M. K. BENNETT

FOOD CROPS AND THE ISOLINE OF NINETY FROST-FREE DAYS IN THE UNITED STATES*

The principal purpose of this study is to apply an empirical test to the hypothesis that one of the geographical "limits" to production of food crops[1] is the isoline of 90 days free of 32° F. frost. The inquiry is limited to the United States, although a mapping of this isoline for Canada, using different methods, was published early in 1959 (*1*). The hypothesis cannot be tested in the absence of a mapping of the isoline, which has never been undertaken in terms of 32° F. frost, so that the first step is to describe basic data and the methods of mapping. The resultant mapping is then compared with Reed's map, published more than 40 years ago (*2*), of the national area free of "killing" frost for 90 days or less, and with the United States segment of a Russian world map, probably but not certainly pertaining to killing frost, published in 1937 (*3*). Next is undertaken a general survey of demographic and agricultural distributions in the 11 western states (pre-1959), contrasting those of the "cold zone" with those of a "dry zone" and a zone climatically not so unfavorable as either. Finally, since a small amount of foodcrop acreage is found within the cold zone circumscribed by the isoline of 90 frost-free days as we map it from meteorological and physical data, evidence is examined to determine whether the crops are in fact grown under conditions of so short a frost-free season or whether the mapping of the cold zone is itself in fault. The conclusion emerges that, in general, imperfections of the mapping of the cold zone and of crop acreages explain the apparent presence of foodcrop acreage within it.

BASIC DATA AND PROCEDURE

Land areas of the United States climatically (for an average of about three decades) free of frost for under 90 days are found, with possible minor exceptions,[2] only west of the 100° meridian. Nor is such cold territory found in the states traversed by that meridian—North and South Dakota, Nebraska, Kansas,

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[1] "Food crops" in general are crops that are edible by man and are of relatively high output of calories per acre, such as cereals, starchy roots and tubers, beans and peas, and oilseeds; they exclude feed crops like hay, and low-calorie crops like spinach or radishes.

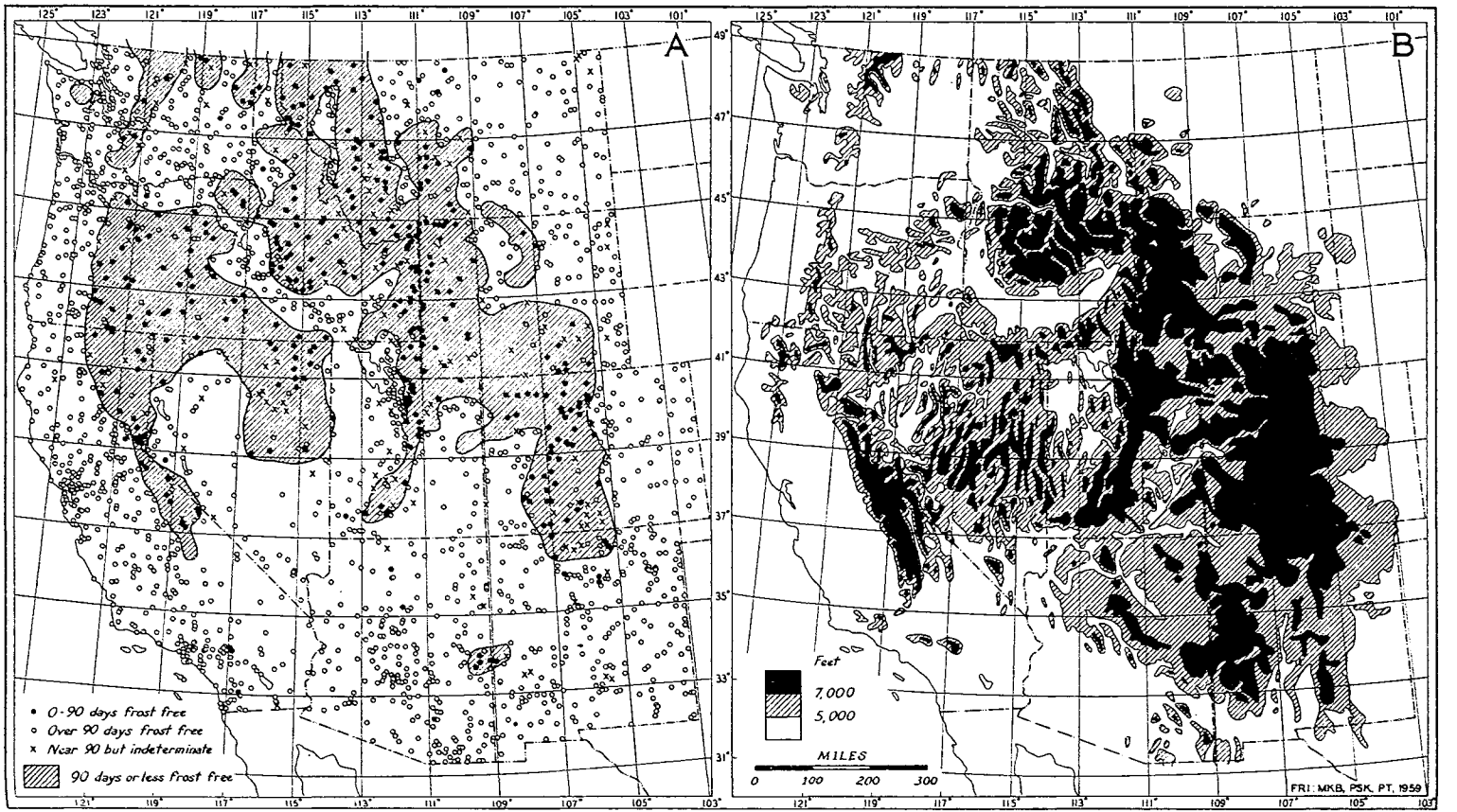
[2] Apparently in three small areas of northern Michigan one of which extends into eastern Wisconsin, and a small spot in New York (the Adirondacks), to judge by maps in *4*.

Oklahoma, and Texas—unless it be for a small region in the Black Hills of extreme western South Dakota. Accordingly we limit inquiry to the western states of Washington, Oregon, Idaho, Montana, Wyoming, California, Nevada, Utah, Colorado, Arizona, and New Mexico. The areas frost-free for 90 days or less in these states, and hence in the 48 older United States, exist chiefly by reason of altitude and not by reason of latitude. At altitudes below 1,000 feet in all latitudes of these 11 western states one finds no weather stations which report a frost-free season of less than 90 days. Only farther north, in Canada, do such inhospitably cold areas at low altitudes present themselves.

The basic statistical information is drawn from four sources: (1) the United States Department of Agriculture's *Climate and Man . . .*, the Department's yearbook for 1941, which for many stations lists the average number of days between killing frosts in spring and fall, called the "growing season," in terms of averages variable from station to station as to number of years covered; (2) annual summaries (*Climatological Data*) of the United States Weather Bureau, Department of Commerce, for each of the 11 western states for each year 1949–57 inclusive, wherein frost-free periods of stations are given annually (and here averaged) in terms of number of days between 32° F. frosts in spring and fall; (3) microfilm supplied by the United States Weather Bureau giving averages, with statement of number of years covered, of number of days between 32° F. frosts in spring and fall typically within the period 1921–50; and (4) a publication of the United States Weather Bureau when it was under jurisdiction of the Department of Agriculture, commonly known as "Bulletin W" but officially titled *Climatic Summary of the United States: Climatic Data Herein from the Establishment of Stations to 1930, Inclusive* (1930). This publication presents in terms of averages of all years available (before 1930) the number of days between killing frosts in spring and fall, and additionally, though for relatively few stations, annual data on that period with dates of first and last occurrence of 32° F. frost, so that for those relatively few stations one can reckon differences between average periods free respectively of killing frost and of 32° F. frost. In 1948 the Weather Bureau discontinued recordings of killing frost, perhaps considering that a killing frost is an occurrence on opinion of an observer and not on mechanical evidence such as thermometers provide. Up-to-date mapping of frost-free zones in the United States will henceforth necessarily be expressed in terms of specific thermometer readings.

The procedure here followed was first to list, by counties within each state, all temperature-reporting stations as determined first from *Climate and Man . . .*, second from the 1957 issues for each state of *Climatological Data,* and third from the microfilm covering the years 1921–50 (although very few stations were added by the microfilm data). Latitude, longitude, and elevation were ascertained for each station, with rare exceptions. While the list might have been somewhat augmented by inclusion of stations named in "Bulletin W" but omitted from the other three sources, the number is small. It seems probable that, in spite of the Weather Bureau's practice over time of dropping some stations from the roster and adding others, the three sources together provide nearly the maximum number of points of observations of frost-free period available over the past 40 or 50 years.

MAP 1.—Eleven Western States: (A) Temperature-Reporting Stations, and Area Free of 32° F. Frost for 90 Days or Less, and (B) Land Elevations



Evidence on length of frost-free period[3] having been assembled for all reporting weather stations in the 11 western states, the stations were sorted into those (1) frost-free for 90 days or less over an average of some 30 years, and (2) frost-free for 91 days or more over an average of some 30 years. No attention was paid to comparability in time sequence of the imagined 30-year periods, on the ground that differences between an average covering, e.g., the years 1890–1920 would not differ appreciably from one covering the years 1927–57. Arrangement of the data by counties and evidence on elevation permitted much heavier reliance on meager statistical evidence of actual temperatures than would otherwise have been reasonable. The great bulk of the stations could readily be classified into one category or the other: if, for example, a given station showed for a time span as short even as four or five years a frost-free period of more than 200 days, it is practically inconceivable that 25 more years of record could throw it out of category 2 into category 1; and the reverse can be said of a station recording frost-free periods of less than, say, 50 days for four or five years. Classification naturally becomes more dependable with increase in the number of years of observation.

Yet some problems of classification remained. These arose especially when one considered a station with a long-term average of killing-frost-free period in the approximate range of 90–125 days, but for which no data on 32° F. frost could be found. The average relationship between length of killing-frost-free period and length of 32° F.-frost-free period is by no means constant from station to station but ranges, whatever the reasons may be, from zero at some stations to (occasionally though rarely) over 50 days at others. Hence it was impossible to estimate closely the length of period free of 32° F. frost from a known length of period free of killing frost, if that period lay only moderately above 90 days. The problem also arose when one considered a station for which one had no more than a seven-to-nine-year record of occurrence of 32° F. frost, and the average frost-free period lay between 80 and 100 days. The possibility then arose that if there were 20 more years of observation the average might fall either above or below 90 days. However, many of these problems could be resolved by analogy, reliable information being available on stations near at hand and of about the same altitude. Even so, a few stations could not be securely placed in either category, and were therefore classified as intermediate or borderline. In Map 1A stations with 90 days or less frost-free are indicated by solid dots, those with 91 days or more frost-free by hollow circles, and those not clearly falling in either category by x's.

Map 1A shows at their proper locations all of the temperature-reporting stations in the 11 states which were amenable to classification into the three categories—a total of 2,205. Within the hatched area lies the territory which, in general, seems appropriately to be characterized as frost-free for 90 days or less.

Demarcation of this cold zone was necessarily a procedure of approximation, for a far larger number of points of observation would be required, given the many abrupt and extreme changes of elevation within short distances, if pre-

[3] The average number of days between last occurrence of frost in the spring and first occurrence in the fall, whether expressed as killing or as 32° F. frost. Subsequently the terms "frost" and "frost-free" refer to 32° F. frost except as stated specifically to mean killing frost.

cision were to be attained. The isoline enclosing the inhospitably cold zone was of course drawn to include a maximum of the points of observation recording less than 90 frost-free days and a minimum of points recording more than 90 frost-free days. Placement of the isoline had additionally to be guided, however, by reference to land elevations, since scores of miles often separate the weather stations and increase of elevation tends generally to shorten the frost-free period. Map 1B shows the land elevations (up to 5,000 feet, 5,000–7,000 feet, and above 7,000 feet) that were used in the process of placing the isoline. Clearly, however, contour lines could not reasonably be followed closely, since with increase of latitude there is decline in length of frost-free period at any stated elevation; and also, it would appear, there is increase in the length of frost-free period at a given elevation on comparison of locations in maritime climates of the west coast with locations in continental climates of the interior. (Note, for example, how preponderant are stations with less than 90 frost-free days at elevations of 5,000–7,000 feet and below in central and southeastern Oregon, while in corresponding latitudes and elevations of eastern Wyoming the preponderance is of stations frost-free for more than 90 days.) Yet it seemed probable, as rough guides, that north of the 43° parallel in the United States (a degree north of the southern border of Idaho and Oregon) all land above 5,000 feet in elevation (and some below that level) ought to be encompassed in the cold zone; and above about the 39° parallel all land at elevations above 7,000 feet might properly lie within it.

The principal problems of isoline placement on the basis of meteorological data and elevations arose in fixing upon the southern extensions of the cold zone in California, west-central Nevada, south-central Utah, and south-central Colorado and north-central New Mexico. Here the observations are somewhat sparse and without clear preponderance of category, and the probability that all land above 7,000 feet in elevation lies in the cold zone is weakened. For the same reasons it seems possible that the indicated isolated "island" of cold territory at the Arizona–New Mexico boundary ought to extend farther to the northeast. There were also problems in location of the isoline in the rugged terrain of eastern Idaho, in the neighborhood of the upper Snake River Valley.

Needless to say, additional though smaller islands of cold territory might properly have been designated, solely on the basis of weather-station records—one or several in each state. But in the main these seem to represent frost conditions in restricted localities at relatively high elevations[4] as compared with the bulk of the surrounding territory. They were excluded from the cold zone in the interests of generalization. For the same reason, islands of territory with

[4] The southwesternmost station shown in Map 1A as having less than 90 days free of frost is Julian Wynola, elevation 3,655 feet, lying east of San Diego, California, on the 33° parallel. South of the 37° parallel are 31 more stations where the frost-free period is under 90 days (including doubtful cases). Julian Wynola is remarkable in that it alone, among the 31, has an elevation of less than 5,000 feet, and indeed only one other, Seven Oaks, almost due north of Julian Wynola, stands at an elevation below 6,500 feet. Inquiry, through the kindness of the Office of State Climatologist of California, makes clear that the temperature observations at Julian Wynola are not in error. An explanation of the low summer temperatures is offered in terms of cold-air drainage into the valley where the thermometer is located, along with rapid radiational cooling, especially after the passage of an upper cold low or trough. Whatever the explanation may be, Julian Wynola seems to represent for the United States the most extraordinary available observation of short frost-free season at low latitude and low altitude.

more than 90 frost-free days within the cold zone, which might properly have been indicated, were ignored. For the most part these represent conditions in rather small intermountain valleys.

COMPARISON OF MAPPINGS

The Russian mapping of the regions of the United States free of frost for less than 90 days, presumably referring to killing frost,[5] does not bear a notably close resemblance either to our mapping of regions free of 32° F. frost for less than 90 days or Reed's mapping of regions similarly free of killing frost. The contrasts appear in Map 2. Little would be gained from an attempt to explain the differences between the Russian mapping and the others, since the sort of meteorological phenomena which gave the basis for the Russian mapping is not stated. It is perhaps not surprising that the Russian mapping should have assigned to the cold zone large areas around Flathead Lake in Montana, or in Idaho at the Washington border and in the upper Snake River Valley, or in Utah west of the Wasatch and Paunsaugunt plateaus: such assignments might occur simply in reflection of a choice to generalize very broadly and paint a broad picture. Inclusion of a substantial area east of Walker Lake in Nevada might have been determined by the presence there of a good deal of land area above 7,000 feet in elevation; but if this be the explanation, it is difficult to comprehend exclusion in the Russian map of such regions as the Cascade Mountains in Washington and Oregon, the Sierra Nevada in California, and highlands of the Rocky Mountains extending southeasterly through Montana, Wyoming, and Colorado. In any event the Russian mapping, so far as concerns the United States, seems not to have rested heavily either upon frost data from meteorological stations available at the time of mapping, something prior to 1937, or upon Reed's mapping, which made use of such data, available two decades earlier.

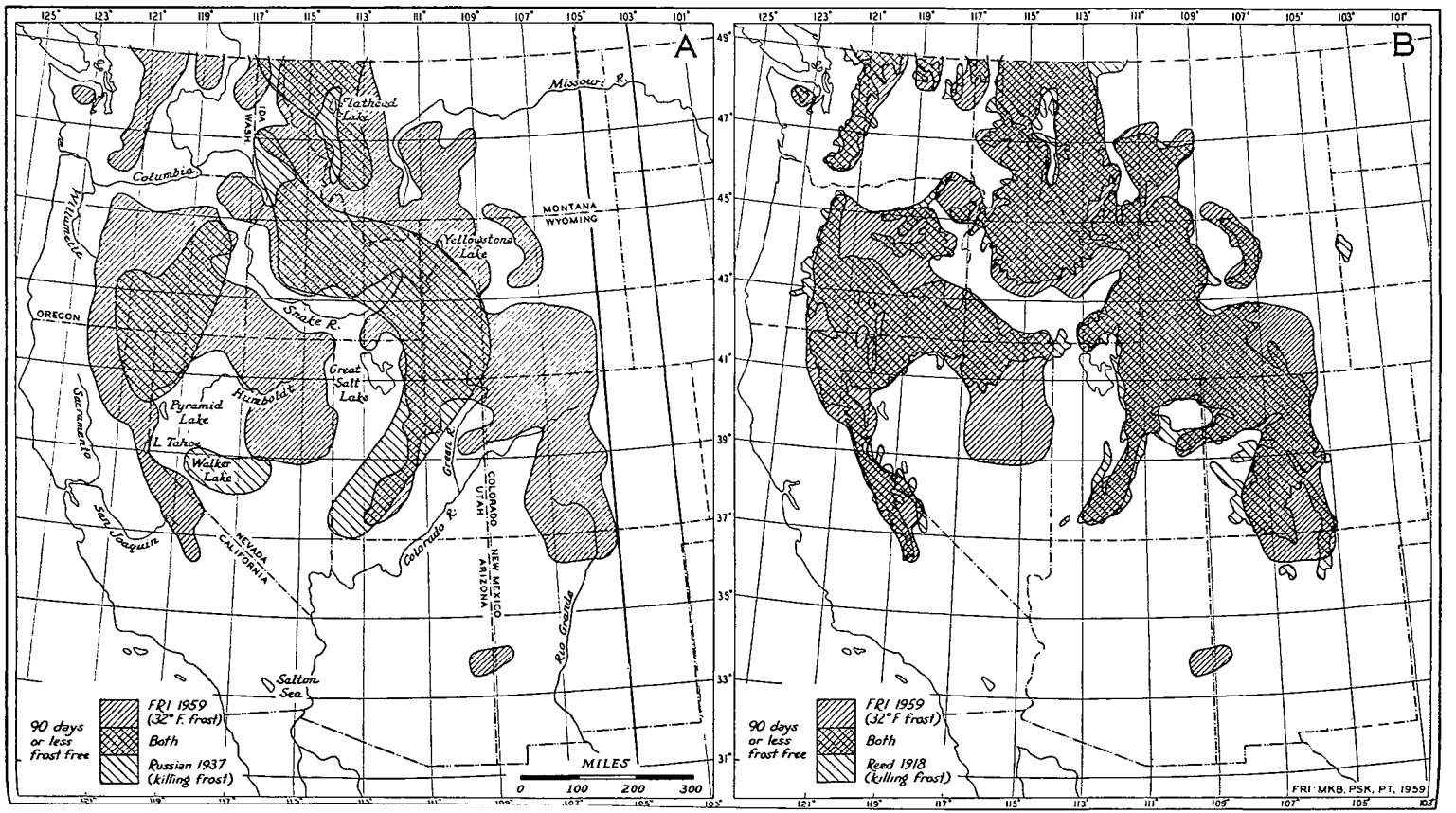
Concordance is much greater between our mapping of the cold zone and Reed's mapping of area free of killing frost for under 90 days. These are mappings produced independently one of the other. The degree of concordance is perhaps surprising in view of the difference in basic definitions, one map referring to area free of 32° F. frost and the other to area free of killing frost. However, both mappings had to depend in part upon land elevations, and Reed's observations of killing frost were in fact not uncommonly observations of 32° F. frost, since reporters seem often not to have found it feasible to distinguish one from the other.

Yet fairly conspicuous differences exist between the two mappings, as would be expected because of differences in definition of frost, in accumulated mass of information from meteorological stations, in interpretation of relationships between land elevations and frost-free period, and in disposition to generalize and smooth the 90-day isoline.

If Reed's mapping and ours differed only with respect to definitions of the

[5] The basis for presumption of killing frost lies (a) in M. Y. Nuttonson's work (*5*), wherein he gives dates of occurrence specified to be killing frost for all Siberian meteorological stations where data were available, the data being Russian; and (b) in use of the term by Lois B. Bacon and others in geographical work involving European Russia (*6*). The official Soviet publication (*3*), which provides the basis for the mapping in Map 2, gives no indication whether the frosts are killing or are as measured by a particular level of thermometer reading.

MAP 2.—Comparisons of Three Mappings of Area Frost-Free for 90 Days or Less in the 11 Western States



isoline mapped and not as to basic data or interpretations, one would expect the territory enclosed within the 90-day isoline of 32° F. frost to exceed the territory enclosed within the isoline of killing frost, killing frosts being more severe than 32° F. frosts. At any given elevation (or latitude) the number of days between killing frosts in spring and fall would exceed the number of days between 32° F. frosts, so that points on the 90-day isoline of 32° F. frost would fall lower on mountain slopes, or lower in latitude, than points on the 90-day isoline of killing frost. As Map 2B shows, the cold zone as defined by 32° F. frost does exceed that zone as defined by killing frost, in accordance with general expectations.

There are, it is true, various extrusions of Reed's cold zone beyond the cold zone as we map it. While small in total area, they run contrary to expectations. Close comparison of Map 1A with Map 2B indicates that within a good many of these extrusions lie meteorological stations reporting less than 90 days free of frost, however defined; and comparison of Map 1B with Map 2B shows that within others of these extrusions are elevations above 7,000 feet but no meteorological stations. Forty years ago Reed could bring to bear much less evidence from meteorological stations than is available today,[6] and had to rely more than would today be necessary upon evidence on land elevation and hence upon probable though ill-established relationship of length of frost-free season to elevation.

There are five principal blocks of territory which by our mapping appear to be frost-free for less than 90 days but by Reed's mapping are free of killing frost for 90 days or more—in northeastern Oregon, in Idaho on the northern fringe of the Snake River Plains, in southeastern Wyoming, in northeastern Nevada, and in south-central Colorado extending into New Mexico. It is of course impossible to say to what extent an up-to-date mapping of the isoline of 90 days free of killing frost would include these regions, though it could not fail to do so in some degree. Of more interest here is the question whether all of the territory or the great bulk of it in these five regions is rightly to be classified in the category of land climatically free of 32° F. frost for 90 days or less.

With the qualification that each of these five regions presumably contains spots where the frost-free season somewhat exceeds 90 days, it can reasonably be concluded, by comparison with Map 1A, that northeastern Oregon is appropriately mapped; for of 26 meteorological stations not overwidely dispersed, 17 yield clear evidence of the short frost-free season, 3 yield insecure evidence, and the 6 which point to a longer frost-free season lie in the narrow valley of the John Day River, exceptional to (warmer than) surrounding terrain. The same may be said of the western portion of the Snake River Plains. But east of the 114° meridian in those plains, the meteorological evidence seems inconclusive,

[6] As was stated above, data from 2,205 meterological stations in the 11 western states were used in drawing the isoline in Map 1A. It is not possible to determine how many stations in these states provided data for Reed's mapping published in 1918, although he states (2, p. 1) that his work for the United States as a whole was based upon data "from about 4,000 regular and cooperative stations of the Weather Bureau." A few years later, Kincer published (in 7) a map dated 1923 showing the location of all Weather Bureau stations in the nation; 1,248 of these lie in the 11 western states. Not all of them, Kincer states, were stations making observations of temperature. In 1949 in the 11 western states, the stations reporting temperature observations made up about 60 per cent of all stations. If some such ratio held in 1923 and earlier, the inference is that Reed in 1918 may have had less than half the observations utilized in the present study.

there being only nine stations, of which three yield doubtful and two negative evidence of under-90-day-frost-free season, and three of the five yielding positive evidence lie on the northern, presumably cooler, periphery. For eastern Wyoming, too, the meteorological evidence is scanty and mixed, with twice as many stations yielding uncertain or negative evidence as there are of stations yielding positive evidence. The situation is equally confused in south-central Colorado and northern New Mexico, where "doubtful" observations (8) are more numerous than either negative (4) or positive (4) ones. Doubtful and negative observations also preponderate over the positive in part of northeastern Nevada, though not its most northeasterly portion. Even so, if one must face the joint problems of generalizing a map sufficiently and ascribing relevance to differing elevations lacking meteorological stations, these five principal regions—with the qualification stated above—seem properly to fall in the zone free of 32° F. frost for less than 90 days. But as will appear on inquiry into foodcrop distributions, south-central Colorado and the eastern portion of the Snake River Plains appear not clearly to belong in the cold zone.

DEMOGRAPHIC AND AGRICULTURAL CHARACTERISTICS OF COLD AND DRY ZONES

The area of the United States with less than 90 frost-free days, as mapped above in Map 1A, constitutes about a third of the total land and water area of the 11 western states. Another large fraction of the area of these states is also naturally unfavorable, at least to unirrigated crop production, by reason of low rainfall. A third portion, half of the total, is neither so short in frost-free season nor so dry. If one divides the whole area into these three categories—the portion with less than 90 frost-free days, an *additional* portion wherein annual rainfall is less than 10 inches, and a third residual portion not characterized by such extremes of short frost-free season or low rainfall—acreages in the several categories are as follows:

Region	Thousand square miles	Per cent
Western states (11)	1,188[a]	100
Cold zone	373[b]	31
Dry zone	218[b]	18
All other	597[c]	51

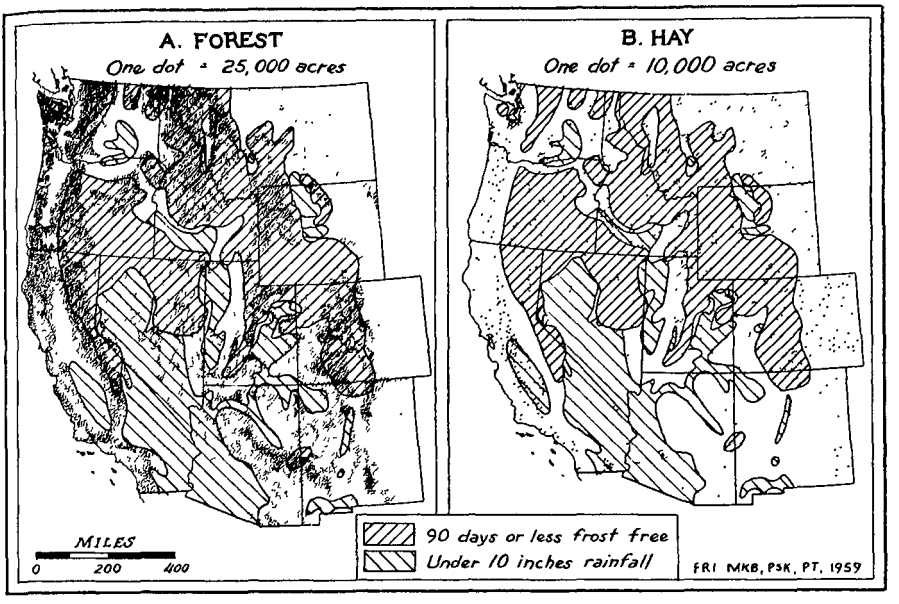
[a] Data from U.S. Dept. Comm., Bur. Census, *Statistical Abstract of the United States, 1957* (1957), p. 158; "gross area."
[b] Measured by planimeter (Map 3A).
[c] Arithmetical residual.

Maps 3 and 4 show these three zones[7] each in relation to the others, and also, respectively, the distribution among these zones of forest land, land from which hay was cut, all land in farms, and cropland.

The density of population (persons per square mile) in 1950, in the 11 western states, was 16.5. By count of symbols on a population map given in the *National*

[7] The mapping of the dry zone is after Kincer (*8*), excluding from his mapping of a zone with less than 10 inches of rainfall the parts falling within the cold zone of Map 1A.

MAP 3.—Distribution of Forest (1953) and Acreage of Land Cut for Hay (1954) in Relation to the Cold and the Dry Regions of the 11 Western States



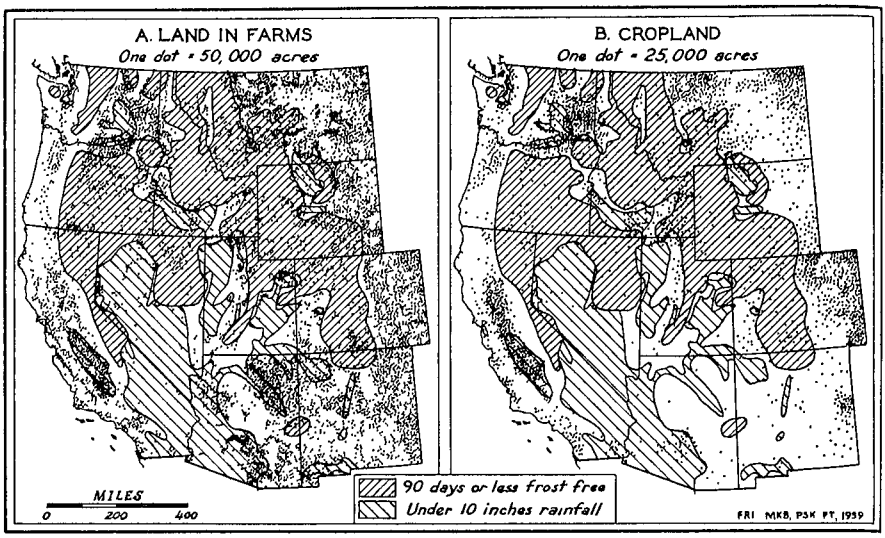
Atlas of the United States,[8] taken in relation to the three zones measured by planimeter, the densities were 2.5 in the cold zone, 12.6 in the dry zone, and 26.6 elsewhere in parts of the 11 western states less disadvantaged climatically, lying mostly east of the Rocky Mountains and west of the Sierra Nevada and Cascade ranges.[9] These relative densities are reflected in the geographical distribution of cities. In 1950 there were 65 cities with populations in excess of 25,000 in the 11 western states. Of these, 56 were outside the cold and the dry zones, only 9 within them. Within the dry zone were 8 cities: Bakersfield, East Bakersfield, Fresno, and San Diego in California, though San Diego does not fall within the 10-inch isohyet according to other mappings; Phoenix and Tucson in Arizona; Albuquerque in New Mexico; and Yakima in Washington. (Las Vegas in Nevada probably joined the list in 1951.) In the cold zone, however, there was only a single city with a population exceeding 25,000—Butte, Montana, with 33,251 (9).

Clearly the cold zone of the 11 western states has thus far proved less hospitable to population and urbanization than the other two portions. Whether it would be so in relation to the dry zone in the absence of irrigation need not be considered here, although the differences would presumably be less marked. Population densities in the dry zone obviously exist in far the greater part only

[8] Sheets of this publication, issued separately by the United States Department of Commerce, Bureau of the Census (*c.* 1956), have been used throughout the present study; they will be cited as *National Atlas.* Acreages subsequently discussed are largely based upon count of dots on maps in these sheets. The method, while necessarily approximate, seems sufficiently reliable for present purposes.

[9] The total population of the 11 western states in 1950 was 19.56 million persons; the distribution between zones as determined by count of symbols was roughly .95 million in the cold zone, 2.75 million in the dry zone, and 15.86 million elsewhere.

MAP 4.—Distribution of 1954 Acreage of All Land in Farms and of All Cropland in Relation to the Cold and the Dry Regions of the 11 Western States



because water supplies are spread to land and people by artificial control of rivers traversing the dry areas but originating elsewhere. The mentioned cities of the dry zone all depend upon such water supplies, and most of them are situated in the midst of agriculturally productive irrigated valleys.

The relatively forbidding character of the cold zone is suggested also by uses of land, although one cannot differentiate the effects of short frost-free season, low annual rainfall, terrain, soils, and vegetative cover. From Map 1B it is apparent that much of the cold zone is of mountainous character. Map 3A shows that a good deal of it is forested; some of the forest remains in private hands, some is in national or local forests, parks, and monuments. The combined influences reduce the proportion of land in farms in the cold zone to a lower figure than even in the dry zone, to say nothing of other parts of the 11 western states. Statistical appraisal derived from count of dots in pertinent maps of the *National Atlas* indicates that in 1954 all land in farms in the cold zone constituted 26 per cent of its total land and water area; at 29 per cent the proportion was a little higher even in the dry zone; and it was much higher, about 62 per cent, elsewhere. The distribution of land in farms in the 11 western states among the three zones is shown in Map 4A.

Data on cropland within farms, as in Map 4B, similarly emphasize the relatively inhospitable character of the cold zone; the ratios of cropland to total area in 1954 range upward from 4.1 per cent in the cold zone through 5.8 in the dry to 12.7 elsewhere. Ratios of cropland harvested to total area show the same type of progression (2.4, 4.1, and 7.1 per cent). The considerably lower ratios of cropland to total area than of land in farms to total area in all three climatic categories point toward a preponderance of grazing over cropping in the use of land in the 11 western states, and this is further indicated by ratios of land in farms other than cropland to the total area of land in farms. The ratios

decline from 84.0 per cent in the cold zone to 80.0 per cent in the dry and 79.4 per cent elsewhere. The use of land in farms for grazing is clearly the predominant agricultural use throughout the 11 western states but appears to receive some relative emphasis in the cold zone.[10] Within the cropland of farms, emphasis in the cold zone falls with relative weight upon production of hay, of which the acreage (dominantly alfalfa, not wild hay) is shown in its distribution among the three zones in Map 3B. In the cold zone land from which hay was cut in 1954 constituted 30.3 per cent of the cropland, in the dry zone 18.0 per cent, elsewhere 11.9 per cent. If finally one considers the ratios of harvested acres in 1954 of the nation's 15 major food crops[11] plus land in "fruit orchards, groves, vineyards, and planted nut trees" to total land and water area of the three zones (1.0, 2.0, and 4.5 per cent), it becomes clear that the cold zone as mapped is the least hospitable to forms of agricultural activity involving food production.

By way of sharpening contrasts, the following tabulation gives significant ratios pertaining to use of all land respectively in the cold zone of the 11 western states and in the agriculturally lush state of Iowa:[12]

Item	Cold zone	Iowa
Land and water area	100.0	100.0
All land in farms	26.0	94.6
Cropland	4.1	72.2
Cropland harvested	2.4	62.3
Major food crops, orchards	1.0	50.0

The density of population in 1950 in Iowa was 46.8 persons per square mile as compared with 2.5 in the cold zone.

Reed wrote in 1918, with reference to his mapping of the area of the United States free of killing frost for less than 90 days: "There is very little agriculture, except that based upon wild hay and grazing, where the average season between killing frost is less than 90 days" (2, pp. 10–11). The data given above demonstrate that the same general conclusion holds for the larger territory here mapped as free of 32° F. frost for less than 90 days, despite the lapse of four decades during which settlement, had climatic conditions been favorable, might have expanded greatly the acreage in harvested crops.

The economic return from farming of all kinds together is lower in the aggregate in the cold as compared with the dry and the residual zones of the 11 western states—in terms of farm products sold, $368 million in 1954 in the cold zone, as compared with $1,136 million in the dry zone and $3,419 million elsewhere. Farm products sold per acre of land in farms amounted to only about $6 in the cold zone, $28 in the dry, and $14 elsewhere. Per acre of crop-

[10] However, not all of the land in farms which is not cropland is necessarily used for grazing. Some of it is in unpastured woodland, is waste, or is in roads and farmsteads.

[11] The nation's major food crops are here defined as all crops of the United States with harvested areas exceeding 500,000 acres, except for crops of hay, cotton, flaxseed, and tobacco. Included additionally are dry edible peas, since their acreage is peculiarly concentrated in the western states. The full list of 15 major food crops is wheat, barley, oats, rye, corn, rice, grain sorghum, soybeans, peanuts, dry beans, dry peas, Irish potatoes, sugar beets, sweet corn, and tomatoes.

[12] Based on data of the census of 1954.

land the values were respectively $37, $140, and $70. As would be expected from such differences in value of per-acre sales, the average size of farm varied in such a way as to tend to equalize sales per farm. Average farm sizes were respectively some 1,350 acres in the cold zone, 645 in the dry, and 745 elsewhere. Even so, gross sales per farm remained lowest in the cold zone ($8,400); they were highest in the dry zone ($18,200), and intermediate elsewhere ($10,800). In Iowa, the value of farm products sold per acre was $54; and, although the average size of farm at 176.5 acres was only an eighth as large as in the nation's cold zone, the value of farm products sold per farm in Iowa, some $9,530, was somewhat higher.

The range of nationally important food crops occupying harvested acreage in 1954 was decidedly narrower in the cold zone than in the dry zone or elsewhere in the 11 western states. The following table provides the statistical evidence:

ACREAGES OF CROPLAND, ORCHARD AND VINEYARD, AND NATIONALLY IMPORTANT FOOD CROPS IN CLIMATIC REGIONS OF THE 11 WESTERN STATES, 1954

(Thousand acres, except as noted)

Item	Total 11 states[a]	Cold zone[b]	Dry zone[b]	Other parts[c]
Cropland (*million acres*)	66.6	9.8	8.1	48.7
Orchards, vineyards, groves, etc.	1,632	35	355	1,242
Wheat	11,199	1,230	830	9,139
Barley	5,567	750	930	3,887
Oats	1,258	130	50	1,078
Irish potatoes	384	101	55	228
Sugar beets	586	29	105	452
Dry peas	247	16	22	209
Dry beans	834	12	210	612
Corn (for grain)	416	0	40	376
Rice	474	0	55	419
Sorghum (for grain)	876	0	125	751
Rye	44	1	0	43
Soybeans	1	0	0	1
Peanuts	5	0	0	5
Sweet corn	77	2	59	16
Tomatoes	104	0	55	49
Total 15 food crops	22,072	2,271	2,536	17,265

[a] Census data for "The West."
[b] Calculated by count of dots as described in text.
[c] Derived by subtraction.

In the cold zone as mapped only seven of the nation's major food crops were harvested from more than 10,000 acres—wheat, barley, oats, Irish potatoes, sugar beets, dried peas, and dried beans; eight crops were not grown at all or were grown on trifling acreages. The dry zone had a wider range, although three crops were absent: rye, soybeans, and peanuts. None were missing elsewhere in the 11 western states, although less than 10,000 acres of soybeans and rye were reported as harvested.

Most, but not all, of the major crops missing from or of negligible importance

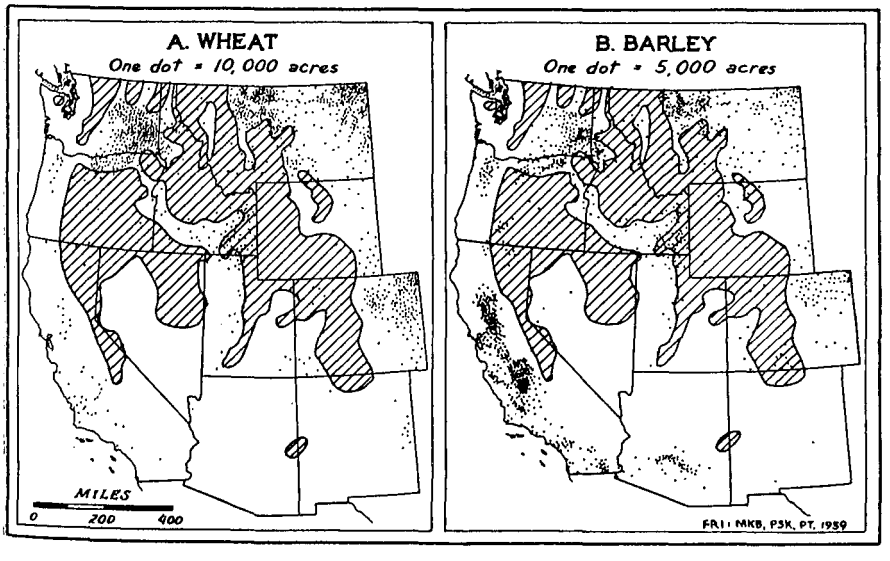
in the cold zone clearly are excluded by reason of climate: the frost-free season is too short to permit maturation of rice, corn, grain sorghum, tomatoes, peanuts, and soybeans. Sweet corn, of course, is a crop not brought to maturity before use. Even so, its acreage is trifling in the cold zone and perhaps does not in fact exist there. But the absence of rye (harvested for grain; rye cut for hay is cultivated in the cold zone) is attributable more to economic than to climatic circumstances. If, as is indicated, some wheat and some barley are produced within it, rye might also be grown.

APPARENT *VS.* REAL INTRUSIONS OF FOOD CROPS

The foregoing discussion has taken for granted the presence of the specified food crops within a zone of the United States characterized climatically throughout by a frost-free period of 90 days or less. The mapping of the cold zone has been taken as reasonably or approximately accurate, as well as the placement of dots indicating the location of crop acreage. But, as explained above, the mapping of the cold zone cannot be meticulously accurate. Neither can official mappings of the location of crop acreages, since these are based upon crop statistics by counties and a dot representing, e.g., 10,000 acres of wheat in a given county with a land area of a million acres may be placed in mid-county rather than in a corner where it actually lies or in scattered spots where portions of it, perhaps a score of them, actually lie.

With a view to deciding whether a meticulously correct mapping of the cold zone would or would not diminish the acreage of food crops lying within the cold zone as mapped, one may examine in some detail subregions of the cold zone wherein substantial acreage of wheat and barley appear to be concentrated. These two crops constitute over 80 per cent of the acreage of all food crops in the cold zone as mapped. Map 5 shows the distribution of their acreage.

MAP 5.—Distribution of 1954 Acreage of Wheat Threshed and Barley Threshed in Relation to the Cold Regions of the 11 Western States



The most prominent clusters of dots indicating presence of wheat and barley taken together will be found in south-central Colorado above the new Mexican border, in northeastern California and adjacent south-central Oregon, and most notably in eastern Idaho with extension into northern Utah. The Colorado region accounts for about 5 per cent of the barley apparently in the cold zone, the California-Oregon region for 15 per cent, the Idaho region for over 20 per cent. The Idaho region accounts for a fourth of the wheat acreage, but there is only a little of this crop in the other regions—none, apparently, in Colorado. The three subregions additionally contain three-fourths of the cold-zone total of potato acreage; south-central Oregon and eastern Idaho are well known as centers of commercial potato production.

It seems probable that the food crops in south-central Colorado do not represent invasion of a zone factually free of frost for less than 90 days; on the contrary, our mapping of the zone is there too highly generalized to represent properly the climatic facts. This region lies along the 37° parallel in the valley of the upper Rio Grande River between the Sangre de Cristo and the San Juan mountains. It contains one of the three or four complete counties (Rio Grande) within the cold zone wherein the area of cropland exceeds 20 per cent of the total land area. It appears to contain all of the lettuce and romaine commercially grown throughout the cold zone, practically all of the cabbage, and perhaps half of the green peas—crops of negligible importance generally in the cold zone. As was pointed out earlier, Map 1A shows that so far as concerns data from weather stations, the evidence of prevalence of territory frost-free for less than 90 days is conflicting. Reed (Map 2B) did not map this region as free of killing frost for under 90 days; nor is it so mapped in *Climate and Man* . . . (*4*, p. 806), so far as one can judge of a map wherein the isolines are of 80 and 100 days frost-free. Its inclusion on our mapping rested partly on the conflicting data from weather stations, partly on the fact that its elevation exceeds 7,000 feet (Map 1B). In this instance at least, and possibly in some others, it seems likely that even at a latitude as high as 37° N. and an altitude as high as 7,000 feet in the United States, the period free of 32° F. frost may exceed 90 days.

There is reasonable probability also that in the indicated California-Oregon region the food crops are not in fact grown where the frost-free period is less than 90 days. Weather stations indicating a longer frost-free season are interspersed with stations indicating a season of 90 days or less (Map 1A); the terrain is notably variable in elevation, some of it in intermountain valleys below 5,000 feet (Map 1B); and Reed differentiated some spots as having a longer frost-free season than most of the territory surrounding them (Map 2B). The spots lie in Modoc County in California and Klamath and Lake counties in Oregon; they presumably represent valley bottoms of the Pit and of the upper Klamath rivers and their tributaries and, if weather stations were trebled or quadrupled in number throughout the three counties, might well emerge clearly as small areas with a season of more than 90 days frost-free, surrounded by larger areas with less than 90 days frost-free.

Much the same can be said of the cold zone in eastern Idaho, wherein lies so much of the total cold-zone acreage of wheat, barley, and potatoes. Our

mapping of the isoline was here guided by a combination of evidence from weather stations, not as numerous as would be required for exactness, and the 5,000-foot contour of elevation. Choice of the 5,500-foot contour would have been about equally reasonable in that latitude as a general indicator of the position of the isoline of 90 frost-free days but was not available.[13] To choose it would have appreciably constricted the area mapped as frost-free for less than 90 days in eastern Idaho. There would be fingerlike extensions of the warmer region into the intermountain valleys to the south and southeast, and a northeasterly extension farther up the valley of the upper Snake River.

Under such constriction of the cold zone of eastern Idaho, the probability appears high that meticulously accurate mapping of the location of the 1,001,143 acres of wheat, barley, and potatoes accounted for in the 13 counties of that part of the state by the 1954 census would place all of the acreage outside it, in localities where the frost-free period exceeds 90 days. Such localities would be indicated in all 13 counties and their area would amply accommodate the total acreage of the three crops, which constitutes under 10 per cent of total land area. But meticulously accurate mapping of the location of crop acreages within counties is not feasible on the basis of published census data.

The presence of a substantial acreage of winter wheat in eastern Idaho is certain; it constituted in 1954 about 35 per cent of the combined acreage in winter wheat, spring wheat, barley, and potatoes, and was located in each of the 13 counties. If its presence appears unusual at such high elevations and latitudes, a major reason is probably to be found in the climatic circumstances that make for a seasonal peak of precipitation in winter, with heavy snowfall, affording continued protection in the winter months, and sunny and hot, though brief, summers.[14]

Similarly detailed analysis of other places where the food crops apparently invade the cold zone as mapped might well lead to similar conclusions—that the apparent invasions are made to appear almost without exception on the one hand through inadequacies of our mapping, especially sacrifice of precision to generalization, on the other hand through misleading if unavoidable imprecision in placement of crop acreages within counties. If so, the cold zone of the United States, rigorously defined to include nothing but territory free of 32° F. frost for less than 90 days and meticulously mapped, would be demonstrably much less hospitable to food crops than the statistics above pertaining to the

[13] In 13 counties of Idaho east of the 114° meridian, all but one of 18 weather stations lying at elevations above 5,500 feet clearly record average frost-free periods of less than 90 days. The single exception, Lifton Pumping Station at an elevation of 5,926 feet, lies less than 20 miles from the southern boundary of the state and thus would be relatively more subject to influences of low latitude. At elevations ranging from 4,700 to 5,500 feet there are 12 stations; only 4 of these seem to record less than 90 days free of frost, and for 2 of these we have respectively only 8 and 9 years of record giving average frost-free periods of 82 and 83 days, which might readily be raised above 90 were the record 10–20 years longer. Another station, which we have classified as showing less than 90 days frost-free, might equally well be regarded as borderline, for the records of different series show 63 days free of 32° F. frost in 1949–57 and 93 days in 30 years prior to 1949, while a 35-year average applicable to killing frost and to unnamed years prior to 1941 was 97 days. While we cannot explain the 72-day frost-free period of Hamer, at an elevation of 4,791 feet, the 8-year period to which it applies may be too short to provide a representative average. The weight of the meager evidence thus suggests that a contour line of 5,500 would have provided about as good an indication of the position of the isoline of 90 days free of frost as the contour line of 5,000 feet which was used.

[14] See H. G. Carter, "Climate of Idaho," in *4*, pp. 839–40.

cold zone imperfectly mapped would indicate. So far as concerns the United States, and perhaps the world as a whole, the true isoline of 90 frost-free days may reasonably be taken as a physical "limit" to production of major food crops, though not to production of hay crops or to grazing on natural grasses.

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