Plantclimates of California

zones of similar plant responses and their possible interpretation by effective day-night temperatures

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Climate is one—and perhaps the most important—of the fundamental determinants of what plants can be grown in a given area. Climate, in this broad sense, includes temperature, total annual rainfall and seasonal distribution, as well as atmospheric humidity, air movement and light and other factors.

Irrigated agriculture does not depend on either local annual precipitation—total rainfall—or favorable seasonal distribution of rainfall for crop production. In the northwest section of California—where rainfall and humidity are high—the range of crops and ornamentals is primarily limited by a climatic factor other than temperature. Thus in all the principal farming areas of California temperature is the major factor of climate that controls plant growth.

Farm advisors of 26 California counties have requested lists of ornamental trees, shrubs, vines, ground covers and fruit trees suitable for home plantings. Nineteen of the 26 requested lists specifying plants for the different climatic zones of the counties.

In view of the dependence on irrigation for most crop and ornamental plantings these requests called primarily for a study of plant distribution. Associating these leads to the delineation of plantclimate zones.

The experienced farm advisors working with commercial crops recognize the existence of local temperature differences and the need for special lists of ornamentals. Their knowledge—of crop adaptation, season of production, survival of tender species among food, fiber, and ornamental crops—points the way to the development of detailed plantclimate zone maps for each county. When the recording of the over-all crop data is accomplished, county maps can be consolidated into areas and subsequently into a more generalized state map. Within these larger areas there will be, of course, local differences which may be greater than between major zones. The accompanying map is the first tentative step in the development of a detailed map delineating the plantclimate zones of California.

Seven major zones are established and numbered from the coast inland. The seven zones are divided into subzones with consistently rising day and night temperatures from north to south. For this tentative map, subzones are designated geographically as northern, central, and southern. Numbered zones do not include mountains and mountain valleys. Detailed study, probably, will result in establishment of many additional subzones reflecting significant plantclimate differences.

Present zone numbers are similarly tentative pending development of some systematic method that will describe zones and subzones from the standpoint of their plant environment.

Day and Night Temperatures

The importance of differing day and night temperatures for optimal plant growth has been understood—even partially—only in recent years. These daily temperature changes are in addition to seasonal variations required by many perennials. Many laboratory studies of the effect of temperature on plant growth have been made but most of them were conducted at relatively uniform day and night temperatures. Only in the past 10–15 years has research proved that practically all plants do better with higher day temperatures than night temperatures and that night temperature is more commonly the controlling growth factor. Photoperiod—duration of daylight required for plant growth—is probably second in importance.

When plants are grown in a phytotron—a plant growing chamber where both temperature and light can be accurately controlled—it is possible to determine the most favorable day and night temperature combination, or the optimal condition for the plants.

In a phytotron day and night temperatures are each usually held constant at different levels. A chart of daily temperature fluctuations in a phytotron is a square wave of horizontal lines at day and night levels. For outdoor conditions a chart of day and night temperature fluctuations is an undulating curve. Therefore, transfer of laboratory findings to outdoor conditions requires a somewhat arbitrary interpretation of the natural outdoor daily temperature cycle.

United States Weather Bureau records of monthly mean maximum and monthly mean minimum temperatures are available for a large number of stations. These temperature records are currently the best data by which the temperature characteristics of an area can be expressed.

The simplest satisfactory method found for relating plant response in a controlled temperature laboratory to plant response outdoors was to consider the effective daytime temperature as the monthly mean maximum minus one fourth the difference between the monthly mean maximum and monthly mean minimum, and the effective night temperature as the monthly mean minimum plus one fourth of the same range. Effective day and night monthly temperatures for some typical stations in each tentative California plantclimate zone are given in the accompanying table. Five stations are listed for the Central Valley because of cooler summer weather in the middle portion.

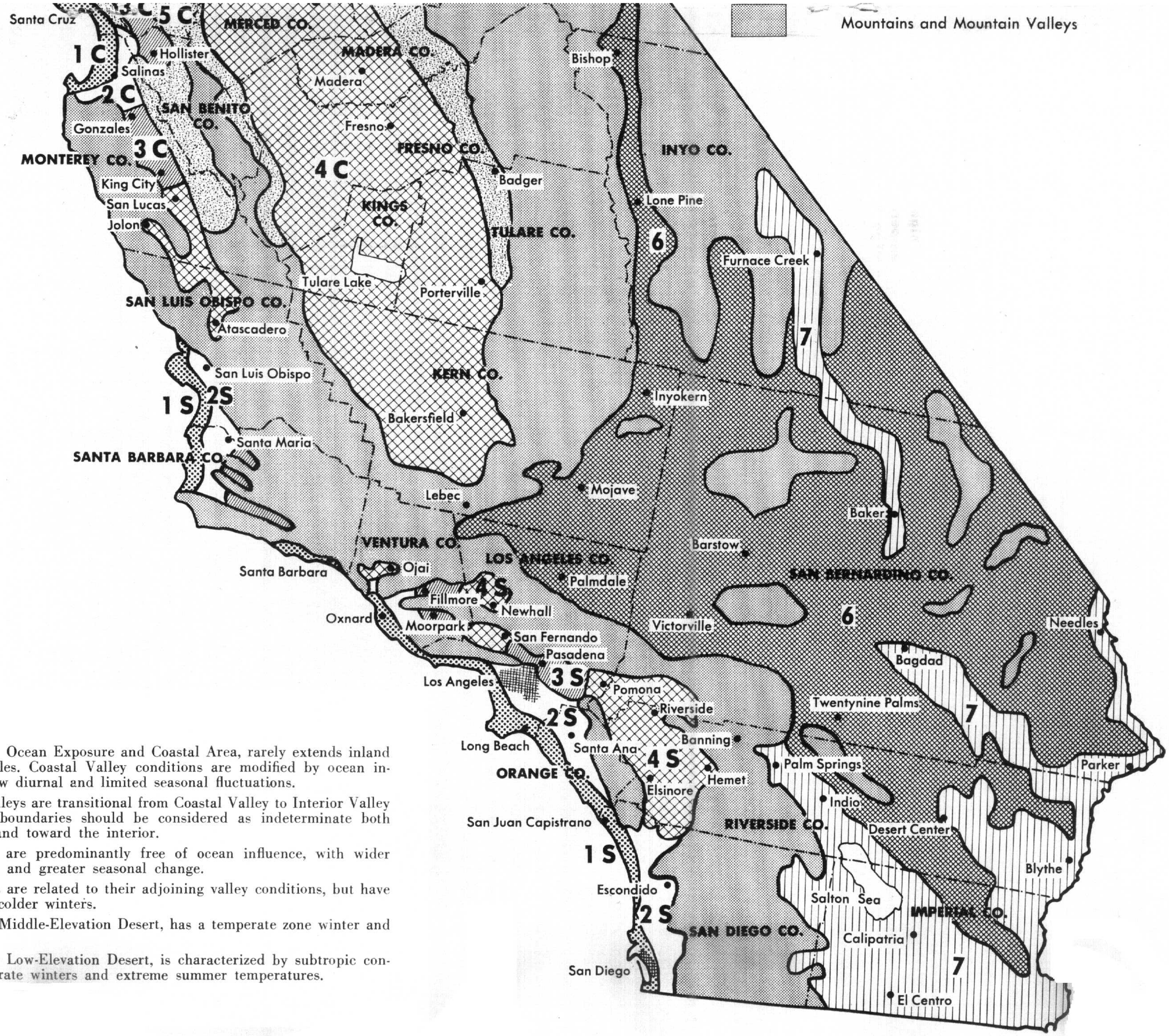
Use of effective day and night temperatures as a description of plantclimate fits in with the four-dimensional relationship of: *1*, photoperiod; *2*, effective day temperature—temperature during photosynthesis; *3*, effective night temperature—temperature during growth and sugar translocation; *4*, stage of growth.

Most significant for flowering and fruit production is the mean daily relationship of effective day temperature and effective night temperature, often with progressive lowering of effective night temperature toward harvest time. The progressive lowering of effective night temperature is indicated by an arrow in the zinnia area of the following chart and by an arrow in the diagram. Optimal day-night temperatures are found only in certain months in any single field location and explain how such annuals as lettuce and carrots can be grown in the winter near El Centro and grown during the spring near Salinas.

Day-and-night temperature relationship is being used now by agronomists as well as horticulturists. Entomologists have found daily fluctuating temperatures increase survival of some insects. Day-night temperature relationship may prove significant in animal environment.

A two-part description of daily temperature can be considered an important factor in the field of agriculture.

In general, the tolerable range of night temperature is rather broad for vegeta-



The zone, Direct Ocean Exposure and Coastal Area, rarely extends inland more than 3–5 miles. Coastal Valley conditions are modified by ocean influence with narrow diurnal and limited seasonal fluctuations.

Intermediate Valleys are transitional from Coastal Valley to Interior Valley conditions. Their boundaries should be considered as indeterminate both toward the coast and toward the interior.

Interior Valleys are predominantly free of ocean influence, with wider diurnal fluctuation and greater seasonal change.

Foothill climates are related to their adjoining valley conditions, but have cooler nights and colder winters.

The Mojave, or Middle-Elevation Desert, has a temperate zone winter and hot dry summer.

The Sonoran, or Low-Elevation Desert, is characterized by subtropic conditions with moderate winters and extreme summer temperatures.

PLANTCLIMATE ZONES OF CALIFORNIA

(Tentative)

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University of California—1956.
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Zones are numbered from the coast inland, with sub-zones indicated for northern, central, and southern sections of the state. Mountains and mountain valleys are not numbered.

Direct Ocean and Coastal Areas

1 N northern—humid
1 C central
1 S southern

Coastal Valleys

2 N northern—humid
2 C central
2 S southern

Intermediate Valleys

3 N northern—humid
3 C central
3 S southern

Interior Valleys

4 C central
4 S southern

Foothills to 3000 feet

5 N northern—humid

5 C central

6 Mojave, or Middle-Elevation Desert

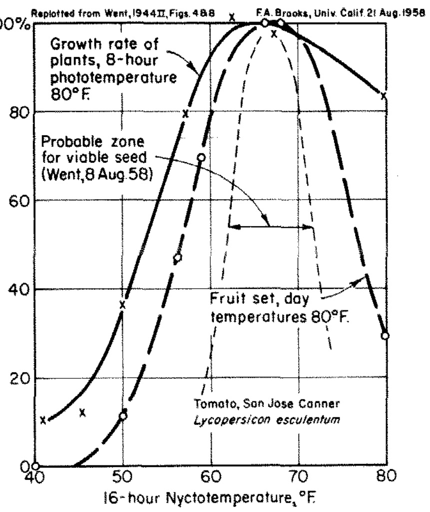
7 Sonoran, or Low-Elevation Desert

tive growth as indicated by the solid line in the upper small graph on this page. The temperature range for flowering is somewhat narrower, and the range for fruit set is strongly reduced as shown by the broken line. A much narrower temperature range, as indicated by the dashed line, is expected for the greatest production of viable seed.

Laboratory determination of proportional rates of growth for the Essex Wonder tomato, in terms of effective day and night temperatures, is shown in the lower small graph on this page. The whole pattern is typical but day and night temperatures are too low because the artificial illumination used had but 1,500 foot-candle intensity instead of full daylight of 4,000 foot-candle intensity or more. The optimal night temperature under field conditions is 67°F compared to 50°F in the low light intensity of artificial illumination.

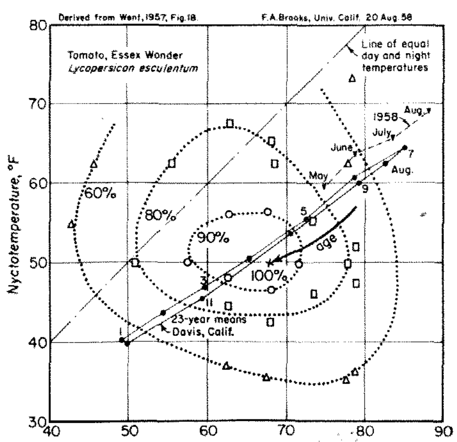
An example of the effect of unusually high night temperatures on tomato production occurred in the summer of 1958 in tomato growing areas of the Sacramento–San Joaquin valleys. Because of the wet spring, tomato planting was about three weeks late and canneries estimated a light late crop. The 1958 peach harvest was a little late, but tomatoes came in early and growers were put on box quotas for delivery to canneries on August 24, the earliest on record. Generally, all commercial varieties of tomatoes behaved the same and late varieties ripened about the same time as early

Graph showing the relation between temperatures favorable for plant growth, fruit set, and production of viable seed. The narrow range shown indicates for viable seed how limited the temperature range is. The best temperature for seed production may be either higher or lower than shown.



Variation of growth rate and fruiting of tomatoes with various dark-period temperatures. Ref. Went, 1944 II.

Diagram showing reduction of growth rate as day and night temperatures differ from optimal—central oval—temperature. The entire pattern would be found at higher temperatures with light intensity increased to approach daylight of 4,000-foot-candle intensity or more. Plants show a progressive decrease in optimal temperature requirements with age—indicated by the arrow—higher for total plant growth, lower for seed production and flavor development. The tomato data at high temperatures are not sufficient to complete the diagram. Effective day and night temperatures at Davis are shown by the diagonal, 1, January; 3, March, etc.

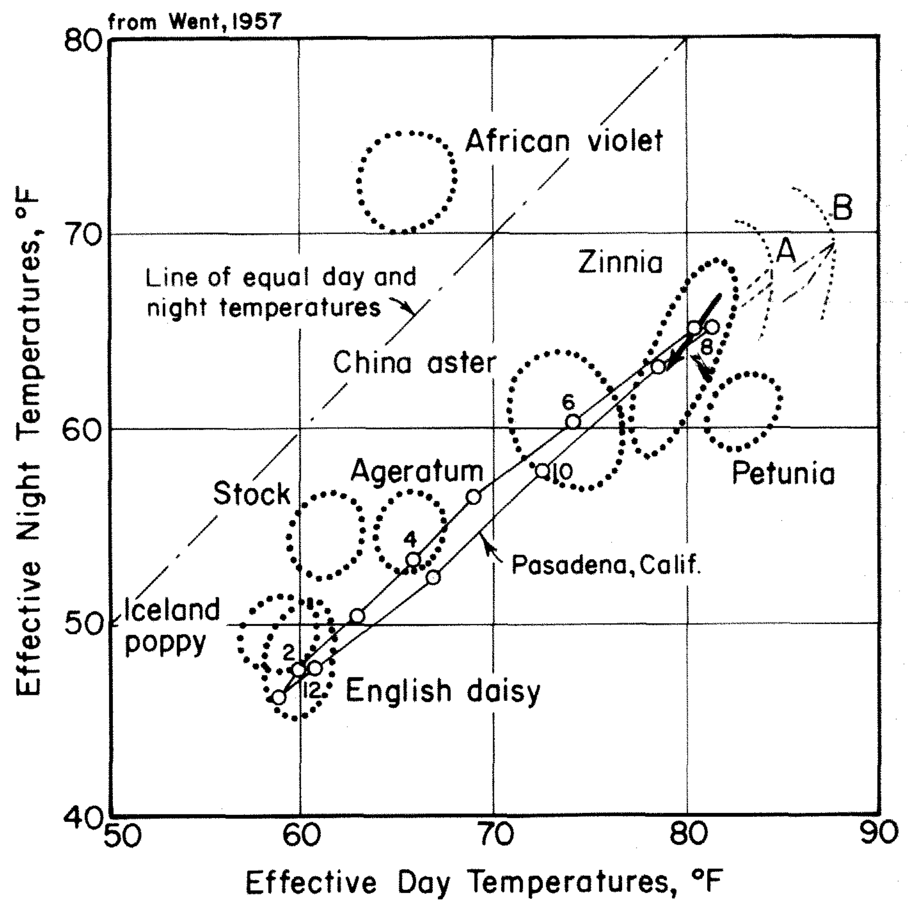


Variation of tomato plant growth rate for various photo- and nyctotemperatures, grown in artificial light at 1,500-foot-candle intensity. Interpol. from Went, 1957, Fig. 18.

Chart showing temperature ranges in which optimal growth and flower production can be expected for the flowering plants shown. All, except African violet, do better with lower night than day temperatures. Had these growth tests been made in a constant temperature, day and night, the plants would not have had the advantage of colder nights and this principle would not have been demonstrated.

The optimal ellipse indicated for zinnia includes the Pasadena temperature indicated by o for the months of July, August, and September. Nearby El Monte, in the experience of seed producers, was the area giving highest seed yield. If the ellipse is enlarged to pass through the July-August temperatures of Perris Valley—A, in the chart—the 50% production zone would be indicated. Temperature limits for seed production are indicated when the ellipse is further enlarged to include the temperatures of Marysville—B, in the chart—where no seed was obtained. Gradual lowering of both night and day temperature needed by the plants at later stages of growth is indicated by the arrow in the zinnia ellipse. Higher temperatures are needed for plant growth and lower for seed maturity.

If effective day-night temperature curves for other areas are constructed on 1" coordinate paper a tracing of this chart can be superimposed for comparison.



Effective Day-Night Temperature Requirements for Various Flowers. Went, 1957

Effective Day and Effective Night Monthly Temperatures* for California Plantclimate Zones

Calculations based on United States Weather Bureau Data

Zone	Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Direct Coast Expos.														
1N	Eureka (Elev. 62 ft.)	Day	50.4	51.5	52.1	53.3	55.3	57.9	58.5	59.2	58.9	57.1	54.6	51.8
		Night	44.0	45.3	46.1	47.9	50.5	53.3	54.3	54.8	53.5	51.3	48.0	45.4
1C	Half Moon Bay (Elev. 60)	Day	53.3	54.0	55.6	56.7	58.7	60.8	61.2	62.0	62.9	60.9	58.5	55.0
		Night	45.8	46.7	47.8	48.8	51.3	53.5	55.2	57.6	55.0	51.9	49.6	48.1
1S	Oxnard (Elev. 51)	Day	60.4	61.0	61.5	62.6	64.9	66.1	68.8	69.0	68.2	67.0	66.5	61.3
		Night	47.4	49.1	49.8	51.1	53.1	55.6	58.1	58.4	56.7	54.5	52.5	49.0
Coastal Valleys														
2N	Scotia (Elev. 139)	Day	51.3	53.4	54.7	57.2	59.9	63.0	65.2	66.0	66.2	62.7	57.3	52.7
		Night	44.1	46.0	47.2	49.7	52.6	55.8	57.5	57.7	56.4	53.5	49.2	46.1
2C	San Jose (Elev. 141)	Day	52.9	56.2	59.5	62.9	66.8	71.1	73.9	73.4	72.4	68.4	60.3	53.6
		Night	43.5	46.7	48.8	51.2	54.2	57.1	60.5	60.1	58.8	54.6	48.6	44.3
2S	Santa Ana (Elev. 133)	Day	58.4	60.9	63.7	66.6	69.5	73.3	78.0	78.5	76.9	71.9	67.0	61.4
		Night	45.0	48.7	49.9	53.4	57.2	60.8	64.9	65.0	62.4	57.4	51.0	46.9
Intermediate Valleys														
3N	Orleans (Elev. 401)	Day	48.3	53.2	60.0	65.7	70.1	76.8	84.1	84.3	75.9	66.3	55.2	48.3
		Night	40.0	42.7	46.5	50.8	54.7	60.2	63.8	64.9	59.0	52.4	45.8	40.5
3C	St. Helena (Elev. 255)	Day	50.8	54.6	58.9	69.2	69.6	76.3	80.4	79.1	76.1	68.8	60.2	52.2
		Night	40.1	43.4	46.0	49.2	53.2	57.7	60.0	58.9	56.4	52.0	45.9	41.3
3S	Pasadena (Elev. 805)	Day	58.7	57.7	62.5	65.6	68.6	74.0	80.2	80.7	78.2	72.1	66.9	60.6
		Night	46.2	47.8	50.2	53.2	56.5	60.3	65.2	65.3	63.1	57.8	52.3	47.8
Interior Valley														
4C	Red Bluff (Elev. 342)	Day	49.2	54.5	59.4	65.7	74.6	83.0	91.0	88.5	82.3	71.5	60.0	50.8
		Night	41.0	45.3	49.2	54.2	61.4	69.0	75.3	73.4	67.6	58.7	49.0	42.7
4C	Marysville (Elev. 67)	Day	49.2	54.4	59.8	65.9	73.6	81.6	88.3	86.3	80.4	70.8	59.2	50.2
		Night	39.9	43.8	47.2	51.8	57.8	64.5	69.3	67.5	62.6	55.0	46.3	40.9
4C	Davis (Elev. 51)	Day	48.6	54.6	59.7	64.6	72.0	77.3	85.0	83.5	78.3	69.9	59.0	49.5
		Night	40.0	43.9	46.7	49.9	54.7	59.9	63.9	62.4	57.4	53.0	45.0	39.9
4C	Fresno (Elev. 327)	Day	49.1	55.9	61.6	68.5	76.6	84.0	91.1	88.6	82.1	71.6	59.9	50.7
		Night	40.3	45.4	49.3	54.5	61.1	67.0	73.1	70.4	64.9	56.5	47.1	41.9
4C	Bakersfield (Elev. 404)	Day	52.1	58.3	63.4	69.7	77.5	84.9	92.7	90.2	83.6	73.7	62.9	53.9
		Night	41.7	46.7	50.8	56.2	62.9	68.9	75.7	73.4	67.6	59.2	49.4	43.5
4S	Riverside (Elev. 851)	Day	59.0	60.6	63.4	67.9	71.8	78.2	84.7	84.7	81.5	73.8	66.9	60.3
		Night	44.8	46.9	48.5	53.0	56.7	61.2	66.1	66.0	62.8	56.4	49.9	45.6
Foothills—Humid														
5N	Branscomb (Elev. 2000)	Day	47.3	49.5	52.0	56.6	60.7	67.3	75.1	74.9	70.0	64.6	55.0	48.8
		Night	37.8	38.9	39.8	43.1	46.0	51.1	57.6	57.3	53.8	49.3	42.9	38.4
Foothills—Dry														
5C	Lakeport (Elev. 1450)	Day	47.7	51.5	55.6	61.8	69.0	74.9	83.6	81.7	78.6	67.1	56.3	49.5
		Night	35.8	39.3	42.0	46.1	51.6	56.6	63.2	61.3	58.7	50.4	42.9	39.1
5C	Placerville (Elev. 1925)	Day	45.9	49.4	53.6	59.3	65.6	75.6	82.9	80.4	73.7	63.7	53.5	46.6
		Night	35.6	38.7	41.3	45.5	50.0	56.6	62.0	60.2	55.4	48.2	40.3	36.1
Middle Elev. Desert														
6S	Bishop (Elev. 4450)	Day	45.8	49.0	55.6	63.2	72.0	79.3	86.2	84.4	77.9	66.8	55.3	46.8
		Night	30.0	33.6	39.2	46.1	53.2	59.4	64.8	62.6	56.6	47.4	37.1	31.3
6S	Barstow (Elev. 2105)	Day	52.3	56.7	63.0	70.2	77.1	86.7	93.4	91.6	84.4	73.1	60.3	53.7
		Night	37.8	41.7	47.6	53.9	60.3	68.8	75.5	73.4	66.3	55.9	44.7	38.5
Low Elev. Desert														
7S	El Centro (Elev. –50)	Day	61.3	65.4	72.2	79.7	87.2	94.7	100.6	99.7	95.0	83.5	71.3	63.6
		Night	45.6	49.6	55.5	62.3	69.5	76.0	83.6	83.6	77.6	66.2	53.9	48.0
Mountain Valleys														
	Yreka (Elev. 2625)	Day	38.8	44.5	50.4	56.9	64.0	73.3	81.5	80.0	70.5	60.2	47.7	38.9
		Night	28.8	33.1	36.9	41.6	48.1	54.8	61.7	60.2	52.0	43.6	35.3	29.6
	Alturas (Elev. 4446)	Day	33.7	39.1	45.3	54.2	59.6	68.7	78.3	77.0	68.0	58.3	46.1	36.7
		Night	21.5	26.8	30.6	37.7	42.9	49.5	56.0	53.6	46.4	38.4	31.2	24.0

* Effective Day = Monthly mean maximum minus one fourth (mo. mean max. – mo. mean min.) and Effective Night = Monthly mean minimum plus one fourth (mo. mean max. – mo. mean min.)

cause there was little excessively hot weather to retard fruit development. In June and July there were only six days of 100°F or higher at Davis—where 12 days is the usual number—and the highest temperature was only 103°F.

In the Davis area the temperature regime in the six weeks from May 1 to mid-June is critical for the development of the tomato plant and for pollination. In the diagram the line representing the Davis mean temperatures runs diagonally across the graph and the 1958 monthly mean effective night temperature in June is shown to be 3°F above the 23-year mean. As the 1958 effective day temperatures in June and July were equal or less than normal, the high night temperatures were the main cause of the early harvest.

Similar narrow temperature tolerance ranges exist in commercial flower seed growing.

Before subdivision for residences, the El Monte area of the San Gabriel Valley was recognized as the highest yield producing section for commercial zinnia seed. The effective day-night temperature curve for Pasadena—the nearest available point of record—for July, August, and September lies entirely within the zinnia ellipse on the preceding chart, with the August-to-September line almost identical with plant age as indicated by the arrow.

In Perris Valley, about 15 miles southeast of Riverside, the production of viable seed is about half that of the El Monte area. Effective temperatures for Perris for both July and August are about 2°F higher than the optimal ellipse boundary.

Attempts to grow zinnias at Marysville—where the July and August temperatures exceed the optimal ellipse boundary by 4°F to 5°F—resulted in plenty of flowers but no viable seeds.

Column stock—*Matthiola incana*—requires three weeks of 50°F to 60°F nights to initiate flower buds. In the fall of 1950 the three-week bud initiation period in southern California was 4–6 weeks later than normal. As a result, flower buds on plantings timed for December through February were initiated simultaneously. Favorable temperatures during late fall and winter accelerated later plantings timed for spring. As a consequence, stock harvest which normally spans four months was shortened to six weeks.

Night temperature is the more commonly controlling part of the diurnal fluctuation and many plants have different optimal temperature requirements at certain or specific growth stages. Most tomato varieties will not set fruit at night temperatures below 60°F or above about 70°F. Some early varieties tolerate temperatures as low as 50°F. However, night temperatures above 70°F are more favorable for growth and development of fruit. Pepper requirements are similar to tomato. California poppy needs night temperatures near 60°F for seed germination, in the low 50's for plant growth, and again 60°F or above for flowering. Citrus and some deciduous fruits develop richer color and better flavor in areas where diurnal fluctuations are greatest.

Some perennials require periods of different night temperatures for certain functions. Camellia flower bud formation requires about five months of 60°F–65°F night temperature following which best bloom occurs at 50°F. Peach tree growth and fruit bud formation occur during the summer at night temperatures of 60°F and above, but rest is broken in the winter by periods at 40°F or lower.

Knowledge of effective day and night temperatures may be a valuable tool in determining the most favorable environment for plants and animals.

That same knowledge may also be a means of interpreting and relating controlled laboratory, or phytotron, studies to field conditions.

The characterization of California's plantclimate zones with effective day and night temperature may make it possible to apply these studies to field conditions.

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F. W. Went, Director of the Earhart Laboratory, California Institute of Technology, Pasadena, in Experimental Control of Plant Growth, *1957, reported the research on the effect of four-dimensional relationship of day and night temperatures on plant growth which was basic information for the study reported in the foregoing article. He also devised the system of relating United States Weather Bureau data to phytotron temperatures, called effective day and effective night temperatures in this article.*

G. C. Hanna, Olericulturist, University of California, Davis, reported the effect on tomatoes of the high night temperatures that occurred in 1958 in the Sacramento-San Joaquin growing areas.

***Left*—Changing night temperature—ordinate—requirements with age of plant or stage of growth—abscissa—are indicated for three annuals, tomatoes, peppers, California poppy; and two perennials, peach and camellia. The coordinates of the two graphs are the same. *Right*—Twelve months of effective night temperatures at representative locations in California. A tracing of the graph on the left can be superimposed with the 40° lines coinciding and moved sideways to determine whether night temperatures of a given area suit the plant needs, and when and/or how long the needs exist.**