stage of development. By using from 75 to 100 pots an acre it is nearly always possible to raise the temperature enough to save the crop in Missouri.

Thiessen, Alfred H.
Smudge pot test [at Salt Lake City]. Mo. weather rev., 1909, **37**: 658–659.

In the absence of wind temperature was raised 4.7 degrees (F.) under rather unfavorable conditions. With a slight wind the increase was very much less.

1908.

Milham, Willis I[sbister].
A two years' study of spring frosts at Williamstown, Mass. Mo. weather rev., 1908, **36**:250–254, 1 fig.

Predictions and characteristics of spring frosts are discussed. Spring frosts may occur until the first of June on clear nights with northwest wind. Plant temperatures are lower than air temperatures. Temperature variation over a limited area may be several degrees. At Williamstown the minimum temperature of vegetation *in the open averages 11°F. lower than the shelter minimum.*

1906.

Garriott, Edward B.
Cold waves and frost in the United States. U. S. Weather Bur. Bul. **P.** 22 p., 328 charts.

A chronological statement of the more important cold periods which have been experienced in the United States is given. Charts showing the meteorological conditions preceding and accompanying the principal cold waves and frosts from 1888 to 1902 are presented.

1905.

Mead, Theodore L.
A frost-proof orange orchard. Country life in America, **7**:367–369, illus.

A cloth-topped shed over an orange grove and a method of heating by a spray system of irrigation with artesian water at 70°F. is described. A temperature of 48°F. can be maintained inside when that outside is 18°F.

1904.

Cline, I[saac] M.
Irregularities in frost and temperatures in neighboring localities. *In* Third Convention of Weather Bureau officials, Proc., p. 250–253.

During frost the temperature varies locally in a manner which can not be explained by air drainage. This is probably due to differing radiation conditions probably dust is important. There is also different susceptibility of plants at different times. Different soil conditions are also important.

1903.

McAdie, Alexander G.
The Climatology of California. U. S. Weather Bur. Bul. **L**, 270 p., incl. tables, 31 fig. (incl. pl. I–VI), 12 charts: "Frost," pp. 227–237, incl. table, figs. 13–19.

The losses of fruit crops by frost is very important in California. The nature of frost is discussed. The work of the Weather Bureau in forecasting frost in California is described. Methods of protecting against frost damage are outlined in groups based upon the physical principles involved. These are grouped as follows: Methods based on mixing the air, methods based on warming the air, methods based on cloud or fog formation, methods based on irrigation. Of these, warming the air and fog formation are the most satisfactory. A list of the last frost in spring and the first frost in autumn for stations in California in 1899 is given.

1902.

Lelong, B. M.
Culture of the citrus in California . . . Revised by the California State Board of Horticulture. Sacramento, 1902. "Frost protection," pp. 155–160.

A report by a committee of the Riverside Horticultural Club is quoted. The conclusions of the committee are (1) that the temperature can be raised by dry heat; (2) that radiation may be lessened by moist smudges; (3) that raising the dew-point seems impracticable; (4) that covering will prevent damage, but is too expensive; (5) that windbreaks are partly effective; (6) that severe cold is confined to a thin surface layer; (7) that heating is wholly practicable. Experiments made with lath roofs are described.

1896.

Webber, Herbert J.
The two freezes of 1894–95 in Florida, and what they teach. U. S. Dept. Agr. Yearbook, **1895**: 159–174, fig. 16–22, pl. 3.

These freezes caused very serious damage. Methods of lessening damage are discussed. The methods of treatment of trees to help recovery are described. Pineapple plants entirely recover from freezes after one year. Large bodies of water afford great protection to citrus trees in the immediate vicinity.

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1910. Brackett: *Prevention of frost injury* (U. S. Dept. Agr. Yearbook, **1909**).

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