Environmental studies have been essential to understanding the distribution and spread of lettuce mildews in California. Downy mildew has been found to increase with cooler temperatures of the late fall, winter and spring in the Salinas Valley, while summer temperatures restrict it primarily to the coastal areas. Powdery mildew, however, is not found in the cool, northern and coastal portions of the valley, but rather increases toward inland areas and with warmer spring and summer temperatures.

Distribution of LETTUCE MILDEWS *as related to environment*

W. C. SCHNATHORST · H. B. SCHULTZ · ROY BARDIN

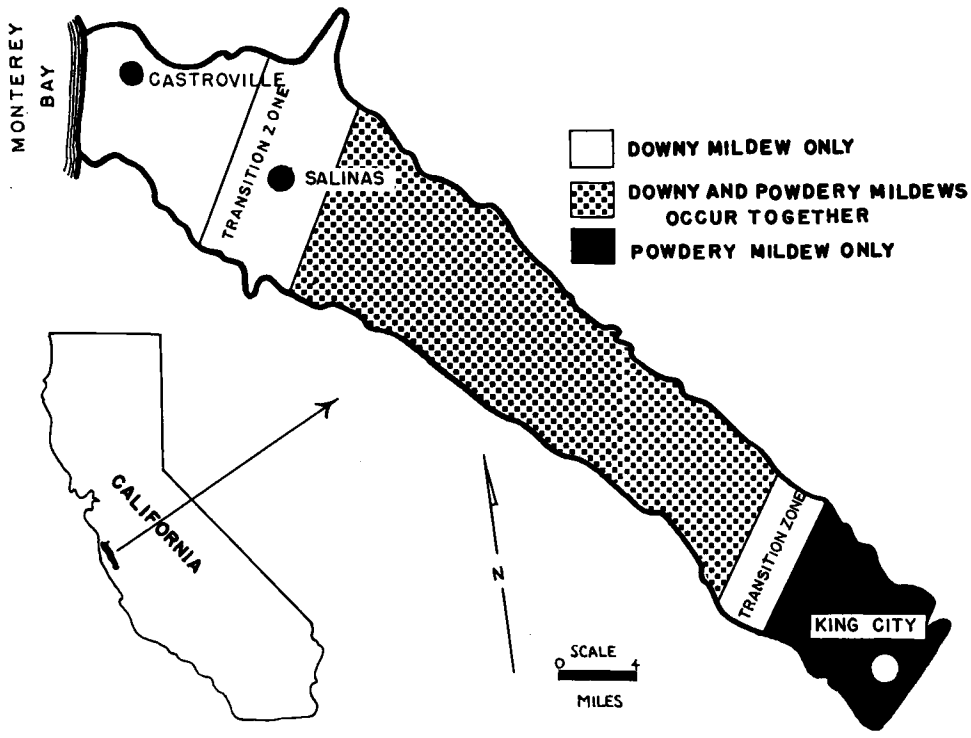
LETTUCE IS ATTACKED by two different mildews in California's Salinas Valley: downy mildew, caused by *Bremia lactucae*, which has long been a problem; and powdery mildew, caused by *Erysiphe cichoracaerum*, which was first observed on commercial lettuce only in the last decade. Downy mildews require high atmospheric moisture and low temperatures for good spore germination, infection, growth and sporulation. Powdery mildews usually occur in areas where atmospheric moisture is relatively low and temperatures are higher.

Downy mildew of lettuce is worldwide in distribution, but powdery mildew of lettuce occurs only in California and Arizona. Powdery mildew is most severe in the Salinas Valley where it may have originated. Consequently, this semiarid coastal valley is the only area where the two diseases can be studied simultaneously. This study compared the distribution of the two diseases on lettuce in the Salinas Valley and related their distribution to meteorological conditions.

Comparative distribution

The Salinas Valley was divided into three zones of disease distribution, as shown on the map. In the northwestern portion of the valley, bordering on Monterey Bay, only downy mildew was found. In the central part of the valley, both downy and powdery mildews occurred—even on the same plants. In the southernmost portion of the valley, only powdery mildew was present. These three rather distinct areas existed simultaneously only from August to November. Downy mildew decreased in the central (mixed disease) area as distance from the coast increased. During November, downy mildew developed in the southernmost portion of the valley, thus creating two infection zones—a mixed powdery and downy mildew area in the southern end of the valley and a zone near the coast in which only downy mildew was present. This last distribution pattern continued until the end of February, 1955, when only downy mildew continued active. The regions in which disease boundaries fluctuated in the summer are designated on the map as "transition zones."

Fig. 1. Comparative distribution of downy and powdery mildews of lettuce in the Salinas Valley in 1954–55. The infection zones depicted existed only from August to November.



Standard weather shelters instrumented with hygrothermographs, an anemometer, and a pair of black and white Livingston atmometers were erected at three locations in the Salinas Valley—6, 16, and 35 miles from the coastline. Data were also obtained on fog, wind direction, rain, and cloudiness.

Salinas Valley climate

The Salinas Valley has an average rainfall of 13.5 inches of which approximately 90% falls in November to April. Data collected from 1955 to 1956 showed that temperature increased, and relative humidity (RH) decreased with distance from the Pacific Ocean (Figure 2-A). Average temperatures reached their maximum of 57°F, 61°F, and 64°F in the three areas during September. On the other hand, RH was highest in August as shown in Figure 2. The rate of evaporation, determined by the black and white Livingston atmometers, directly correlated with humidity. RH increased and

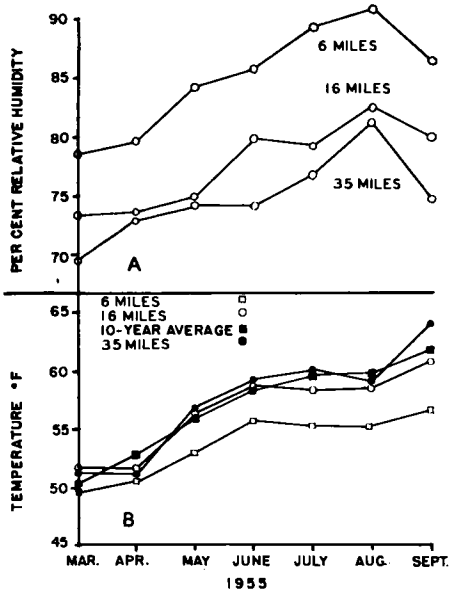


Fig. 2. Average temperature and relative humidity in 3 portions of the Salinas Valley in 1955. The average temperature for each month, determined by averaging maximum and minimum temperatures each day, was 2°F higher than the average temperature determined by averaging temperatures taken at 2-hour intervals. The long-time average temperature of the Salinas Valley, derived from maximum and minimum data from Weather Bureau records, taken in a region with conditions comparable to those at the 16-mile station, was corrected by subtracting 2°F from the average temperature of each month.

evaporation decreased in late summer along with the increase of fog. At least 10 foggy days can be expected each month from June to September; but in 1955, August had 26 foggy days.

Average wind velocity decreased from 9 mph in June to 7 mph in September. This is similar to the wind conditions in the lower Sacramento and San Joaquin valleys, where a gradual weakening of the speed of the "sea breezes" is observed as the season progresses. The Salinas Valley sea breeze had a northwesterly direction, and velocity reached an average of 15 mph at its peak in the early afternoon.

The data on wind direction and velocity help to explain the build-up of powdery mildew. The regular occurrence of strong northwesterly winds in summer greatly facilitates the rapid and far-reaching dispersal of spores throughout the valley. Wind velocity gradually increased during the morning and averaged 15 mph at its peak (generally between 12 and 4 p.m.). Wind velocity, coupled with low RH and higher temperatures at this time, apparently explains why more powdery mildew spores are disseminated.

Downy mildew spores germinate between 34 and 68°F with an optimum of 50°F. Powdery mildew spores, in contrast, germinate over a range of 41 to 93°F with an optimum of 64°F. Infection and sporulation by the downy mildew fungus is greatest at 59°F in a range of 37 to 68°F, whereas the optimum for powdery mildew is 64°F in a range of 50 to 81° F.

Downy mildew spores require a RH of 100% for germination. Powdery mildew spores germinate best at 95 to 98% RH, but will germinate to some degree at a RH as low as 0.1%. Free moisture inhibits germination of powdery mildew. Downy mildew requires a period of high RH (90 to 100%) prior to sporulation, but humidity is not critical during the incubation period. Growth and sporulation of powdery mildew appear unaffected by RH once infection starts.

Downy mildew occurs independently in the part of the valley with the lowest summer temperature (average for the summer months is 55°F), and frequency decreases as temperature increases with distance inland. Since average temperatures continued to increase south of the 35-mile station during the summer months (longtime average is 66°F), it at least approaches and often surpasses the maximum average temperature at which the downy mildew fungus will germinate, grow and sporulate. Downy mildew, therefore, is favored in the Salinas Valley by late fall, winter, and spring temperatures—and in the summer is restricted primarily to the coastal areas.

Powdery mildew, in contrast, is not found in the cool northern portion of the valley, but occurs with increasing frequency as distance inland and temperature increase. Later, in the spring and summer, temperature increases and becomes generally more favorable for powdery mildew development.

The atmospheric moisture (expressed in Figure 3 as vapor pressure deficit, or VPD) of the northern portion of the Salinas Valley from May to August is favorable for sporulation of the downy mildew fungus. With long periods (12 to 14

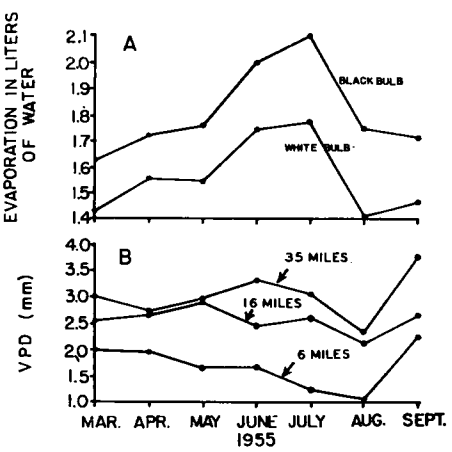


Fig. 3. A) Evaporation of distilled water (in liters/month) from black and white bulb atmometers at the 16-mile station during the spring and summer of 1955. B) Vapor pressure deficit (VPD) for several portions of the Salinas Valley, calculated from data in Fig. 2 for the spring and summer months of 1955.

hours) when VPD values are near zero at night, this area appears ideal for development of the disease. As distance inland increases VPD increases, becoming less favorable for germination and sporulation. The frequency of downy mildew infection diminishes correspondingly. The increase in VPD within certain specific limits with increasing distance inland would favor the development of powdery mildew. The fungus was found with increasing frequency approximately 8 to 16 miles inland. The ability of powdery mildew to do well in the warmer, drier, southern portion of the Salinas Valley appears related to its tolerance to dry conditions in all phases of its development.

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COMPARATIVE RESPONSE OF DOWNY AND POWDERY MILDEW FUNGI ON LETTUCE TO TEMPERATURE AND RELATIVE HUMIDITY

	Germination of spores				Infection and sporulation			
	Temperature °F		Relative humidity %		Temperature °F		Relative humidity %	
	Optimum	Range	Optimum	Range	Optimum	Range	Optimum	Range
Downy mildew	50	34–68	100	100	59	37–68	100	90–100
Powdery mildew	64	41–93	95–98	>0.1–100	64	50–81	95–98	>0.1–100[a]

[a] The lower limit not known with certainty but assumed to be the same as the lower limit for germination.