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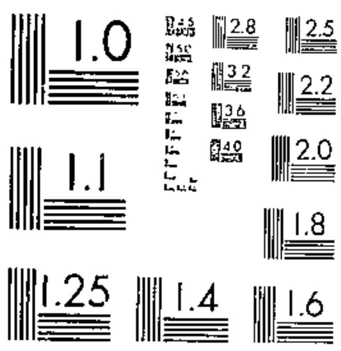

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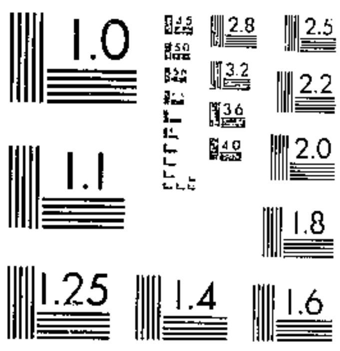

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TECHNICAL BULLETIN No. 463 FEBRUARY 1935

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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WASHINGTON, D. C.

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INTRODUCTION [1]

The celery leaf tier, or greenhouse leaf tier (*Phlyctaenia rubigalis* Guenée), is one of the most widely and uniformly distributed insects in the United States and is a well-known pest of chrysanthemums and other greenhouse plants. It is found in every area where celery is grown, but until 10 years ago had never been reported as a se-

[1] This bulletin is one of a series of papers on the factors controlling the abundance of the celery leaf tier in Florida. It deals entirely with the broader biological relationships of the problem, and most of the detailed information upon which it is based is reserved for publication in more technical papers, which will discuss (1) the life history of the celery leaf tier, (2) birds in relation to the celery leaf tier, (3) insect parasites of the celery leaf tier, (4) cycles of winter temperature in Florida in relation to the celery leaf tier, and (5) the control of the celery leaf tier in Florida.

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riously injurious pest in the field, except in certain localities in southern California.

Very little has been published on the factors affecting the control of *P. rubigalis*. Weigel et al. (*13*)[2] have described its habits and food plants and have presented results of detailed studies on the length of the different stages, the seasonal life history in the greenhouse, and experiments in fumigation, but with no indication of the temperature or humidity under which the observations and experiments were made. Campbell (*3*) discussed the relation of sugar-beet fields to the infestation of the tier in Orange County, Calif., and gave the seasonal history and the duration of life-history stages, together with the temperature during the period.

THE OUTBREAK AT SANFORD, FLA.

The celery leaf tier has occurred in the Florida celery fields ever since celery was first cultivated there in 1899, but until recently has not been considered a pest.

Early in the spring of 1923 this insect increased in numbers in certain localities in the Sanford district until it seriously injured a large part of the late celery crop. In 1924 the injury was somewhat less, but in 1925 another destructive outbreak occurred. The cumulative losses of the three seasons threatened the stability of the celery industry and, as a result of an appeal for help, a cooperative investigation was organized by the Florida State Plant Board and the Bureau of Entomology of the United States Department of Agriculture.

The fact that an insect, well known but never heretofore abundant, should suddenly jump to the rank of a major pest, becoming a limiting factor in the production of late celery, suggested a radical departure from the normal in one or more of the factors entering into the balance maintained by nature. Although the immediate need was for an efficient method of controlling the pest without leaving a poisonous residue on the celery, it was recognized that an equally important problem was to ascertain whether this outbreak was the inevitable result of a continually increasing concentration of the celery industry and could be expected to continue indefinitely, or whether it had been brought about by extreme fluctuations in climatic or biological factors which, when they returned to normal, might be expected to reduce the tier to its previous noninjurious status.

Celery grows only in the winter and early spring in Florida, and the three celery seasons that ensued after this investigation was begun were widely different in every way. The first season (1925–26) was cold and wet, and the celery leaf tier did no commercial injury. The second season (1926–27), on the other hand, was extremely warm and comparatively dry, and the injury would have been far worse than in previous years had not efficient control methods been developed. The third season (1927–28) was slightly colder than normal and very dry, and although the tier fluctuated in numbers with the changes in temperature, it caused no commercial injury.

The first problem was to establish a satisfactory method of control without the use of arsenicals. This problem was happily solved and

[2] Italic numbers in parentheses refer to Literature Cited, p. 54.

the results of the research have been published (*1, 9*). In addition, however, the authors have been able to work out, at least in a preliminary way, an extremely complicated biological complex involving two host plants, four leaf tiers, three insect parasites, several birds, a fungus, a bacterial disease, and a number of insect predators, all intimately associated in an unstable balance largely influenced by temperature factors involving inhibiting maxima as well as minima.

GENERAL ECOLOGICAL RELATIONS

TEMPERATURE THE DETERMINING FACTOR IN THE LOCATION OF CELERY-PRODUCING AREAS

In order to analyze the factors that normally control the leaf tier in the various celery-producing areas it was necessary to ascertain what the forces are that have determined the location of commercial celery production in North America. Celery, like lettuce, is known to be very restricted in its adaptations to temperature. In nature it is a biennial, seeding in the spring and developing the young plants in the fall. After the plant recovers from the winter temperature it soon develops a seed stalk. In commercial production it is necessary to keep the temperature of the seed bed from falling much below a mean of 60° F., or the resulting plants will go to seed in the field (*10*). After having been transplanted to the field, celery can stand mean temperatures below 50° F., provided the minimum temperatures do not drop below 22° or 24°, but when the mean temperatures range above 74° in either fall or spring the plant deteriorates rapidly. As celery does not mature until it has been from 6 to 8 weeks in the seed bed and from 3 to 5 months in the field, it can be grown successfully only in regions that afford relatively long periods within this temperature range.

With the extension of distribution facilities, the production and consumption of celery have increased rapidly. The car-lot shipments of celery (table 1) more than doubled in the 10-year period ended with the season 1926–27, and there has been a considerable shift in the relative importance of different producing areas. No doubt this shifting, like that of other food crops, is due largely to economic factors and to the development of new areas.

TABLE 1.—*Car-lot shipments of celery by shipping seasons from 1916 to 1927* [1]

State	Shipments										
	1916–17	1917–18	1918–19	1919–20	1920–21	1921–22	1922–23	1923–24	1924–25	1925–26	1926–27
Florida	2,221	2,462	2,051	2,652	4,218	4,954	6,308	7,219	7,952	5,504	7,409
California	1,877	2,779	1,498	2,003	3,472	2,017	4,334	4,631	4,240	5,953	7,564
New York		1,696	1,352	1,654	3,110	3,047	3,247	3,742	4,529	4,492	4,898
Michigan		439	458	598	954	1,031	1,026	1,486	1,332	2,224	1,880
All other States		474	613	482	671	793	759	903	1,109	1,201	1,153
Total	4,098	7,850	5,972	7,389	12,425	12,442	16,364	17,981	19,162	19,404	22,994

[1] Data from the Division of Fruits and Vegetables, Bureau of Agricultural Economics, U.S. Department of Agriculture.

Finch and Baker (*6, p. 99*) show the general distribution of celery production in 1909. Corbett, Gould, Beattie, et al. (*5, p. 395*) have mapped the production of celery in 1919, showing gradual concentration into a few especially adapted areas and the extension of winter production in California and Florida. Figure 1 shows the relative production of the different areas in 1927 and indicates still greater development of the winter production, both in Florida and California. On this map have been traced the isotherms of mean temperatures of 70° and 75° F. in July, as used by Ward (*11*). It will be noted that all the important producing areas are located in regions where the monthly mean summer temperatures rarely reach 75°, their averages during the hottest period of the summer being much nearer 70° than 75°. The small celery area in northeastern Ohio, which in latitude is farther south than the New York and Michigan areas, is really in the same temperature belt, as shown by the loop of the isotherm of 70° in this area. The areas of winter production are all located in regions where the prevailing mean temperatures during the growing season are above 45° and below 70°.

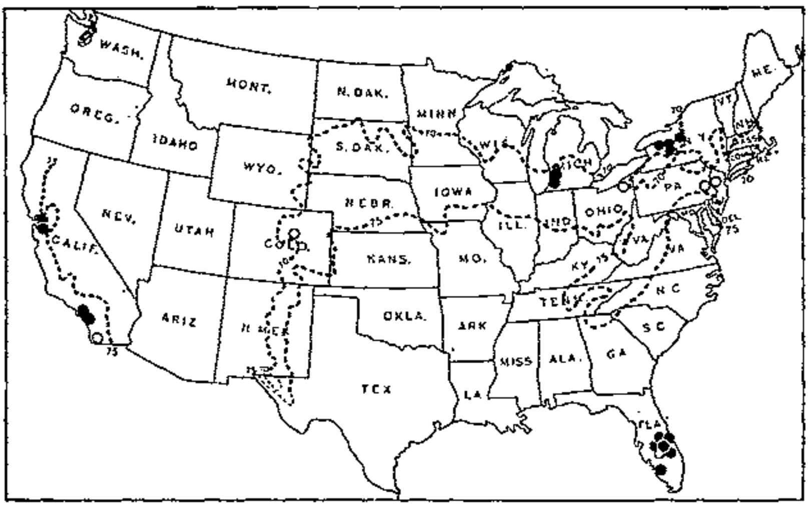

FIGURE 1.—The commercial celery-producing areas in the United States. Black circles represent shipments of 1,000 cars; light circles, less than 1,000 cars; dotted lines, isotherms of mean temperatures for July.

The celery plant is adapted to a rich, damp soil, preferably some type of muck, but in commercial production many other types of soil have been used and the deficiencies in richness and moisture have been made up by fertilization and irrigation. The soil factor undoubtedly has been very important in determining the areas in which commercial production has been centered within the limits of the favorable temperature belts, but the fact that the temperature of the growing season (table 2) has been the principal factor in determining the belts is evident, when one considers the large areas of favorable soil types between Michigan and New York on the north, and central Florida on the south. The monthly mean temperature curves of the major celery-producing areas are shown in figure 2, with the limiting temperatures of celery production indicated by shading. Figure 3 in the same way shows the monthly mean temperature of the eastern part of the Cotton Belt, as contrasted with the Michigan–New York and the Florida celery areas. In the entire eastern part of the cotton-producing area the summers are too hot, the winters too cold, and the spring and fall seasons with favorable temperatures far too short to produce a crop of celery. In the California area the temperature belts practically parallel the coast and the temperatures of the Imperial Valley, or the warmer parts of the interior valleys, resemble those of the Cotton Belt.

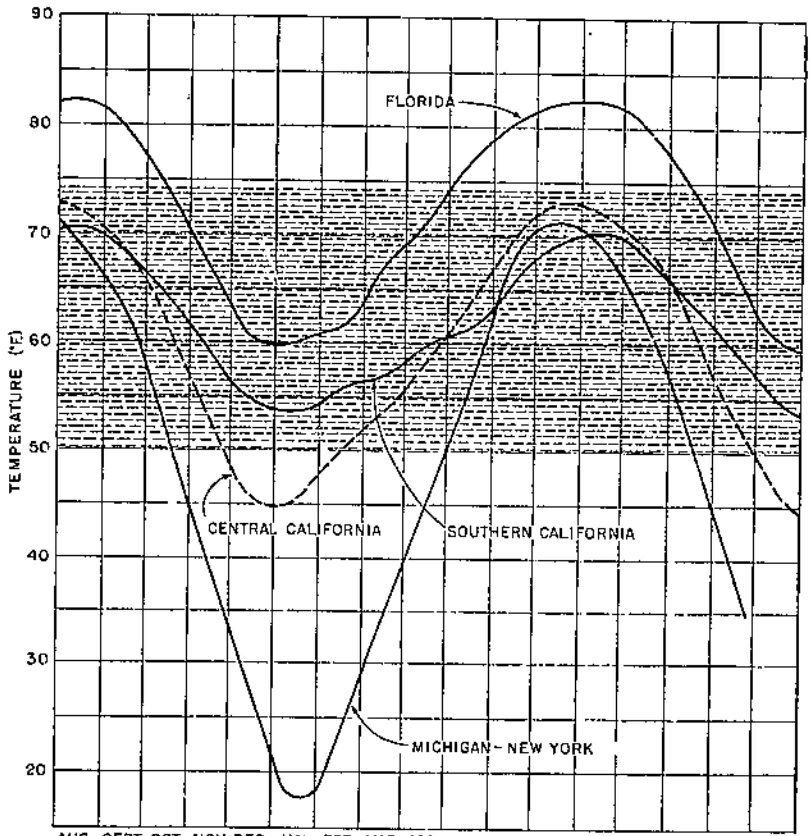

FIGURE 2.—The celery belt. Monthly mean temperature curves of the principal celery-growing areas in the United States in comparison with the limiting temperatures of celery production. Optimum conditions for celery growing are represented by the median part of the shaded belt, favorable conditions by the parts slightly farther from the center, and limiting conditions by the parts nearer the margins of the belt.

TABLE 2.—*Monthly mean temperatures of favorable and unfavorable areas for celery production*

Area	Temperature											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	°F.	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
Summer celery area	18.0	24.0	34.5	45.0	56.5	68.5	71.5	69.0	62.5	51.0	39.0	28.5
Central California	45.8	50.0	53.8	58.5	63.5	70.0	73.0	72.2	69.0	61.5	53.0	40.0
Southern California	53.4	56.0	57.0	60.0	61.4	66.0	69.3	70.3	68.0	64.0	58.8	54.5
Central Florida	60.2	61.5	67.4	71.1	76.7	80.4	82.0	82.2	79.6	74.0	66.6	60.4
Cotton Belt	44.5	45.0	53.5	62.5	71.7	77.5	81.0	80.0	75.0	63.5	53.7	45.0

It is also being recognized that the areas of major production of food plants lie close to their colder limits of adaptation. This involves factors of grade of the product, keeping quality, and freedom from insect pests and diseases.

THE CELERY CROP IN THE FIELD

Celery is a crop which involves much hand labor in planting and in harvesting. For the most economical use of that labor the

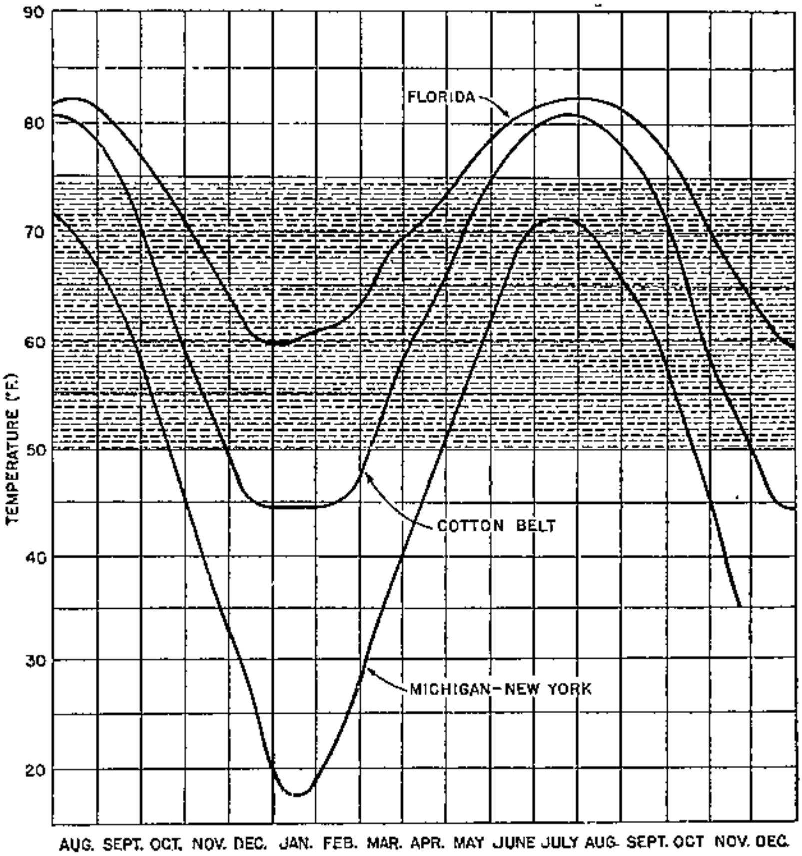

FIGURE 3.—The Cotton Belt. Monthly mean temperature curves of the summer and winter celery-producing areas, contrasted with the mean monthly temperatures of the cotton-producing area.

planting and harvesting should extend over as long periods as possible. In some sections the planting is continued right up to harvesting time and in others a second crop may follow the harvesting of the first. These different plantings are subject to very different climatic conditions. Information as to dates of beginning and ending of planting and harvesting are fairly easy to obtain, but to determine the relative amount of the crop in a field at any given time has proved to be very difficult. The monthly car-lot movement (tables 3 and 4, and fig. 4) from a given area is the only accurate record available. By moving these dates back for a period of approximately 4 months (more or less, depending on the temperature) and correlating them with the known dates of beginning and ending of operation, it has been possible to plot curves indicating the relative volume of the crop in the field at any given period, as shown in figure 5. The temperature curves indicate the monthly mean temperature of the area. The celery crop has been plotted on the 60° F. line in each case, as indicating the more favorable temperature for the production of a high-grade product. Higher temperatures when the plants are young increase the rapidity of growth and lower temperatures at maturity improve the quality of the celery.

TABLE 3.—*Car-lot shipments of celery by months for the 4 seasons from June 1922 to May 1926*

Area and season	Shipments												
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
New York:													
1922-23	------	3	53	406	1, 208	742	672	161	2	1	------	1	3, 248
1923-24	------	1	36	202	1, 172	1, 020	990	314	5	1	------	------	3, 741
1924-25	------	10	87	310	1, 258	1, 203	1, 257	396	7	1	------	------	4, 529
1925-26	------	28	118	565	1, 202	1, 047	941	584	7	------	------	------	4, 492
Average	------	11	74	371	1, 210	1, 003	965	364	5	1	------	------	4, 004
Michigan:													
1922-23	------	51	162	188	178	606	328	109	14	------	------	------	1, 626
1923-24	------	36	152	173	185	517	313	95	15	------	------	------	1, 486
1924-25	------	9	166	238	211	428	172	72	36	------	------	------	1, 332
1925-26	------	39	285	335	468	661	263	139	32	2	------	------	2, 224
Average	------	34	180	234	261	553	200	104	24	1	------	------	1, 667
California:													
1922-23	------	------	------	------	50	888	1, 468	1, 157	510	220	7	------	4, 324
1923-24	------	------	------	------	85	905	1, 532	1, 108	422	510	40	68	4, 088
1924-25	84	55	6	2	72	860	1, 362	983	386	360	24	66	4, 210
1925-26	202	77	4	3	124	1, 317	1, 638	1, 459	506	381	72	190	5, 953
Average	72	33	3	1	85	993	1, 500	1, 172	458	367	38	81	4, 801
Florida:													
1922-23	15	------	------	------	------	------	------	646	1, 370	2, 220	1, 743	396	6, 396
1923-24	42	------	------	------	------	------	------	1, 332	1, 812	2, 017	1, 397	509	7, 109
1924-25	33	------	------	------	------	------	------	538	1, 786	2, 408	1, 855	1, 303	7, 953
1925-26	53	------	------	------	------	------	------	181	1, 000	1, 866	1, 728	405	5, 293
Average	36	------	------	------	------	------	------	674	1, 492	2, 129	1, 688	691	6, 710
All other States, average for 4 seasons	6	36	55	114	317	229	192	69	1	0	------	------	1, 019

TABLE 4.—*Average car-lot shipments of celery by months from 3 areas from June 1922 to May 1926*

Area	Shipments												
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
Total summer-celery area	40	236	363	746	2, 080	1, 501	1, 261	457	7	1	------	------	6, 692
California	73	33	3	1	86	1, 003	1, 515	1, 184	462	371	38	82	4, 851
Florida	36	------	------	------	------	------	------	674	1, 492	2, 129	1, 688	691	6, 710
Total	149	269	366	747	2, 166	2, 504	2, 776	2, 315	1, 961	2, 501	1, 726	773	18, 253

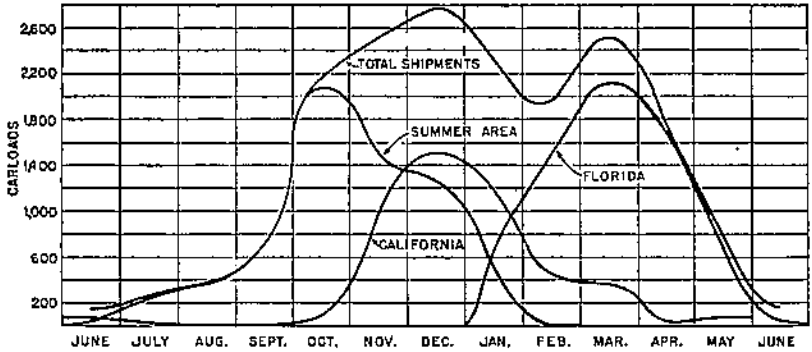

FIGURE 4.—Average car-lot shipments of celery from the principal areas of commercial production during 4 years (June 1922 to May 1926, inclusive).

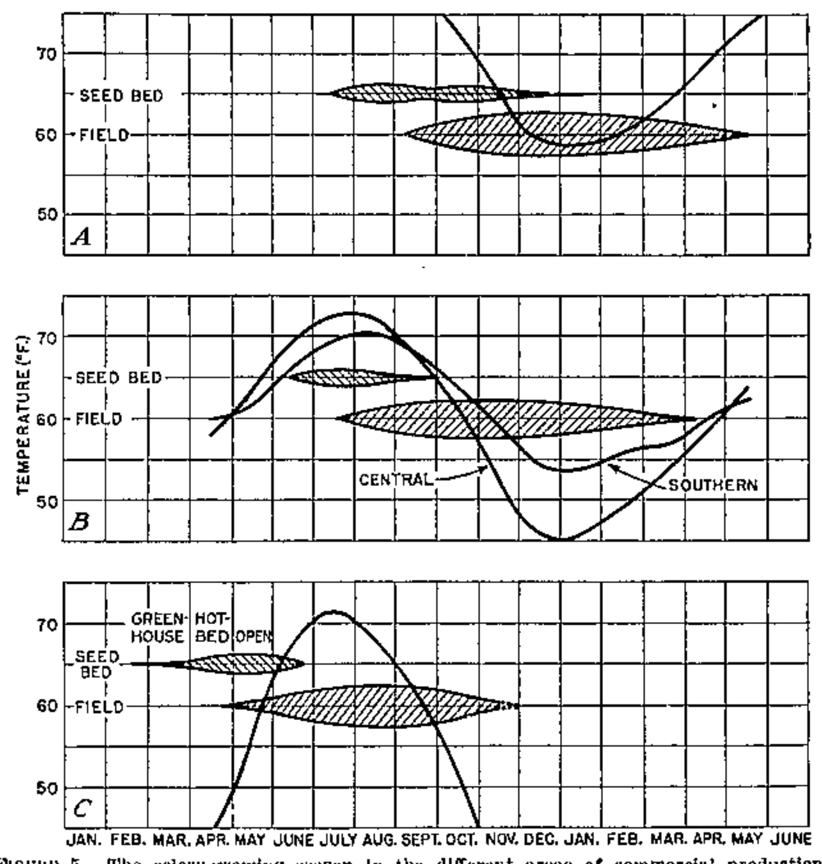

FIGURE 5.—The celery-growing season in the different areas of commercial production: *A*, Florida; *B*, California; *C*, Michigan-New York.

The celery season in Michigan is so short that the earlier seed beds are in heated greenhouses; a little later hotbeds are utilized, but the seed for the greater part of the fall crop is planted in May in the open. At the time of killing frosts there is still a large acreage in the field. This late celery is either protected by banking or placed in storage.

The temperature of the central California area[3] ranges from an approach to the maximum limit in July and August to the minimum limit in December and January (fig. 5). Therefore, the great bulk of the crop is produced in the favorable fall period, maturing in time to be shipped in December and January. The temperatures of southern California, in a very limited belt, are favorable throughout the year. The time of production is determined largely by moisture supply and favorable markets. This area is producing a small amount through a long period, but is increasing its winter planting and spring marketing.

The Florida celery crop is largely concentrated in areas approaching the colder limit of possible production (fig. 5). Summer temperatures in all areas are unfavorable (table 5). The seed beds for the early crop are shaded and sprinkled, as well as subirrigated. Planting begins in September, but the early plantings frequently do not mature until later than those planted in the more favorable temperatures of October. While the normal winter temperatures fall but little below a mean of 60° F., the wide fluctuations of the winter period, as shown in figures 6, 7, and 8, occasionally approach the minimum.

TABLE 5.—*Mean monthly temperatures at Florida stations, and mean monthly maximum and minimum at Orlando*

Station and year	Temperature											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Northern Florida mean (1925)	54.0	55.2	64.0	68.5	76.7	80.4	82.0	83.2	78.0	70.5	62.0	55.0
Orlando mean (1920)	60.5	61.5	67.5+	70.0+	76.0+	80.3	82.1	82.2	79.5+	74.1+	66.6	60.4
Sanford mean (1925)	59.0	61.3	64.4	69.3	75.2	79.0	81.0	81.0	78.9	74.0	65.6	59.8
Miami mean (1925)	66.5	67.1	70.2	72.8	76.4	80.0	81.0	81.4	80.1	77.0	71.8	68.0
Orlando mean maximum (1920)	71.3	72.5	79.6	82.8	88.0	90.4	91.8	91.8	88.4	83.1	77.0	71.1
Orlando mean minimum (1920)	49.7	50.5	55.5	59.1	65.3	70.2	72.4	72.6	70.7	65.2	56.2	49.8

THE SANFORD CELERY AREA

A small amount of celery is grown in widely scattered localities in Florida, but the commercial development, so far, has been confined largely to two areas. The larger area (fig. 9), with Sanford as a central shipping point, utilizes the broad expanse of muck and low pineland bordering on Lake Monroe and Lake Jessup, a little north and east of the center of the State. The smaller area is located

[3] The Government celery reports divide the celery-producing areas of California into the northern (the delta), the central (the Los Angeles area), and the southern (San Diego and south). The authors have followed the usual geographical nomenclature and speak of the delta area west of Stockton as central California; and, as the Los Angeles and San Diego areas have similar climatic conditions, they have been considered together as southern California.

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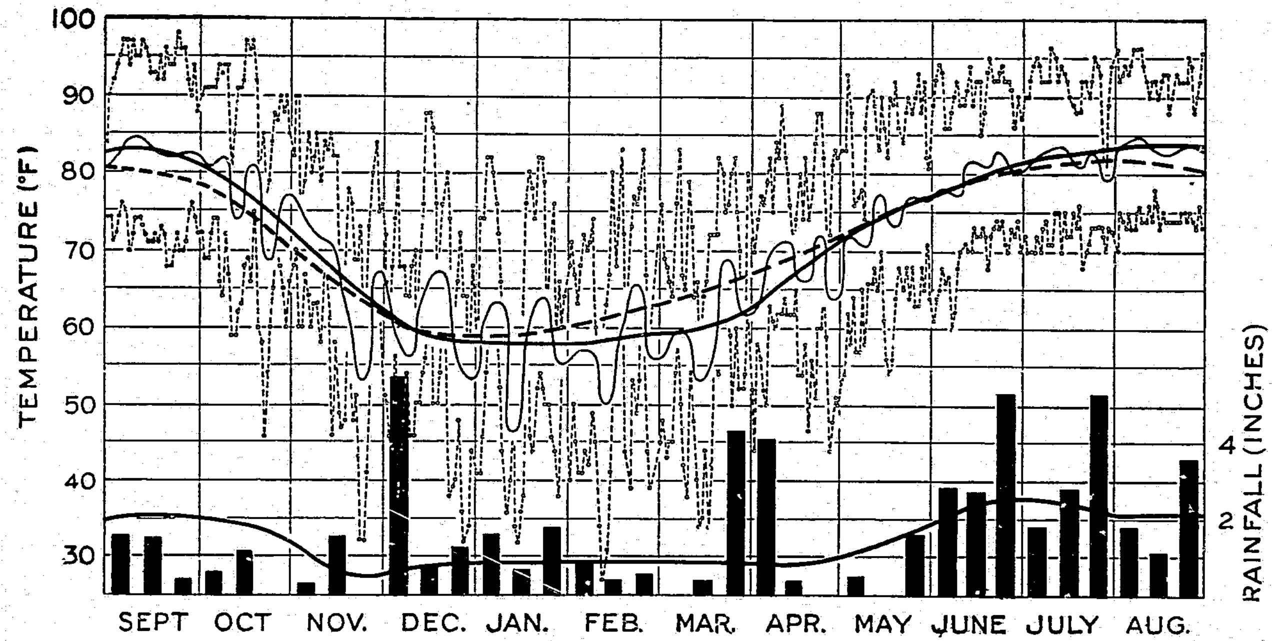

FIGURE 6.—Temperature and precipitation records of the Sanford, Fla., celery-producing area for the season of 1925–26. In the temperature records the light broken lines represent daily maximum and minimum temperatures; the light curve represents the 5-day average of the mean temperatures; the heavy curve represents the monthly average of the mean temperatures for the season; and the heavy broken curve represents the normal monthly mean temperature. In the precipitation records the bars represent the rainfall during 10-day periods and the curve represents the normal precipitation.

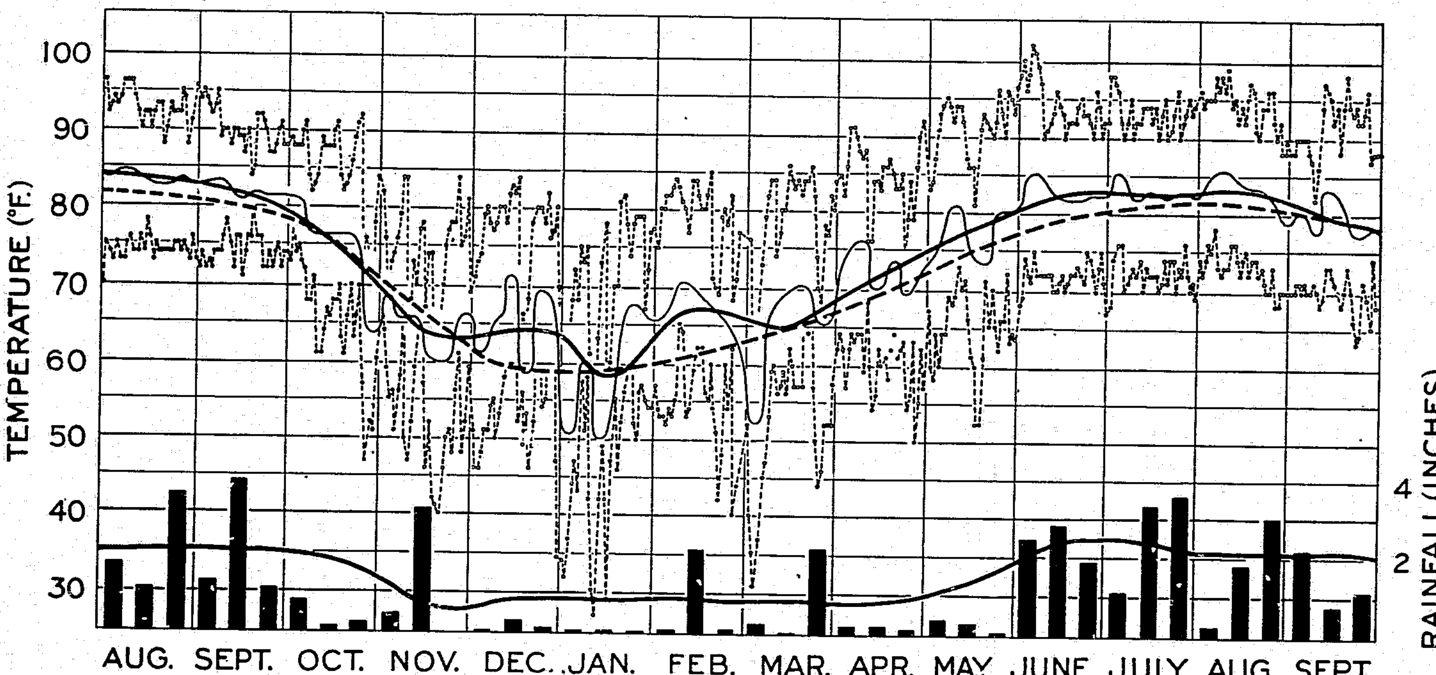

FIGURE 7.—Temperature and precipitation records of the Sanford, Fla., celery-producing area for the season of 1926–27. (See explanation under fig. 6.)

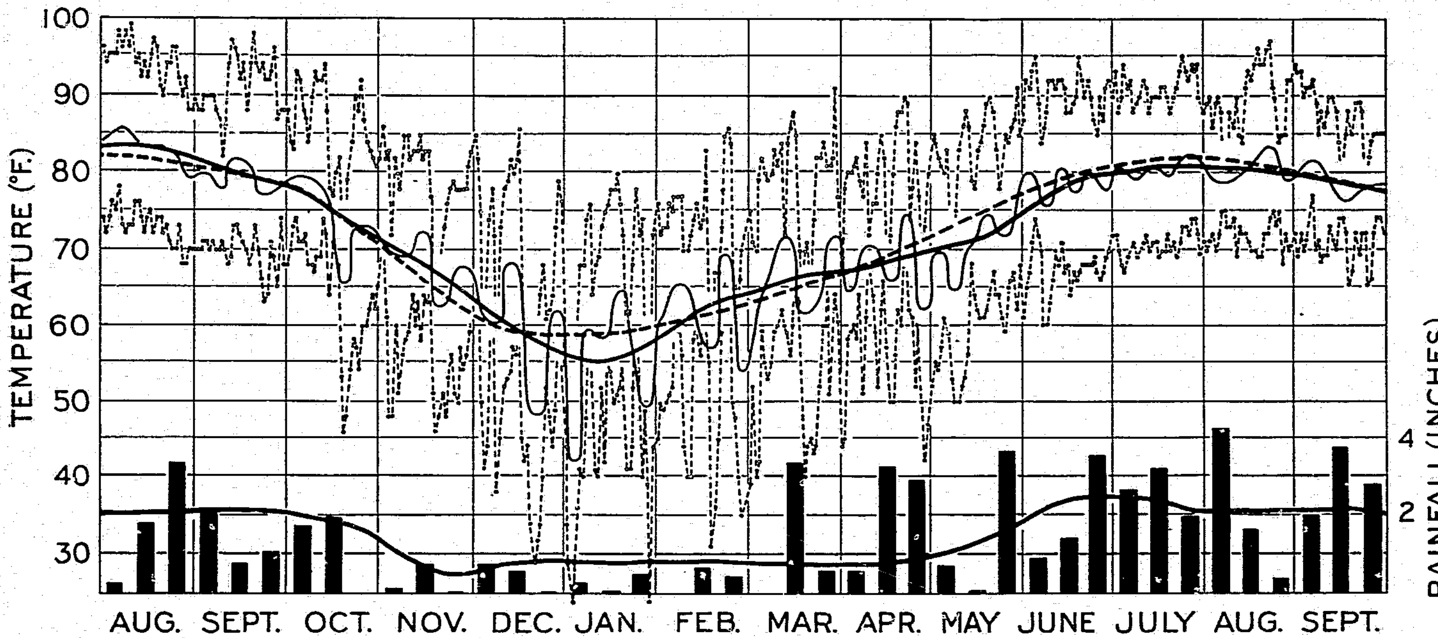

FIGURE 8.—Temperature and precipitation records of the Sanford, Fla., celery-producing area for the season of 1927–28. (See explanation under fig. 6.)

on somewhat wetter and heavier soils south and west of the center of the State, in a drainage district south of Manatee and east of Sarasota.

There is a variation of about 15° between the winter temperatures of the southern and northern parts of Florida (table 5). In figure 10 this variation is shown, with the temperature of the Sanford celery area (Orlando or central Florida), representing almost a mean between the other two and even more closely the mean of Florida temperatures. As will be seen, the minimum temperatures in northern Florida represent a considerable frost hazard in the

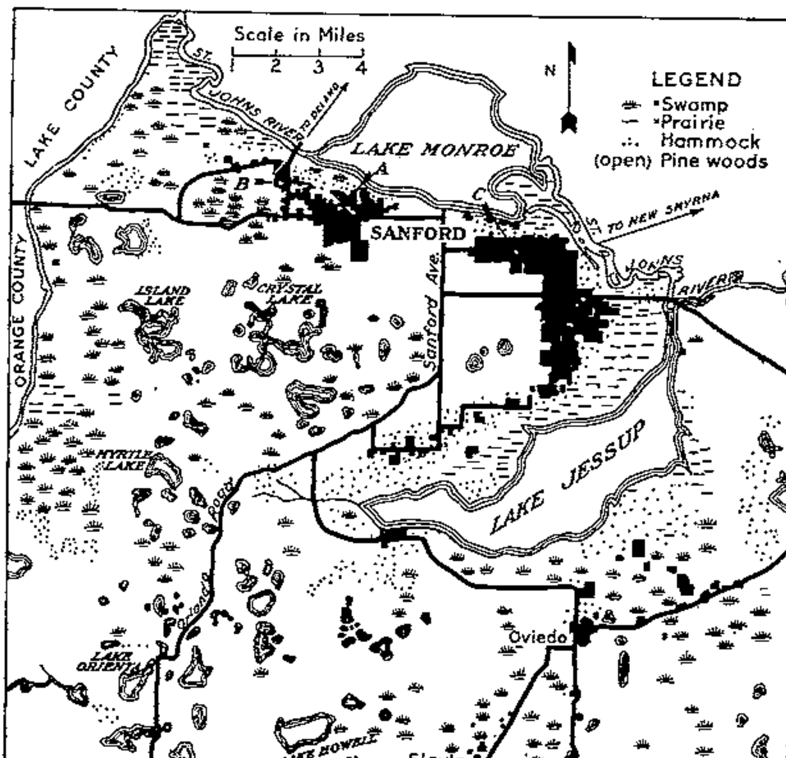

FIGURE 9.—Map of the Sanford, Fla., celery-producing area. Location of Weather Bureau instruments: *A*, Location of the experiment farm; *B*, field not benefited by the tempering effects of Lake Monroe; *C*, central portion of the heavily infested area.

winter season, while those of the southern coastal section, as represented by Miami, approach so closely to the maximum as to endanger the quality of the crop. The Manatee-Sarasota celery area, although situated at the edge of the southern section, has winter temperatures approximating those of the Sanford area; in fact, both of these areas are probably relatively near the colder limits of adaptation and therefore should be favorable for both quantity and quality in celery production.

SOURCE OF THE WEATHER RECORDS

All weather records prior to August 1925 have been compiled from the published Weather Bureau records taken at a weather station[4] in Sanford. Temperature and humidity records from that time on were obtained from a recording hygrothermograph in a standard Weather Bureau instrument shelter located on the experiment farm in the center of the second largest celery-producing area at Sanford (fig. 9). This instrument was checked by standard maximum and minimum thermometers and a sling psychrometer. Although the rainfall was recorded at this station, an average of that recorded by the Weather Bureau stations at Sanford and Orlando has been used instead, as representing a better average for the entire celery-growing area.

CROP SEASONS

The crop season of 1925–26 was ushered in by an exceptionally hot and dry fall (fig. 6). September was hotter by 1° than any preceding September in the Weather Bureau's 35-year record, and the

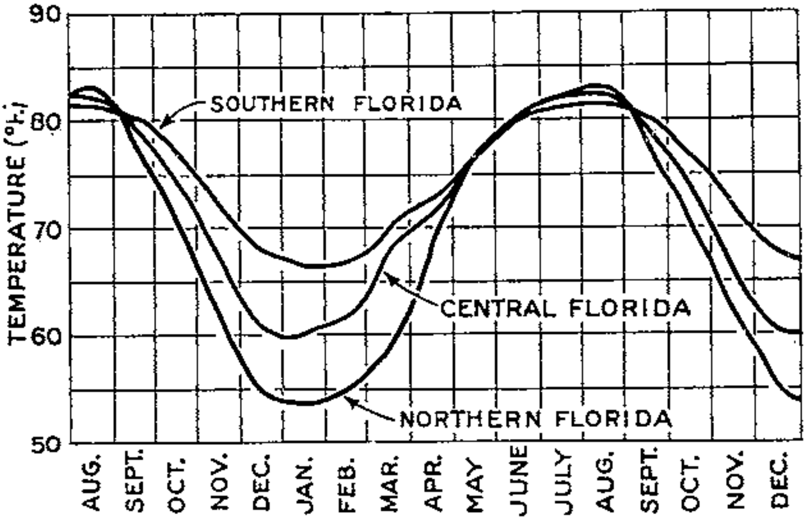

FIGURE 10.—Monthly mean temperature curves for northern, central, and southern Florida.

minimum of precipitation had been equaled only once in the same period. The scant precipitation came in a few destructive storms, rather than in showers that would have been of more value. The temperature of the winter season was below normal, beginning with a slight departure in December and increasing to nearly 4° below normal in March and April. This gave a very long cold season, characterized by sudden fluctuations both above and below the normal, with temperatures down to freezing or below during each of the 5 months from November to March, inclusive. The first normal temperatures of the season occurred in May and June.

The crop season of 1926–27 (fig. 7) likewise started out with temperatures above the normal in August and September but not so high as in the previous year. October, which should usher in the

[4] This station was maintained by A. C. Foster, of the Bureau of Plant Industry, until June 1927, when it was taken over by these investigations.

transition period, including the most favorable temperatures, was ideal, in sharp contrast to the wide extremes of the same period of the previous year. November was decidedly below normal until after the 20th. From that time on the winter season was from 5° to 7° above normal, with the exception of two extremely cold periods, one during the first half of January and the other early in March. The January cold snap carried temperatures far below freezing, destroying the celery in certain exceptionally low spots and even more seriously injuring the citrus orchards. The March drop in temperature did not injure the celery as much as did the hot weather that followed, but it was disastrous to the early trucking interests. From March until the following September the temperatures ran from 1° to 2° above normal. As a whole, the winter was one of the three warmest in the 30 years of celery growing, with precipitation below normal from October to the end of May. The moisture was in the form of three heavy showers that injured rather than helped the crop.

The third season (1927–28) was very variable, with alternating warm, cold, wet, and dry periods (fig. 8). The mean for the 3 winter months was the same as for the first season but the spring period was much warmer, therefore the celery season as a whole was only a little below normal. The celery leaf tier approached injurious numbers several times, and some dusting was done, but without treatment the damage would have been negligible.

The differences in the three seasons gave an exceptional opportunity to observe the relative importance of the several factors under the varying conditions and to check the response of the tier and its parasites to the various temperatures in the field, as compared with their response to controlled temperatures in the laboratory. The second winter, one of the three warmest in the 30 years of celery production, was sufficiently warm throughout for both tier and parasites to be active. The first and third winters, although not so cold by several degrees as many that have been recorded, were cold enough to retard the activities of the tier sufficiently to prevent commercial damage and to suspend entirely the activities of the two most important parasites. Further reductions in temperature would not have given data of economic importance unless the temperature had fallen so low as actually to destroy some stage of the tier or parasites, and it is doubtful whether such temperatures ever occur. If this is true, then the temperature and moisture ranges of the three seasons have given every important variation ordinarily encountered. These variations have included temperature extremes from 22° to 97° F. during the celery-growing season.

In the following paragraphs the factors affecting celery production and tier injury have been brought together and presented in their relation to the problem as a whole.

HUMIDITY

The humidity of the subtropical region is relatively high and is probably slightly accentuated in irrigated districts. The hygrograph records show that on the average humidities are practically at the saturation point from 10 to 14 hours out of the 24 and occasionally fall below 50 percent for a 2-hour to 4-hour period. In times of extreme drought the length of the saturated period may be shortened to 8 to 10 hours and the extreme minimum of humidity may occasionally fall below 30 percent.

PRECIPITATION

Although the average, by 10-day periods, of the rainfall reported by the official Weather Bureau stations at Sanford and Orlando has been recorded (table 6 and figs. 6, 7, and 8), this cannot be interpreted as representing a large part of the total moisture supply of the crop or the relative distribution for any given field in the district. Therefore, it has not been found feasible to make any use of this information, except as represented by periods of excessive rainfall or long drought.

TABLE 6.—*Precipitation in the Sanford, Fla., celery area by 10-day periods, August 1925 to September 1928, inclusive*

Month	Sanford	Orlando	Average
	Inches	*Inches*	*Inches*
1925			
August	2.69	3.64	3.27
	1.44	1.15	1.30
	4.39	5.00	4.70
September	1.94	1.17	1.56
	2.09	.94	1.52
	.37	.44	.41
October	.14	1.20	.67
	1.69	.62	1.16
	.02	.10	.06
November	.27	.24	.26
	1.67	1.37	1.52
	.02	.13	.08
December	5.74	5.65	5.70
	.73	.68	.71
	.92	1.48	1.20
1926			
January	1.98	1.15	1.57
	.70	.59	.65
	1.42	2.08	1.75
February	.80	.74	.77
	.42	.35	.39
	.30	.72	.51
March	.00	.14	.07
	.36	.36	.36
	4.00	4.55	4.28
April	3.90	4.24	4.07
	.20	.43	.32
	.00	.00	.00
May	.90	.06	.48
	.00	.00	.00
	2.69	.46	1.58
June	3.30	2.30	2.80
	2.26	3.12	2.69
	4.72	5.84	5.28
July	1.47	2.13	1.80
	1.76	3.72	2.74
	7.36	3.32	5.34
August	2.70	.78	1.74
	1.50	.62	1.06
	3.40	3.59	3.50
September	.60	1.93	1.27
	3.60	4.05	3.83
	1.00	1.06	1.03
October	1.10	.40	.75
	.10	.07	.09
	.01	.53	.27
November	------	.48	------
	------	3.18	------
	------	.00	------
December	------	.05	------
	------	.20	------
	------	.12	------
1927			
January	.05	.02	.04
	.06	.07	.07
	.05	.02	.04
February	.12	.02	.07
	2.74	1.53	2.14
	.05	.20	.13
March	0.20	0.31	0.26
	.05	.02	.04
	2.40	1.79	2.10
April	.30	.13	.22
	.24	.30	.27
	.09	.19	.14
May	.74	.00	.37
	.20	.41	.31
	.05	.05	.05
June	3.08	1.78	2.43
	4.89	.70	2.80
	2.34	1.36	1.85
July	.74	1.40	1.07
	4.96	1.76	3.36
	1.78	5.33	3.56
August	.48	.06	.27
	1.20	2.39	1.80
	3.04	2.96	3.00
September	2.19	2.15	2.17
	.16	1.43	.80
	1.57	.57	1.07
October	2.13	1.32	1.73
	1.42	2.57	2.00
	.00	.00	.00
November	.12	.10	.11
	.76	.63	.70
	.00	.01	.01
December	.54	.93	.74
	.73	.35	.54
	.00	.01	.01
1928			
January	.24	.25	.25
	.04	.00	.02
	.38	.49	.44
February	.00	.00	.00
	.66	.56	.61
	.52	.35	.44
March	.00	.00	.00
	3.34	2.58	2.96
	.64	1.35	1.00
April	.58	.32	.45
	3.23	3.54	3.39
	2.87	5.11	3.99
May	.21	1.22	.72
	.01	.11	.06
	4.99	2.22	3.61
June	1.21	.48	.85
	2.10	.54	1.32
	3.83	3.04	3.44
July	2.72	3.47	3.10
	3.73	2.57	3.15
	1.98	1.52	1.75
August	2.74	------	------
	1.72	------	------
	.40	------	------
September	2.12	------	------
	6.38	------	------
	5.05	------	------

The amount and distribution of precipitation are very important factors in crop or insect development in many regions, but for the Sanford area they are probably relatively unimportant, except as they are correlated with temperature or reach extremes of flood or drought. In Florida generally pecipitation is abundant, with an annual mean of 52 inches, but it is principally in the form of local showers; therefore, one field may have an excess of moisture in a given period and another field half a mile away may receive none. The variations have little effect on the production of the celery crop, as the growers depend upon irrigation and drainage to maintain a constant supply of moisture in the soil.

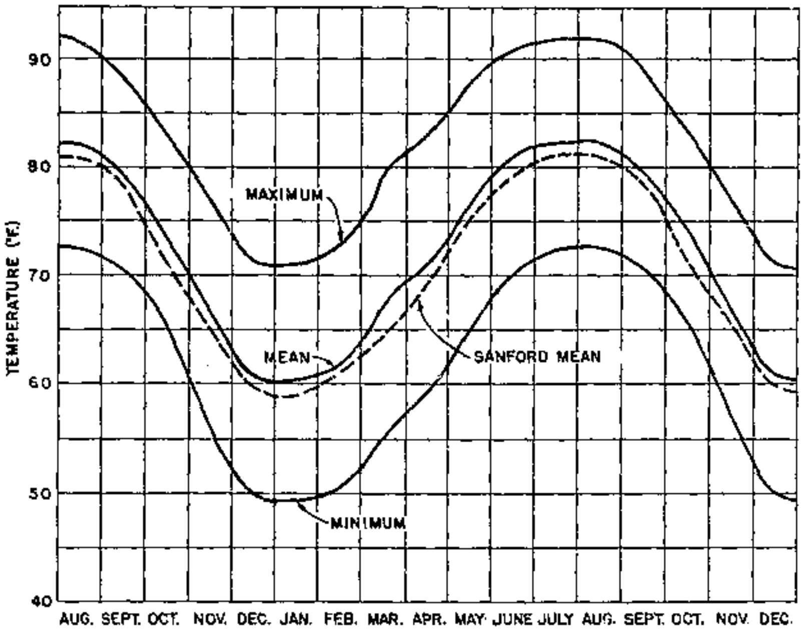

FIGURE 11.—Mean monthly maximum, mean monthly minimum, and mean temperatures at Orlando, Fla.

TEMPERATURE

Of the three climatic factors that affect celery and the celery tier, temperature is undoubtedly the most important, as minimum temperatures range far below the limits of tier activity, while maximum temperatures are higher than those in the region to which celery is normally adapted.

The weather records of the Orlando station are much longer and more satisfactory than those of Sanford, and, as they differ very little from the Florida mean or from the Sanford temperatures, they have been plotted to show normal variations from the mean. In figure 11 the mean monthly maxima, the mean monthly minima, and the resultant mean for Orlando are given, with a dotted line showing the variation in the Sanford mean. (In the study of temperatures under Florida conditions it has been found necessary to show a

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complete winter season followed by a complete summer season in order to get a proper perspective of the two extremes as compared with regions in which only summer temperatures are of importance.) The difference between the mean monthly maxima and the mean monthly minima is almost exactly 20° throughout the year. There is a great difference in the relative fluctuation from day to day in the different seasons. In warm weather the daily fluctuation is usually about one-fourth of the difference between the maxima and minima, so the three records are distinct and almost parallel. In the winter season, on the other hand, and especially during the periodic drops in temperature, this daily fluctuation is often more than double the monthly range, and the resulting lines are almost perpendicular and are constantly crossing the mean.

Figures 6, 7, and 8 indicate that the relative amplitude of daily fluctuation is a function of the temperature itself, rather than of the season. Whenever the mean temperature for a 10-day period falls below 65° F. the daily fluctuation increases. However, in February 1927, when mean temperatures were well above 65°, the type of the daily fluctuation approached that of the summer. This increase in range of temperature in the winter may be due to the southern trend of the transcontinental storm tracks during that season. In that case the February temperatures and fluctuations would be explained either by a lack of storms or by an unusual northern trend of storm paths.

WHAT A GIVEN WEATHER BUREAU TEMPERATURE MEANS

In this bulletin all discussion of temperature with reference to field conditions is based upon the temperatures recorded by standard Weather Bureau instruments in a Weather Bureau shelter 4 feet above the ground. It must be remembered that these temperatures are only relative and do not express the actual temperature under which any plant or insect is existing at that time. By using the standard Weather Bureau temperature records, however, it is possible to make comparisons with similar temperatures in all other regions and the same relative relationships would undoubtedly hold.

In the winter season it is not the mean temperatures so much as the extreme minima that control the distribution of truck crops; on the other hand, these extremes do not affect the insects, except for a temporary cessation of activity, as much as do the means, the latter determining the limitation of activity or the rate of development.

In the summer, however, it is probable that the reverse is true, the extreme maxima of temperature being in many instances the limiting factor in both plant and insect development. During the three hottest months the maximum temperatures of the air layer above the celery fields would reach 97° F. or above every day, were it not for the winds and for the fact that the sky ordinarily becomes partially cloudy before the hottest period of the day is reached. In order to determine just what these maximum temperatures actually meant, a series of observations were made on bright sunshiny days in the hottest period. The air temperature taken with a thermometer at 4 feet above the ground ranged from 99° to 100° F., and when

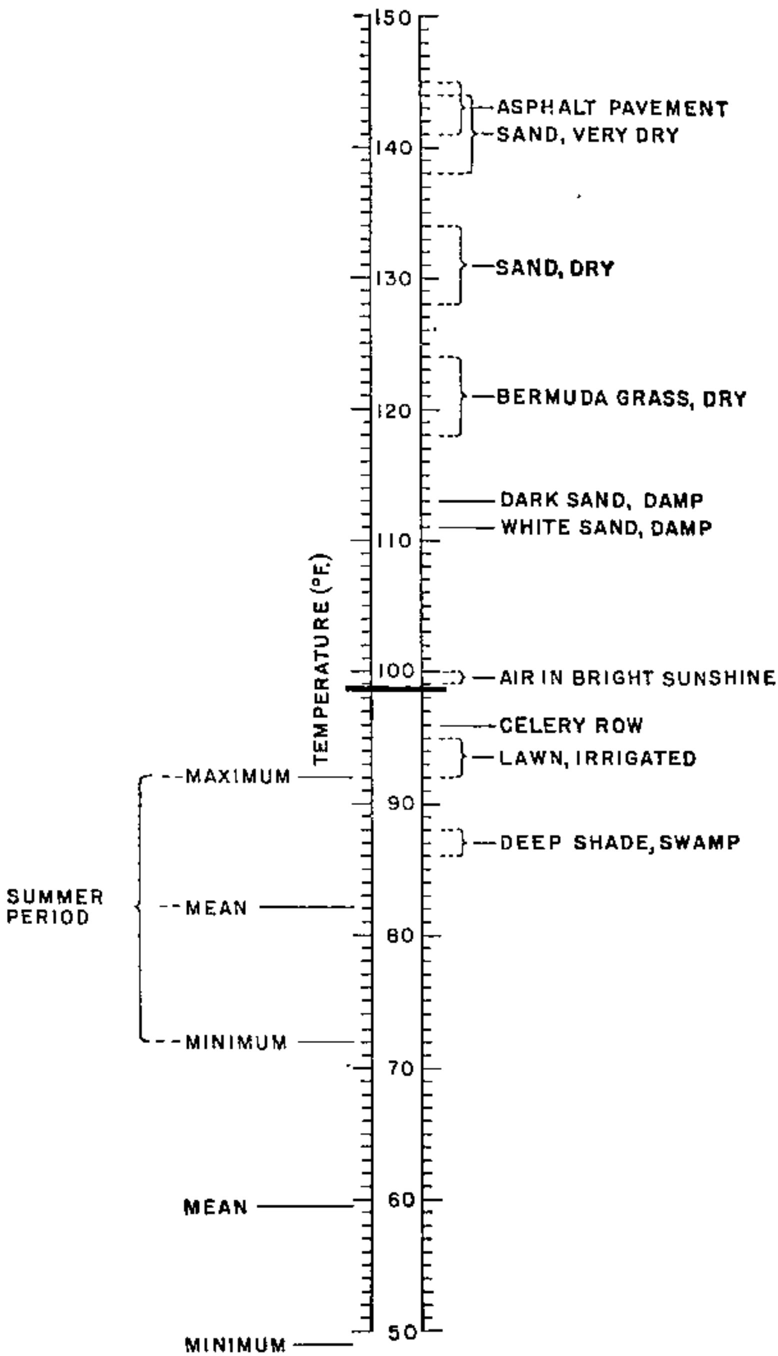

FIGURE 12.—Relative temperatures in full summer sunshine of different locations at Sanford, Fla.

the thermometer was shaded it ranged from 97° to 99°, the average being above 98°, as represented by the cross line in figure 12. Thermometers in standard Weather Bureau shelters would record about 1° below this, owing to the lag of heating the wooden box. The temperatures taken in the middle of a row of celery averaged 96°; those of an irrigated lawn ranged from 92° to 95°; but the air in the deep shade of the swamps ranged from 86° to 88°, the reduction from air temperatures being largely due, no doubt, to the higher rates of evaporation.

In the celery fields where the ground was fairly damp from subirrigation the temperature of the surface soil registered 111° F. and that of the darker sands 113°, while in the short Bermuda grass cover on the dry sands of the uncultivated areas the temperatures ranged from 118° to 124°. In bare areas of dry sand in similar locations the temperatures ranged from 128° to 134°, but in sandy areas that were relatively bare and very dry on account of slight elevation or lack of rainfall the surface temperatures ranged from 138° to 144°. The highest temperatures, 141° to 145°, were found on the asphalt pavements.

As 120° F. is usually considered the upper limit of survival of insect life, it can readily be seen that insects that thrive in the summer period must find locations either in shaded places or on vegetation considerably above the ground line. For some insects there is also the possibility of burrowing beneath the surface of the ground far enough to escape the higher temperatures. Soil temperatures decrease rapidly from the surface down to the depth of a few inches, where they become relatively stable at the mean temperature of the period, which, in the summer season, would be practically 82°. The mean monthly maxima during this period run close to 92°, as shown by figure 11, and the mean monthly minima around 72°, giving mean monthly temperatures slightly above 82° for the period. There are groups of insects whose life habits are such as to enable them to continue their activity and still avoid these temperatures, but by far the larger number of insects have solved the problem by developing generations in the fall and spring and passing the summer season in a quiescent stage.

TEMPERATURE IN RELATION TO THE DEGREE OF INFESTATION

A temperature of 50° F. is usually considered the minimum for insect activity, while 65° is still below the optimum for many species. Figures 6, 7, and 8 show that the normal Florida temperatures during the months of December, January, and February are unfavorable for rapid development of insects. As celery production is limited to the winter months, the temperatures of the crop seasons from 1922–23 to 1927–28 are compared with the normal temperature of the Sanford area in table 7 and figure 13.

TABLE 7.—*Mean monthly temperatures at Sanford, Fla., for the 5 seasons studied*[1]

Year	Temperature											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
1922	-----	-----	-----	-----	-----	-----	-----	81.1	79.2	76.7	69.4	65.0
1923	62.6	64.0	70.2	73.8	75.2	80.0	82.2	83.0	80.4	73.0	63.8	66.4
1924	61.7	58.9	61.9	71.4	77.0	82.8	82.4	83.2	80.7	71.8	66.0	65.2
1925	65.0	64.6	68.8	70.8	74.0	80.8	81.8	82.4	83.0	76.8	66.0	59.0
1926	58.3	58.3	62.4	67.1	74.9	79.8	82.0	83.8	81.4	74.8	64.2	64.2
1927	59.1	66.9	65.2	72.5	77.7	82.0	82.7	83.2	79.5	74.7	67.8	-----
Normal mean	59.0	61.3	64.4	69.3	75.2	79.0	81.0	81.0	78.9	74.0	65.6	59.8

[1] The data for August 1922 to July 1925 are from the annual reports of the Weather Bureau; those for August 1925 to November 1927 are from records made at the Government farm.

In the celery seasons of 1922–23, 1924–25, and 1926–27 the infestation by the tier was severe; in 1923–24 it was less severe; and in 1925–26 and 1927–28 no commercial injury occurred. The summer

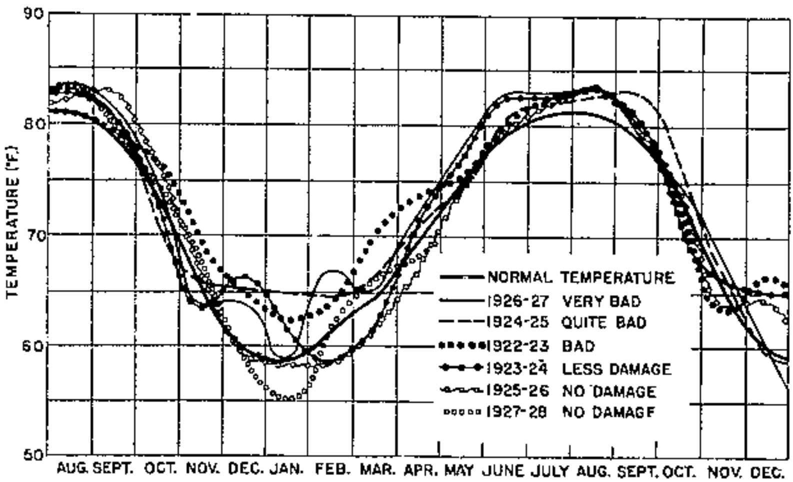

FIGURE 13.—Monthly mean temperatures of seasons in which varying degrees of injury from the celery leaf tier were recorded.

temperatures during these seasons were constantly above normal and the curves very much alike, so there appeared to be no discernible influence of summer temperature on the celery leaf tier. A further study of the curves shows clearly that the widest fluctuations from the mean occurred entirely in the period from December to March, inclusive; that in the 3 years in which the temperatures were constantly above normal during this period the injury was severe; and that in the season of 1923–24, in which the temperature for the first 2 months was extremely high but during the last 2 months somewhat lower than normal, only moderate injury occurred. In sharp contrast, in 1925–26, when the temperature throughout the entire period was below normal, no injury occurred;

and in 1927–28, when a very cold January was followed by alternating warm and cold periods, at no time was the tier present in sufficient numbers to be injurious.

In order to test the correctness of this interpretation the mean temperature of Florida for the 3 winter months (December, January, and February) of each season was plotted (fig. 14), beginning with the first records of the Weather Bureau (1891) and continuing to 1928. The resultant curves show a series of fluctuating but rapidly descending temperatures, ending in a winter temperature almost 5° below normal in the season of 1901–2. For the next 25 years (as shown by the dotted line) the winter temperatures, although still fluctuating widely, rose from an average of 57° for

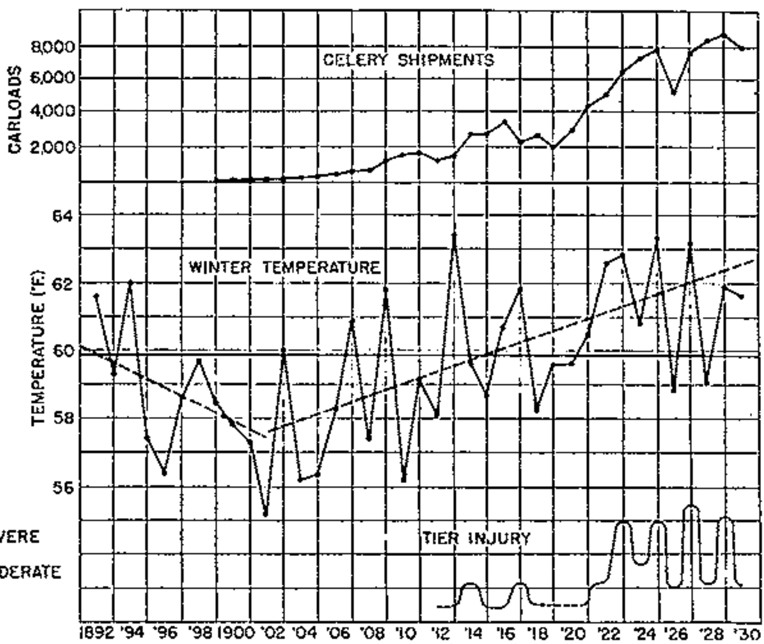

FIGURE 14.—The mean winter temperatures (December, January, and February) in Florida from 1891–92 to 1929–30, with corresponding shipments of celery and injury by the celery leaf tier.

the 5 years following 1900 to an average of 62° for the 5 years following 1920, a change of 5° in the 25 years. This exceptional series of successive warm winters no doubt accounts for the serious outbreak of the celery leaf tier and probably for the outbreaks of other pests that appeared at the same time.

On careful inquiry among the growers it was found that in two previous seasons worms were sufficiently numerous in the celery to be seen when it was put through a washer. The worms falling out of the bunches gathered in piles below the conveyor belt. These two seasons (1913–14 and 1916–17) corresponded to the two occurrences of a relatively warm winter following a previous warm one, as shown in figure 14. Two relatively warm winter seasons preceded the outbreak of 1922–23. These facts suggest that, after a series of cold winters in which the insect had presumably been decreasing, two warm winters in succession are necessary before it can again increase to injurious numbers, after which there will be serious damage in each successive warm winter season.

A single season (1925–26) in which the temperature dropped 1° below the mean apparently did not permanently reduce the number of the leaf tiers, which were exceedingly numerous the next year. The winters of 1914–15 and 1917–18, following the two slight increases, were only slightly colder than 1925–26 but they were apparently effective in suppressing the pest. There are probably other factors involved in this result, but with the information available it seems certain that a winter temperature of 2° or more below normal will terminate an outbreak. The striking reversal in the trend of winter temperatures, as shown in figure 14, suggests that these alternating cycles of cold and warm winters may be a normal condition. A study of a much longer period seemed to confirm this and suggested the possibility of interpreting the factors that control these cycles.

LOCAL DISTRIBUTION OF INJURY

The Sanford celery area (fig. 9) is roughly divided by the town of Sanford into a large east-side and a smaller west-side area, with still smaller outlying areas at Oviedo and on the southwestern shore of Lake Jessup. The area in which the injury has been heaviest is a strip only a mile or two wide, lying along an almost direct northwest-southeast line extending across the widest part of Lake Monroe toward Lake Jessup. Even in this section the outlying and relatively isolated fields have usually escaped injury, as compared with the solidly planted section. West of Sanford the injury has been confined to the solidly planted area and has decreased in severity to the westward until the isolated fields and even the solid block at Lake Monroe station escaped injury. The small areas at Wagner and Oviedo have never been damaged, even in the worst years. It was early observed that in any area the frost damage was almost inversely proportional to damage by the leaf tier. This is attributed to the fact that the cold northwest winds that bring the low temperatures are modified in their passage across Lake Monroe.

Observations in successive seasons have indicated that there is a difference in relative temperatures during cold periods between the areas east and west of Sanford. Standard Weather Bureau instruments were installed in the central portion of the heavily infested eastern area (fig. 9, *C*) and in a field on the west side, beyond the area in which serious damage had ever occurred. This field (fig. 9, *B*) was too far to one side to be benefited by the tempering effects of Lake Monroe during periods of northwest winds. Temperatures from these stations and from the experiment farm (fig. 9, *A*), located in the area of light infestation on the west side, are given in table 8. The tempering effect of Lake Monroe in the winter season is evident in the almost constantly higher minimum temperatures of station C, as compared with station B (fig.15).

TABLE 8.—*Maximum and minimum temperatures in celery areas on the west side (station B) and the east side (station C) of Sanford, Fla., by 10-day periods, season of 1927–28*

Period	Maximum		Minimum	
	Station B	Station C	Station B	Station C
	° *F.*	° *F.*	° *F.*	° *F.*
Oct. 22–31	85.7	87.9	57.4	60.4
Nov. 1–10	81.9	83.1	53.9	57.3
Nov. 11–20	79.6	79.0	56.1	58.0
Nov. 21–30	78.7	76.4	52.1	53.2
Dec. 1–10	73.7	72.9	50.5	52.5
Dec. 11–20	74.6	73.0	48.0	50.5
Dec. 21–31	65.0	64.5	43.2	45.4
Jan. 1–10	63.9	63.7	39.7	41.0
Jan. 11–20	75.0	76.8	48.1	49.3
Jan. 21–31	65.9	66.3	41.8	43.5
Feb. 1–10	77.2	77.5	51.9	52.5
Feb. 11–20	73.6	73.3	49.3	50.3
Feb. 21–29	74.8	73.0	51.4	51.9
Mar. 1–10	79.5	80.0	50.0	51.4
Mar. 11–20	79.3	79.7	53.9	54.0
Mar. 21–31	83.1	81.3	55.0	54.8
Apr. 1–10	78.2	77.7	58.2	58.7
Apr. 11–20	76.0	76.4	55.2	56.9
Apr. 21–30	78.5	----------	55.9	57.2
May 1–10	78.2	----------	55.4	56.5
May 11–20	83.6	----------	63.3	62.4
May 21–31	85.1	----------	64.8	65.1

There are no temperature records available for the Oviedo section. The celery there is planted on very low, heavy muck soils, and the fields are relatively small and isolated in heavily timbered sections.

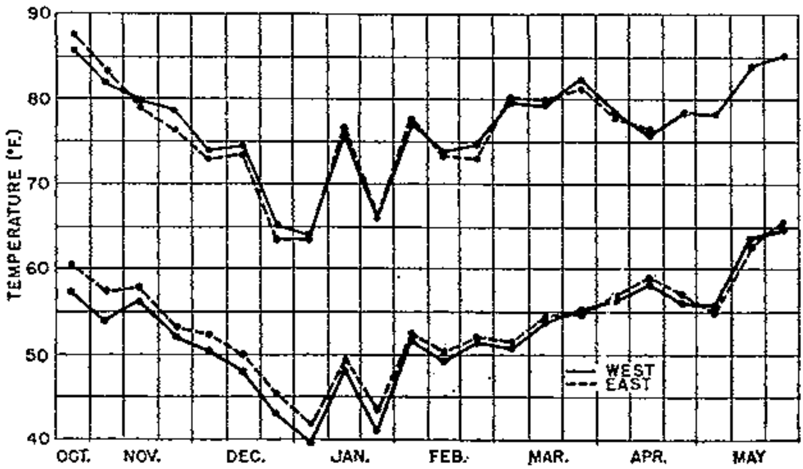

FIGURE 15.—The average maxima and minima of the west side (station B) and the east side (station C) of the Sanford, Fla., celery-producing area, plotted by 10-day periods.

Frost damage is often very spotted but averages more severe in this section, and celery can be grown later than in the Sanford area, indicating lower temperatures.

THE CELERY LEAF TIER

DEVELOPMENT UNDER DIFFERENT TEMPERATURES

In order to test the temperature reactions of the celery leaf tier under different conditions, a series of rearing experiments were carried on, the lower temperatures being in a refrigerator, the median temperatures in the insectary, and the higher ones in an electric oven. The results of these experiments are briefly summarized here. Eggs kept at a temperature of approximately 48° F. were apparently alive at the end of 30 days (fig. 16) but later began to turn black, and by the fortieth day all the embryos were dead. At 49°, or slightly above, eggs hatched in 32 days, the larvae lived but grew very slowly if at all at first, and were scarcely two-thirds grown at the end of 2 months, when the experiment closed. At temperatures of approximately 51° eggs required an average of 30 days to hatch, larvae matured in 77 days, the pupal period required 52 days, and the moths lived an average of 12 days, a total life-history period of 171 days. These moths, however, laid no eggs. Allowing 2 days before egg laying and 4 days to reach the maximum production, provided favorable temperatures occurred, the average complete life cycle from egg to egg at this temperature would have been 165 days.

At 56° F. the moths crawled about on the hand but did not lay eggs. When the temperature reached 58° they began to lay. The eggs hatched in 8½ days, the larval period required 29 days, and the pupal period 17¼ days. Allowing 2 days for preoviposition and 3 days to the middle of egg laying, the complete life cycle required 60 days.

At approximately 68° F. the eggs hatched in 6 or 7 days, the larvae required 20 days to mature, the pupae required 11 days, and the moths lived 12 days. Allowing 2 days for preoviposition and 3 days to the maximum laying period, the average time required for a generation was about 43 days.

At 78° F. the eggs hatched in 4 days, the larval period required 14 days, the pupal period 8 days, and the moth lived 11 days but laid only a small number of eggs. Allowing 2 days for preoviposition and 2 days to the middle of the egg-laying period, the average period for the generation was 30 days.

At 91° F. the life-history period still required 30 days, and the moths did not lay any eggs, either at that temperature or when placed in the insectary.

At 97° F. the eggs turned black and the embryos died on the fourth or fifth day. Young larvae were introduced and they shriveled and died within a few days. Pupae held at this temperature produced adults in the same time as those held at 91°, but these moths also failed to lay eggs. Under field conditions the moths hatching at the higher temperatures would have disappeared, to return in the fall.

NUMBER OF GENERATIONS IN THE FIELD

The celery leaf tier, as will be shown later, does not appear until the mean temperature falls to 77° F. or below. At this temperature the life cycle requires 1 month, or slightly more, but the temperature is falling rapidly at that time. Through the winter period (December to February) the normal temperature is below 60° and the life cycle takes 2 months or longer. If the winter is abnormally cold, with temperatures around 55°, the life cycle requires more than 3 months. Normal temperatures in California fall below 55° and occasionally approach 50°. At these temperatures the life cycle

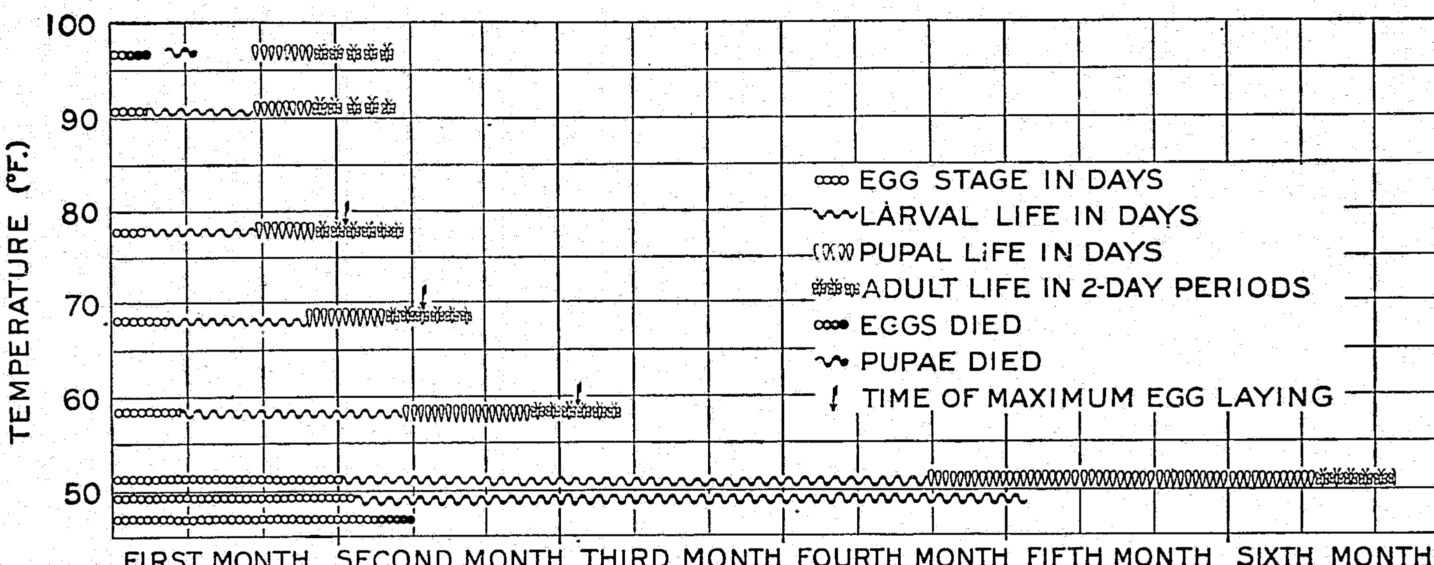

FIGURE 16.—The rate of development of the stages of the celery leaf tier at different temperatures.

requires 6 months. As the temperature increases in the spring the cycle is shortened until, about the time the moths disappear, it reaches its minimum of 1 month. The celery season in Florida is one of rapidly changing and widely fluctuating temperatures; therefore any generation will be subjected to wide extremes and its life cycle will vary accordingly.

The Florida season of 1925–26, as has been explained, was exceedingly hot and dry. The first moths were observed in the field the middle of November after a rain and an extreme drop in temperature (fig. 6). They no doubt continued to appear for some time. The worms of this generation matured after the middle of January (fig. 17). The next generation, under the low temperatures prevailing during February and March, did not mature until toward the end of the latter month, and there was but a single generation after that time, the larvae beginning to disappear before the middle of May and becoming quite scarce before the end of the month.

In 1926 a rain and drop in temperature (fig. 7) began to bring the moths out on October 10. They continued to appear for some time. The earlier start and warm season gave opportunity for rapid development and they were disappearing in December (fig. 17). The next generation extended through January, and the third, starting the last of January, extended over the middle of March. The fourth and last generation was brought to an abrupt termination by extremely hot weather early in May, which not only destroyed the celery but hastened the disappearance of the worms, even before the celery was removed.

In the season of 1927–28 there was rain and a drop in temperature to just below 77° F. on September 9 and 10, with a quick reversal to high temperatures (fig. 8). On September 15 the first male tier moth came to a trap light in a swampy woods along the side of the celery fields. On September 16 and 17 several more males came to the light. On September 18 the first few females were found in the celery beds. On September 23 another rain and a temporary drop below 77° brought out a few more. This small infestation was confined to the older seed beds, as there was no celery in the field big enough to shelter the moths. They gradually decreased in number, were becoming rare by October 10, and had entirely disappeared by October 13. The egg parasites and predators had by this time eliminated the progeny and only one worm was found. On October 18 a storm with a drop in temperature to 15° below normal occurred, and immediately following this the tier appeared in large numbers, the males by the second day and the females in numbers by the fourth day. They continued to appear for some time. The first progeny were nearly eliminated by parasites, but a brood of worms appeared in November (fig. 17), a second generation in December and January, a third in February and March, and a fourth in April and early in May; a small partial brood started late in May but disappeared with the late celery harvested in June and did not complete its cycle. None of these three seasons could be considered normal; the first was almost exactly 1° below normal in the winter period; the second was slightly more than 3° above normal; and the third was almost as cold as the first during the winter season but much warmer later in the spring. From an inspection of these

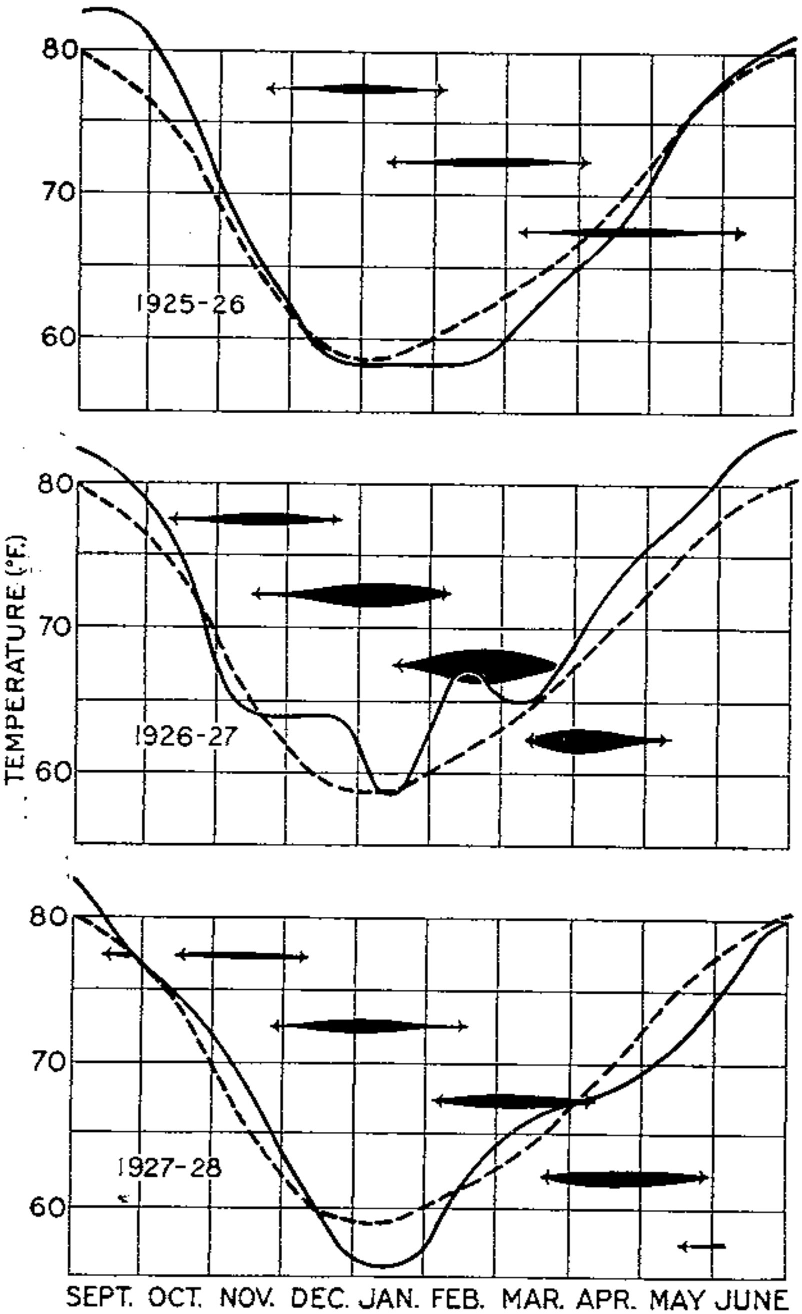

FIGURE 17.—The seasonal history of the celery leaf tier in the Sanford, Fla., area. The broken line shows the normal, the black line the seasonal mean temperature, and the breadth and length of the arrows show the size and duration, respectively, of the broods of the tier.

records it may be inferred that in a season of normal temperatures, with a normal rainfall and drop of temperature early in October, there would be four generations ending late in May or early in June.

With a variation of several weeks in the time of appearance of the moths in the fall and a normal variation in the length of different stages, added to the length of the oviposition period, it would be expected that in the second generation, or at least in the third, there would be so great an overlapping and confusion that the generations could not be distinguished in the field. Instead, there has been a remarkably clear-cut and definite demarcation of broods in any field under observation. The time of appearance and disappearance in different fields has varied to a much greater extent, but even here there has been little difficulty in determining the generation to which they should be assigned.

As a field of maturing celery is harvested the moths are driven out and drift with the wind to the nearest celery large enough to shelter them. The infestation in a field by later generations will therefore depend on its proximity to older fields, and on the direction of the wind currents at the time the older fields are harvested. If fields adjacent to a given field are harvested at different times there may be two distinct infestations of worms of different ages in this field, but the later ones will rarely mature before the celery is harvested and will disappear at that time, whereas the earlier ones may change to moths and in time infest some other field.

LIMITING TEMPERATURES

From the temperature experiments (fig. 16) it was determined that a mean temperature of 58° or 59° F. reduced the rate of development of the celery leaf tier to the point where it would not complete a life cycle on the celery crop under normal conditions of infestation, whereas at 63° its development was rapid enough to provide for a continuous infestation. It was found to increase its rapidity of development up to 75°, but the highest temperature it could withstand and still reproduce was not determined. The study of winter temperatures shows that a mean temperature of 59° for the 3 months was just below the limit of commercial injury, and that the two seasons whose means were above 63° were seasons of serious infestation. Deductions based on the time of its appearance in the fall and its disappearance in the spring indicate that a mean temperature of 77° is the upper limit of tier activity under the conditions of humidity prevailing in this area. With these limits as a basis it is possible to define a leaf-tier belt (fig. 18) in the same way that the celery-growing belt was established. A study of the monthly mean temperature curves of the four celery-growing areas (Florida, southern California, central California, and Michigan-New York) with reference to this leaf-tier belt is very instructive.

In the Michigan-New York area there is only a 4-month season above the minimum temperatures of injurious activity and less than 3 months with favorable temperatures between 65° and 70° F. The temperatures for a brief summer period are extremely favorable to the development of the celery leaf tier but the number of generations is limited; therefore it rarely, if ever, attains injurious numbers before the fall period, when the temperature retards the activity of the worms. This brood of worms may remain on the celery, growing very slowly and doing little injury. Michigan celery stalks shipped to Florida have been found carrying as many as 6 or 8 worms each, but showing little injury at the time of arrival. With the normal increase of activity under the Florida temperatures these same worms will render the celery unsightly in a few days.

Injury has never been reported from the central California area, and a glance at figure 18 will indicate the reason. With the peak

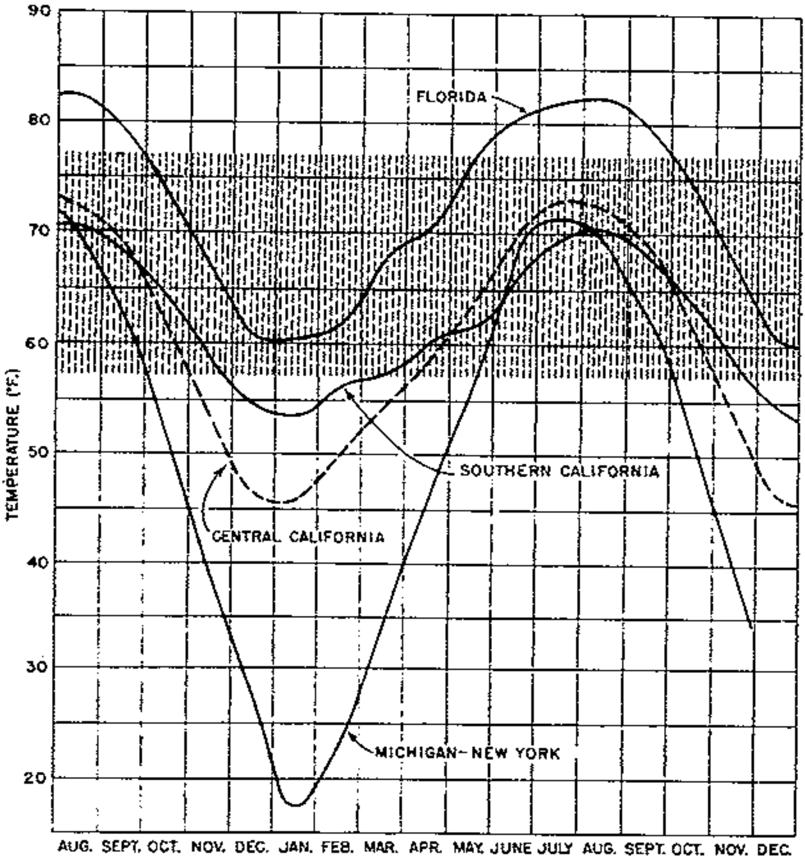

FIGURE 18.—The celery leaf-tier belt. Monthly mean temperature curves of the principal celery-producing areas in comparison with the limiting temperatures of the celery leaf tier. Optimum conditions for the development of the leaf tier are represented by the median part of the shaded belt, favorable conditions by the parts slightly farther from the center, and limiting conditions by the parts nearer the margins of the belt.

of their shipments being made in December (fig. 4) and the temperature passing 65° F. on October 1 and 57° on November 1 there is little opportunity for the development of this insect.

The southern California area has had destructive outbreaks in limited sections. As pointed out by Campbell (*3, p. 82*), this damage has occurred where celery has been grown adjacent to sugar beets. The leaf tier develops on the sugar beet during the favorable summer temperatures but does not reach injurious numbers. The harvesting of the beets forces the moths over to the young celery adjoining, where they become extremely injurious in September and October; but with the limiting temperatures of November the rate of development is reduced so that the insect is not injurious. The solution of the problem in this area has been largely the abandonment of the practice of growing celery adjacent to beet fields.

In Florida the peak of shipment is reached in March, and it will be observed that the mean temperature of the three preceding months in a normal season is between 59° and 60° F., or at the minimum of injurious activity for the tier. In a normal season with 3 months of inhibiting winter temperatures and 4 months at the other extreme and equally inhibiting in the summer, the short period of favorable temperatures in the fall and spring is not sufficient for the production of injurious numbers.

FOOD PLANTS

The food habits of the leaf tier are puzzling and somewhat difficult to explain. In the Sanford area the tier appears to be almost exclusively a pest of celery. It has only once or twice been observed in injurious numbers on any other plant, except as it migrated from harvested celery. In the laboratory the moths lay eggs and the little worms feed on the leaves of beggarticks, *Bidens leucantha* (L.) Willd., as readily as on celery—in fact the worms starting on this plant seem reluctant to leave the wilting *Bidens* for fresh celery. This same *Bidens* grows on the ditch banks throughout the celery-growing area and the moths visit the flowers for the nectar, but it is only occasionally that a larva is taken from this plant. At the times of highest concentration of infestation the moths flying in front of the spraying or dusting outfits sometimes appear in swarms that almost hide the team from view. At such times a few larvae will be found on other plants in the field besides the celery—most commonly on plantain (*Plantago*) and wild lettuce (*Lactuca*). At the time of the first appearance of the moths in the fall, before the celery was large enough to afford shelter, worms were found on rapidly growing plants of marsh marigold (*Caltha palustris* L.) and on crownbeard (*Verbesina virginica* L.). These plants were in extremely rich and fertile areas and were growing luxuriantly. The weeds in the celery field were growing rapidly as a result of subirrigation and the application of fertilizer to the celery. Only a few worms have been taken from table beets. The reason the *Bidens* is not infested in the field may be that its narrow leaves and open type of head do not afford shelter for the moths. All the other host plants have broad leaves and afford shelter.

Weigel (*13*) records a long list of food plants in the greenhouse, the greater number belonging to the Compositae, with chrysanthemum by far the most important. From a study of this list in connection with the observations in the field, it is evident that the determining factor is the forcing of the plants, luxuriance of vegetation apparently being more important than variety of the plant. It is not probable that many of these plants, if growing wild, especially under unfavorable conditions, would be in the least attractive to the leaf tier.

THE TIER AS A GREENHOUSE PEST

Only in the region between the Michigan-New York celery area and the Cotton Belt does the leaf tier become a serious greenhouse pest. This is, of course, the greenhouse belt as well. The temperature curves bounding this region are presented in figure 3. Considering these curves in connection with the 57° to 77° F. limitation of celery leaf tier activity, it will be noted that this belt falls in a region where the outdoor summer temperatures are largely favorable for leaf tier development but where the winter temperatures are far too low.

The celery leaf tier apparently spends the winter period on chrysanthemum and other forced plantings in the greenhouses; then, when the temperatures rise above the limits of tolerance, it flies to the fields to pass the summer on the growing truck crops, coming back to the greenhouse in the fall. In the warmer part of the Cotton Belt many of these insects would no doubt be exposed to fatal temperatures in the greenhouse in the summer and even in the open would find temperatures inimical to multiplication.

TIME OF APPEARANCE IN THE FALL

The normal curve of temperature in Florida passes 77° F. about October 10. Beginning early in September, careful observations were made on the time of appearance of the first moths in the celery beds and on the proportionate increase in numbers up to the time when the progeny of the first moths appeared. In the season of 1925–26 the first moths were found on November 20 and only a relatively small number appeared at any time previous to the maturing of their progeny. The few moths that appeared in November were found immediately after a rain that was followed by a sharp drop in temperature. The latter part of the previous September and October had been extraordinarily hot and dry—in fact, the preceding summer had been abnormally warm. There was a heavy rain on October 10, followed by a sharp drop in temperature but with an immediate reaction to an extremely high point, followed by another drop and an immediate recovery. A few moths may have appeared at this time; but, as the work was just being organized, they were not observed. Careful checking of the seed beds a little later disclosed none.

In the season of 1926–27 October temperatures were practically normal. A rain and a sharp drop in temperature on October 8 to 10 resulted in the appearance of a very large number of moths on October 12, and moths continued to increase in numbers, especially after another drop in temperature later in the month. It was estimated that there were 100 times as many moths in the field in November as during the same month the previous year.

In the season of 1927–28 monthly temperatures in September and October were almost normal. A rain, followed by a drop in temperature that carried the mean just below 77° F., occurred on September 9. Moths began to appear in small numbers by September 12, became increasingly abundant in the next 2 or 3 weeks, then began to disappear, and by October 13 a careful search failed to reveal a moth anywhere in the celery area. On October 14 there was a sharp break in temperature followed by rain and an extreme drop, the mean temperature falling 25° in a few days. A few moths appeared on October 15, practically all being males, and by the 17th many more moths were out, all fresh, in equal numbers of males and females. Temperatures went back to normal, which by that time were favorable, and the moths continued to increase in numbers for some time.

It has been impossible in these observations to differentiate between temperature and moisture because at this time of year temperature drops almost always followed storms. Osborn and the senior author (*8, p. 187*) have recorded similar reactions in the shovel-nosed leaf hopper (*Dorycephalus platyrhynchus* Osb.), where humidity of the atmosphere appeared to be the only possible explanation, as the insects themselves were in a shelter and the reaction took place before the storm struck. The celery leaf tier no doubt passes the summer in places of concealment, where the precipitation does not affect it directly. Therefore it is probable that the determining factor in the time of its appearance is the return of temperatures within favorable limits, although the humidity factor may be necessary to make the temperature operative. If this is true it may explain the nonappearance of the moths in the extremely hot and dry September and October of 1925, even though for two brief periods the temperatures were extremely favorable.

The hurricane of July 28, 1926, was accompanied by a drop in temperature that carried the mean to 74° F. for a 2-day period. No moths were observed after this storm. However, the celery was just coming up and the beds were badly washed out and might not have been attractive to the moths at that time. The hurricane of August 8 and 9, 1928, carried the mean temperature down to almost 75° for a 2-day period, but diligent search following this period did not disclose a tier. After observing the effect of these two hurricanes one may be fairly certain that such out-of-season drops in temperature do not supply all the factors necessary for the appearance of the moths.

EFFECT OF RAINS ON THE NUMBERS OF THE TIER

The suggestion has been made that heavy rains serve to keep the tier under control. There are two reasons why this might be assumed: (1) The tiers, in feeding above the heart of the celery, leave in their abandoned webs a mass of excrement or frass, which often remains after most of the worms have ceased feeding and have spun up to pupate. A heavy rain at this time will wash most of this frass away, thereby improving the appearance of the celery. (2) Even if the worms are still feeding, the rain washes away the old frass and the cold weather that ordinarily follows a rain retards the feeding; therefore the combination of rain and cold improves the appearance of the celery.

In the temperature chambers it has been demonstrated that temperature is a controlling factor in the activity of the leaf tier. On the other hand, insects in the laboratory did not appear to be at all affected by driving storms that occasionally flooded the cages. In order to test this matter further a careful study was made of the direct effects of storms in the fields, and there did not seem to be any correlation between precipitation and the activity of the tier, although there was always a high correlation between temperature and activity. In the season of 1925–26, in which no commercial injury occurred, there were three periods during the celery season in which the precipitation was far below normal (fig. 6) but the tier did not increase in numbers during these periods. During the extremely dry season of 1926–27, three heavy storms occurred—one in November, one in February, and one in March (fig. 7.) The November and March storms preceded extreme drops in temperature, but the February storm occurred during an excessively hot period and the temperature did not drop below normal. Careful counts were made after each of these storms in fields that had been under observation previously so that the relative infestation was known. In no instance was it possible to detect any difference in the relative numbers of any stage of the insect after the storms. On the other hand, during the first half of January 1927 there were two periods of extremely low temperature, and again the first of March was a third period of almost equally low means in which no precipitation occurred. In each of these three periods the activity of the tier was retarded to a much greater degree than it was in the three periods of heavy precipitation but less severe temperatures. On the other hand, the 80-mile wind of the July hurricane, together with the 8-inch precipitation that accompanied it, did destroy most of the amaranth leaf tiers in the field at that time. This was because the rain and wind beat the vegetation down against the ground, in exposed places stripping most of the leaves from the plants. In a number of the exposed situations not more than 3 to 5 percent of the larvae or moths survived. In certain sheltered places, where the force of the wind was broken by buildings or timber and the vegetation was not beaten into the ground, little damage was done and both moths and larvae were found in abundance, notwithstanding the 8-inch rainfall.

HOW THE TIER PASSES THE SUMMER

In a normal year the temperature passes 77° F. at the end of May and there is less fluctuation of the extremes; in fact, a transition between the fluctuating temperatures of the celery season and the constant ones of the summer occurs. In the season of 1925–26, in which May temperatures were near normal, the celery leaf tier began to decrease in numbers about the time the mean of 75° was reached, and practically disappeared before the last of the celery was harvested the first of June. It was expected that at this time the leaf tier would transfer from the celery to the vegetation along the border of fields, or possibly to the cooler swamps. A careful search during the summer season that year and in successive years did not result in the discovery of a single moth or larva anywhere until the return of the moths to the celery fields in the fall.

As all of the moths that returned to the field were extremely fresh and were laying eggs at a rapid rate, it was apparent that they had not come in from other areas. The moths appeared in the celery fields in numbers closely proportionate to the extent of infestation of the previous year, suggesting that the insect passed the summer in or close to the fields. As the fields in the two major areas were separated only by ditch banks, there did not seem to be opportunity for survival, except in the fields themselves. Plans were made to cage a large number of worms at the close of the next season to determine whether the moths would appear the next fall inside the cages, and also to make investigations in other places to ascertain whether the insects were passing the summer in the soil. The exceptionally warm season that followed resulted in the disappearance of the moths in April instead of May, and at the time it was planned to fill the cages disappearance and parasitization had reduced the numbers practically to the vanishing point. It had been previously observed that many celery stalks that were discarded in the field were mined by the worms, and it was thought that either the worms or the pupae would be plowed under in these stalks and would remain in the field throughout the summer. However, no larvae or pupae were found in the soil later in the season.

In the meantime the study of soil temperatures and the observations on other insects suggested that most of the aestivating insects in this region sought dry and sheltered hiding places rather than burrow into a soil that was likely to be heated to a fatal temperature at the surface and frequently saturated below. It was also noticed that the large two-striped walkingstick (*Anisomorpha buprestoides* Stoll) of the saw palmetto (*Serenoa*) was congregating and disappeared very soon after the celery leaf tier disappeared. In the summer a woodpile was moved and hundreds of these walkingsticks were found lying at full length between the logs. When disturbed they crawled about, but immediately returned to their hiding places and disappeared. The day after the celery leaf tier appeared in the fall, the first active walkingstick was seen, and in a few days they were again back in their old haunts. Apparently the temperature relations that limited the activity of the tier were equally potent in controlling the activity of the walkingstick.

In the breeding experiments it had been found that the leaf-tier moths began to lay after the second day and that their heaviest egg deposition came between the third and fifth days. From the freshness and the heavy egg-laying proclivities of the moths found in the fields during the fall periods of the first and second years it was believed that the insects must have passed the summer as larvae or pupae and have just issued at the time of their appearance, therefore search was continued for larvae or pupae. Not until after the appearance of the moths in the fall of 1927 did it occur to the authors that a possible interpretation of the fact that the moths raised at the higher temperatures did not lay eggs, and on examination did not appear to have eggs to lay, was that these moths were going to pass the summer in a dormant condition, probably not developing eggs until they came out of aestivation at the proper time in the fall.

If the celery leaf tier aestivates in the adult stage, the moths may fly some distance—many miles if necessary—to find a satisfactory hiding place. If dryness and equable temperatures are the chief considerations, it is likely that such a position might be found under the drooping leaves of the tall cabbage palmettos (*Sabal*) that grow by the hundreds of thousands in the surrounding swamps (fig. 19). Opportunities for concealment could also be found in the haystacks, sheds, and similar places around the fields, or even under the ragged bark of the larger trees in the swamps.

In the season of 1925–26 no commercial damage occurred but local infestation appeared in a number of places. In one place the celery just adjoining a farmhouse was badly infested, the infestation extending out only a few rods and rapidly decreasing in intensity as the distance increased. The farmhouse had a bay window with an extremely heavy overhanging vine that would have afforded a very cool and dry shelter for the moths from the previous season. In another place the corner of the field next to a number of haystacks and an open shed was almost destroyed, but a little farther away the injury was slight, and at the other side of the field hardly perceptible. The first two moths found that fall were taken from the edge of a field under the shade of a cabbage palmetto. The next five

FIGURE 19.—Cabbage palmettos (*Sabal*) in a hammock bordering the celery-producing area.

were found alongside a rambling shed near the margin of a field. Hours of search in the remainder of these two fields did not reveal another moth. Moths have been seen in the early twilight, coming from the direction of a swamp and drifting steadily along a few feet above the freshly planted celery. No moths could be found in the field itself, but the celery bed that afforded shelter was heavily infested.

These data suggest that moths maturing in the increasing temperatures of the spring season are especially adapted to aestivation and that egg development does not take place until the next October, when temperatures are favorable. Aestivation of other insects under similar conditions is well known. The Colorado potato beetle (*Leptinotarsa decemlineata* Say) is a good example. The common June beetles (*Phyllophaga* spp.) finish feeding in the spring, remain dormant over the summer and winter, and emerge the next spring. Webster and Parks (*12*) show a partial aestivation of the serpentine leaf miner (*Agromyza pusilla* Meig.) in the Salt Lake Valley and quote Wildermuth as recording a complete aestivation of this species through the heat of the summer in Arizona. Marsh (*7*) states that the diamondback moth (*Plutella maculipennis* Curt.) is active throughout the year in the South, but in his long list of occurrences there are no records for extreme southern points in July and August. The present writers have found the diamondback moth swarming on cabbages in the winter, but its injury lessens in the spring, and it has not been found later in the summer. Boll (*2*) found the alfalfa caterpillar, (*Colias*) *Eurymus eurytheme* Bdv., active in Texas from November to the last of June, indicating that it aestivates there from July to November. Coad (*4*) states that the thurberia weevil (*Anthonomus grandis thurberiae* Pierce) hibernates in the cotton bolls and may remain there in a dry season until the rains of July or August, thus prolonging the hibernation into aestivation.

ALTERNATE HOSTS

TEMPERATURE RELATIONS OF SPECIES OF AMARANTH

The earlier harvested celery fields are usually planted to corn, but the later ones lie idle from late in May to September or October. The soil is rich with the residual fertilizer from the celery crop, and this, with the abundant rains of the summer, soon causes a luxuriant crop of weeds to cover the abandoned fields. Among these weeds the dominant species are a number of the subtropical " five-finger " grasses and two species of amaranth, *Amaranthus retroflexus* L., or pigweed, a species of almost world-wide distribution, with broad leaves and enlarged heads, and *A. spinosus* L., commonly called the " careless weed " or " thorny amaranth ", because of its heavy armament of very irritating spines. The latter is more tropical in its limitations than *A. retroflexus.* As will be shown later, these two plants are important links in the natural control of the celery tier. In a normal season *A. retroflexus* first appears in the sheltered spots around the celery fields the last of April, but only a small number appear in open fields until early in May. These are followed in a week or two by *A. spinosus.* The amaranth plants attain luxuriant growth by the time the amaranth leaf tier appears in June. As the later celery fields are abandoned and corn cultivation ceases, a continuous succession of young amaranth plants affords succulent foliage for the amaranth leaf tiers. The amaranth foliage is very tender, the first frosts destroy the upper leaves, and most of the plants are killed early. A few plants in sheltered locations survive the winter, but the foliage of these is much reduced and thickened and apparently is not palatable. The water hemp (*Acnida*), a still more succulent plant and adapted to wetter soils and cooler temperatures, often starts earlier in the spring, reaching a height of 10 or 15 feet in a few months. This plant grows in the rich muck soils along the edges of lakes and marshes and is often spoken of as a " careless weed." Late plants of this species and table beets are often food plants of the last of the amaranth tiers late in the fall and early in the winter.

COMPARISON OF CELERY AND AMARANTH SEASONS

Celery and amaranth represent almost the two extremes in plant adaptation to Florida temperatures. The celery plant for its normal growth is strictly limited to the winter season, or the period when the mean temperatures are below 74° F. (fig. 20). This season may be extended in favorable years by planting the celery before the temperatures become favorable, and the ripening crop can often be carried for a few weeks beyond this limit in the spring; but the favorable and safe season for celery production is from about October 10 to May 15. On the other hand, the amaranths flourish in the extreme heat of the summer. It is probable that their temperature limitations extend upward beyond that indicated in figure 20, but there is no method of determining this, as they have withstood all high temperatures that have occurred in Florida. Their minimum limitations are, however, very definitely marked. They do not appear in the spring until May and in the fall their growth

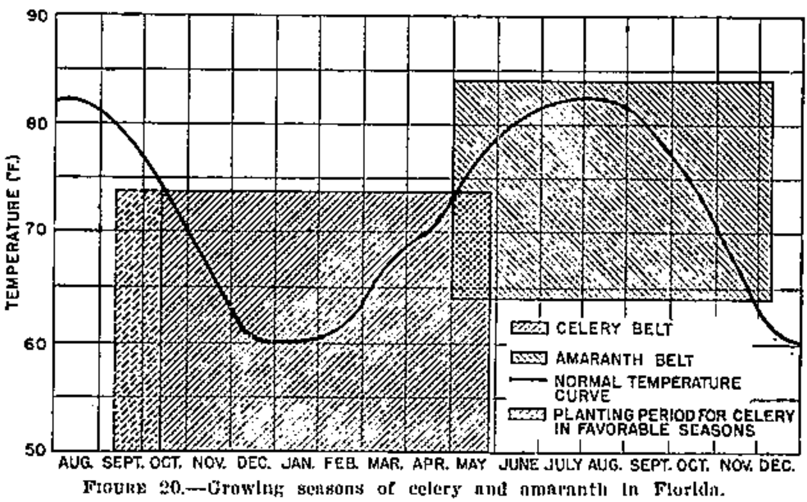

FIGURE 20.—Growing seasons of celery and amaranth in Florida.

is limited and their leaves are dwarfed, even when there is no frost. In order to make the growing season for amaranth strictly comparable with that for celery, the time when transplanted amaranth plants would thrive, rather than the time of normal germination, should probably be considered. This would very likely make the amaranth season begin in April.

LIMITING TEMPERATURES FOR AMARANTH LEAF TIERS

In the Sanford celery area four species of leaf tier are practically dependent upon amaranths for survival, although frequently they seriously injure table beets raised in the fall. These tiers are (1) the garden webworm (*Loxostege similalis* Guen.), (2) the spotted beet webworm (*Hymenia perspectalis* Hbn.), (3) the Hawaiian beet webworm (*H. fascialis* Cram.), and (4) the southern beet webworm (*Pachyzancla bipunctalis* Fab.). These tiers as a group are strictly limited to the summer season. They never appear until early in

June, become increasingly abundant during the hottest periods of summer, and disappear with the colder weather; or the last individuals may remain until the frosts of December kill their food plants. Different species apparently have different temperature reactions. *L. similalis* appears first and disappears before the hot weather. *H. perspectalis* is the next to appear and strips the leaves from large areas, becoming exceedingly abundant in July. It prefers the thicker and more luxuriant growths and its first stripping is always beneath the heavier foliage where it will not be seen. *H. fascialis* and *P. bipunctalis* appear at the same time, usually late in June, and increase in numbers until August, when they defoliate the later growths of amaranth. They prefer the more open growths and are especially abundant on isolated plants. Later in the fall there is usually another less severe outbreak of *H. perspectalis* and this is followed by *H. fascialis* and *P. bipunctalis*, which continue until frost eliminates their food plants.

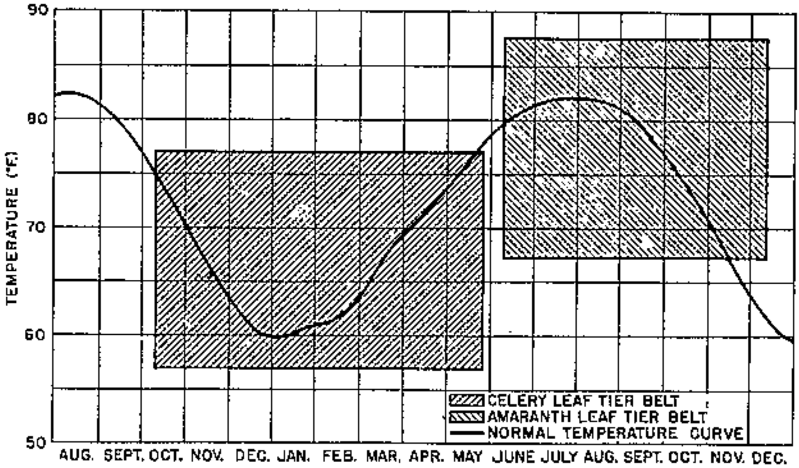

FIGURE 21.—Seasons of the celery leaf tier and the amaranth leaf tiers in Florida.

The eggs and larvae of these tiers are the summer hosts for the parasites and predators of the celery leaf tier and are an important factor in the natural control of the latter species, as will be shown in detail later.

SEASONAL RELATIONS OF CELERY AND AMARANTH LEAF TIERS

Under Florida conditions, the celery leaf tier has been shown to be strictly limited to the cooler months, whereas the amaranth tiers are as strictly limited to the summer period (fig. 21). This alternation of seasons is of importance in maintaining a constant supply of hosts for the parasites, and the overlapping of distribution in the fall is undoubtedly a major factor in the natural control of the celery leaf tier, as the rapid decrease in the numbers of the amaranth tier forces an immediate shift of the parasites to the relatively scarce, and at that time locally distributed, celery leaf tiers.

NATURE'S CHECKS TO MULTIPLICATION

INSECT PARASITES OF THE CELERY LEAF TIER

There are three parasites of the celery leaf tier in Florida that are factors in its control. Extended study is being made of their life histories, distribution, and biological relations, and especially of the possibility of artificial increase and dissemination. Only the broader biological applications and the importance of this factor in the natural control of the celery tier will be discussed in this bulletin.

LARVAL PARASITES

Two hymenopterous parasites that attack the larvae of the celery tier have been found. They have not appeared in sufficient numbers in the Sanford area to be more than a minor factor in control, but in certain critical periods they can be counted on as an aid in reducing the numbers of the tier.

The ichneumonid *Casinaria infesta* Cress., the more important of the two, attacks the larvae of many species of Lepidoptera. It is apparently adapted to even lower temperatures than is the celery leaf tier, appearing later in the season and disappearing early. As the celery leaf tier and the celery looper (*Autographa falcifera* Kby.) are practically the only larvae available during the major portion of the celery season, the activities of *C. infesta* are confined to these species, sometimes parasitizing 4 or 5 percent.

The braconid *Apanteles marginiventris* Cress., the other larval parasite, is much smaller than *Casinaria infesta* and is equally diversified in its host relationships. It disappears during the normal winter season and appears again in the spring, attaining its maximum abundance in April and May, in the latter part of the period of normal abundance of the celery leaf tier. This parasite continues throughout the summer in lessened numbers on the amaranth leaf tiers and is a constant but minor cause of reduction in numbers of the celery leaf tier. Parasitization by this species under the most favorable conditions has rarely exceeded 4 percent.

EGG PARASITES

Next to temperature the most important factor in the natural control of the celery leaf tier is the chalcidoid egg parasite *Trichogramma minutum* Riley. This species is widely distributed and attacks the eggs of many lepidopterous insects. It is active only in warm weather and in this region appears to be closely associated with the different species of amaranth leaf tiers. With the introduction of celery culture into Florida this insect found a new and valuable addition to its food resources. The eggs of the amaranth tiers are abundant on the few remaining leaves of the plants in the fall and the egg parasite increases rapidly in numbers. As many as 160 parasites have been reared from 100 tier eggs at the time the amaranth leaf tiers were disappearing for the winter and the celery leaf tier was just appearing. These parasites immediately transfer to the new host and may be counted upon to destroy from 70 to 90 percent of the eggs of the first celery leaf tier moths to appear, thus limiting the increase of this insect during the period of optimum temperatures in the fall.

C. O. Bare informs the writers that in his controlled-temperature experiments *T. minutum* did not lay eggs until the temperature reached 62° F. This agrees with the occurrence of the insect in the field. In a normal season the parasite practically disappears in December and does not appear again until April. On the other hand, during excessively warm winters of the years of heavy infestation by the celery leaf tier, when the mean temperatures range from 60° to 65°, *T. minutum* continues its activity, although in lessened numbers.

Under normal conditions *T. minutum* gradually multiplies from the time of its appearance in April until it becomes an important factor in control at about the time the celery leaf tier is disappearing in May and early in June. In 1926–27 the extraordinary temperatures of February permitted a rapid multiplication of this species, and by April it had become a major factor in reducing the numbers of the celery leaf tier. The temperatures were about 2 months ahead of normal, and the activity of the egg parasite and the disappearance of the celery leaf tier were in the same ratio. At about the time the celery leaf tier disappears the egg parasites transfer to the eggs of *Loxostege similalis*, the first of the amaranth leaf tiers to appear in the spring, and by the time the other tiers become abundant egg parasitization frequently runs to 90 percent or higher. The succession of different amaranth leaf tiers, however, carries the egg parasite through the summer season, and it is widely distributed and abundant in the fields when the fall drop in temperature brings out the celery leaf tier.

BIRDS AS A CONTROL FACTOR

In a normal season birds are the third most important factor in the control of the celery leaf tier, and for about 5 or 6 weeks in the spring they constitute the major control. During this critical period the rising temperatures no longer inhibit the growth of the tier, but are not yet high enough to be favorable to the egg parasite. F. M. Uhler was detailed by the Bureau of Biological Survey of the United States Department of Agriculture to investigate the relationship of birds to the celery leaf tier, and spent the latter half of February and the first part of March 1927 in the field. The temperatures during this period were from 5° to 7° above normal, and one of the most serious outbreaks of the leaf tier ever recorded occurred, making this an opportune time for Mr. Uhler's study. However, as this was one of the most abnormal winter seasons in Florida in many years, it did not give a true picture of the normal conditions.

In the spring of 1928 Mr. Uhler spent a much longer period in the celery fields. The mean temperature of this season was below normal and the tier was practically controlled by natural factors. The relative numbers of the different species of birds and the time they spent in the celery fields were quite different from those of the previous year, but their importance in the critical spring period was again demonstrated.

The migratory birds remaining in Florida in the fall, or those passing through Florida on their way farther south, have traversed regions of abundant food and are therefore well nourished. They arrive in Florida at a time when there is an abundance of insect life of all kinds in the woods and swamps and when the celery has just been planted and few pests have been established in the fields. These birds rarely visit the fields and are of little economic importance. But when the returning migrants reach this section of Florida in the spring, they have just completed a long ocean flight and arrive hungry and more or less exhausted at a time when insect life in the swamps is dormant; when even in the drier and more sunny sections of the open woods the vegetation is scarcely starting to grow, and insect life is at a minimum. The birds that make Florida their winter home have already reduced the edible insects in the woods to a minimum. On the other hand, the fields are crowded with celery in which the celery looper and the celery leaf tier are rapidly increasing in numbers. The celery plant and its two insect pests are adapted to the moderate summer temperatures of the extreme northern section of the United States and therefore find in this early spring season temperatures favorable to their development at a time when the native insects and native plants, adapted to much warmer temperatures, are still more or less dormant. The birds are thus forced to the celery fields for their food supply.

The yellow palm warbler (*Dendroica palmarum hypochrysea* Ridgway), one of the most important of the 20 or more species of birds that Uhler lists as visitors of the celery fields, appears early in the spring and for a month and a half is found throughout the section. It feeds on the larvae and adults of the celery looper and the celery leaf tier and may be seen at any time resting on the tops of the celery stalks or running along under the shelter of the rows, picking up worms, pupae, and moths. When food is scarce rows of these birds are often seen perched on the empty crates just back of the harvesters and when a moth is shaken out of the celery there is a dash and a snap, then the bird is back on its perch again.

The tree swallow (*Iridoprocne bicolor* Vieillot) is the second most important bird enemy of the leaf tier under normal conditions and during the serious infestation of 1928 it was probably the most important. These birds fly over the marshes in immense flocks, gathering the myriads of gnats, but when any spraying or dusting machine appeared in the celery fields and disturbed the moths, numbers of these swallows encircled the machine, picking up nearly every moth that was dislodged. After the introduction of pyrethrum for control, the importance of the swallow was materially increased. Dusting with pyrethrum, under favorable conditions, was highly effective in killing the larvae of the tier, but it killed only a small percentage of the moths, large numbers flying up to escape its fumes and darting back into the celery at some little distance, only to appear again and repeat the performance until they escaped from the dusted area. With the appearance of the pyrethrum duster in the fields the swallows came in even greater numbers and hung over the fields for hours, skimming just above the celery and snapping up the moths as they appeared. By dusting at a time in the day when the swallows were in the fields it was possible to eliminate practically all the moths, as well as the larvae. The swallows remained for some time after the last of the warblers and pipits had gone, but their numbers continually decreased.

The pipits (*Anthus* spp.) range the fields, picking up the worms that have been shaken out of the celery and often foraging in the growing crop.

In the smaller celery fields, more or less surrounded by woods, birds were usually sufficiently abundant to hold the pests (the celery looper and the leaf tier) in check. On the other hand, in the more concentrated areas where few shrubs remain that could afford shelter for the birds, the numbers were smaller and the pests gained headway.

The grackles (*Quiscalus* spp.), the red-winged blackbird (*Agelaius phoeniceus* L.), and the eastern cowbird (*Molothrus ater ater* Boddaert) visited the fields in large flocks and contributed materially to the reduction in the number of leaf tier larvae. Late in the season, after most of the other migratory birds had left for the north, the resident birds, such as the eastern mocking bird (*Mimus polyglottos polyglottos* L.), the meadowlark (*Sturnella magna* L.), and the remaining grackles were constantly searching the few unharvested fields for larvae to feed to their nestlings. A continuous succession of these birds could be seen flying from their nesting places directly to the fields and returning with green worms hanging from their bills. Their flight was always an air line for the nest. At this time large flocks of returning bobolinks, or rice birds (*Dolichonyx oryzivorus* L.), were cleaning up the last of the worms before continuing their migration northward.

DISEASES AFFECTING THE LARVAE

A bacterial disease frequently attacks the celery looper in the spring and completely destroys that pest. The disease sometimes spreads to the celery leaf tier; however, as it is apparently effective only under rather exceptional conditions of temperature and moisture not yet well understood, and as the tier does not appear in considerable numbers until after the favorable conditions for the development of the disease have passed, its control of the leaf tier is only rarely effective. Attempts to grow and distribute this disease have not proved successful.

A fungus disease has also been noted attacking both the looper and the tier in the field, but it is of even less importance than the bacterial disease.

PREDACIOUS INSECTS AND SPIDERS

Predatory insects and spiders abound in subtropical climates, but most of the species found in Florida are adapted to activity in the summer and are relatively quiescent during the winter. Certain paper wasps (*Polistes canadensis* var. *annularis* L.) and digger wasps (Fossores) are very active on the amaranth leaf tiers and on the southern armyworm (*Prodenia eridania* Cram.) in the summer season, but their activity ceases at about the temperatures favorable to the celery leaf tier, therefore they are a minor factor in the direct control of this pest and are injurious insofar as they reduce the numbers of the other pests that support the parasites of the leaf tier over summer. Species of stink bugs (*Stiretrus anchorago* Fab.

and *Alcaeorrhynchus grandis* Dall.) feed actively on amaranth leaf tiers and armyworms in the summer outbreaks, but, although they occasionally appear in the celery fields, their work is of relatively little importance. Certain spiders are found in the celery fields and are active most of the season. They undoubtedly are a factor in the reduction in the number of moths and worms, and in the early fall, when the egg parasites have reduced the number of larvae to a minimum, they may be of considerable importance. The number of tier larvae reaching maturity from the first-brood eggs is exceedingly small.

The predators all together are probably injurious, as their reduction of the number of summer hosts of the parasites of the celery leaf tier overbalances their effectiveness on the tier itself.

THE BALANCE OF NATURE

The relative importance and periods of activity of the different factors that contribute to the natural control of the celery leaf tier

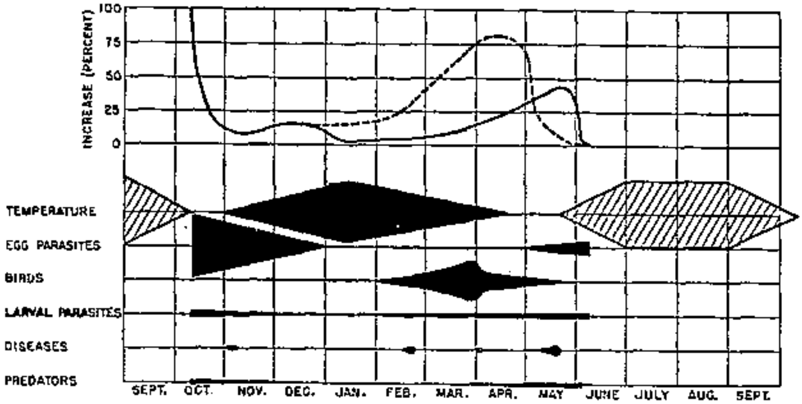

FIGURE 22.—The balance of nature. The relative importance and period of activity of the various factors in the natural control of the celery leaf tier. The black line represents the rate of increase of the tier in a normal season as affected by various factors shown below it. The broken line represents the variation caused by an exceptionally warm winter.

have been brought together in graphic form in figure 22. Under favorable conditions the female tiers lay from 180 to 280 eggs, or an average of about 230, making it possible for one pair of celery leaf tiers to produce a one hundred and fifteen fold increase. There are about four generations in a normal season. A single pair of celery moths appearing on October 10 would, therefore, if their descendants all survived, produce more than 200,000,000 larvae to attack the celery crop in May—an army that could seriously injure about 400 acres of celery. Such a multiplication is represented by 100 percent in figure 22. The celery leaf tier, appearing in a normal season at the first marked drop in temperature after October 10, encounters the controlling factors shown in the lower part of the diagram. The time of action of these factors is indicated by their positions, and their importance is indicated by their relative widths. Their importance in a normal season is indicated by their rank, the more important being placed above.

It will be noted that the curve of increase of the celery leaf tier, starting at 100 percent on October 10, rapidly falls to a very low figure. The activity of the egg parasite is the major factor in this immediate drop. As the lower temperatures appear the value of the egg parasite decreases and the multiplication of the tier increases for a short period. The retarding effect of the temperatures continually increases until after the first of January, and reduces the multiplication of the tier to a minimum again. Beginning in February, after the temperature has become more favorable, the migratory birds appear and in March they become the important control factor. By April the temperature is nearly at an optimum for the celery leaf tier, most of the birds have departed, the parasites have not appeared, and the tier increases rapidly in abundance. About the first of May the egg parasites again appear in economic numbers and, as they increase with about the same rapidity as the tier, the latter does not increase further in rate of multiplication. Before the first of June the parasites and the unfavorable high temperatures cause a decline in the tier population, which terminates abruptly with the disappearance of the pest into summer quarters.

The broken line beginning in December (fig. 22) indicates the relative activity of the tier under the favorable conditions of an extremely warm winter. When the low temperatures of December have reduced the egg parasites to a minimum and January temperatures have been favorable for the tier, the latter gains in numbers and continues to increase throughout the rest of the season. Under such conditions the number of moths and worms in the fields in March is so great that the migratory birds take all they want and still leave an abundance to reproduce and continue the injury, and a destructive outbreak develops. If the temperatures continue above normal the egg parasites will increase in numbers and reduce the infestation before the end of the season, but if temperatures drop back relatively close to normal again the egg parasites will be retarded and the injury will continue to increase unless control measures are employed.

ECONOMIC FACTORS

CONCENTRATION OF INFESTATION

For the first 4 months, or until the first of February, the distribution of the celery tier in the fields is roughly proportionate to the age of the celery. About this time, however, the harvesting of the older celery proceeds more rapidly than the planting of the new, and the area in celery, which has been constantly increasing up to this time, begins to diminish and is steadily reduced until the close of the season in May or early in June. As a field of celery is harvested, the moths are constantly forced back into the unharvested portion, or they may drift with the wind to other fields. In any case, at the end of the harvest of a field the moths are forced out of that field into the adjoining celery. They pass over the younger celery and congregate in the older, to be forced out again as these fields are harvested. As this process continues the concentration increases rapidly (fig. 23) until what might have been a relatively minor infestation, if uniformly distributed over an area, becomes seriously injurious where the concentration is highest.

With moths flying at all times, it would naturally be expected that a constant succession of young worms would be found in the field. Instead the worms are usually practically uniform in size, the size being determined by the time of harvesting the adjoining field. If the moths are forced into the field more than 6 weeks before the celery is harvested, the ensuing generation of worms will mature, if the temperatures are favorable, and produce moths to infest other fields. If, on the other hand, the infestation occurs less than 6 weeks before harvest, in the February and March period, most of the worms or pupae will be shaken out of the celery in handling and will be destroyed by the birds, and the remainder will be shipped. Therefore little, if any, concentration in other fields results. Later in the season, in April and May, the life cycle of the tier is shorter, and by this time practically all of the celery has been infested by concentration and by the normal migration from one field to another.

In years in which the temperature is below normal, a longer time is required for worms to mature and few of them ever reach matur-

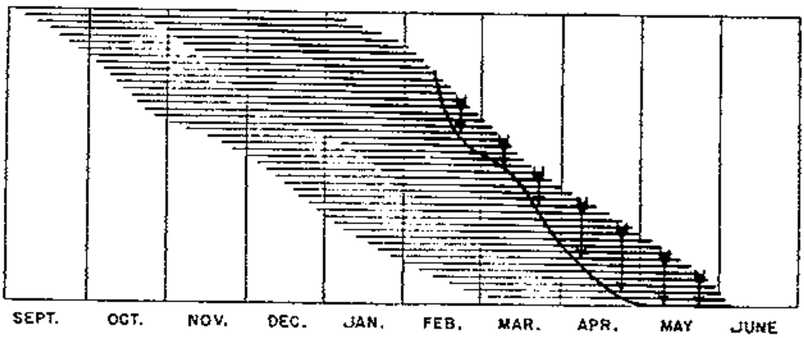

FIGURE 23.—Concentration of infestation by the celery leaf tier in celery fields in Florida. The horizontal lines represent successive plantings of celery, from the time of transplanting to the end of harvesting. The light part of each line represents small, the central part medium-sized, and the heavy part maturing celery. The proportion of each line at the right of the curve indicates the increasing number of moths migrating from the later plantings at the time the celery is harvested.

ity before the celery is harvested. Under such conditions concentration is relatively unimportant and, except in isolated cases, may be neglected. Figure 23 graphically illustrates the concentration process and a glance down any given date line will show approximately the amount of celery of different ages in the fields in a normal season.

In an exceptionally warm season concentration of infestation is an increasingly important factor from the beginning of February until near the end of the season (when the few remaining fields are more or less isolated) and special precautions should be taken to prevent the concentration or to protect invaded fields.

SEASONAL GROWTH OF THE CELERY PLANT

When the celery plant is taken from the crowded seed bed and transplanted to the field it is a spindling plant 4 inches or more in height, with 3 or 4 very small leaves. These plants are set in rows 30 inches apart and spaced about 4 inches in a row, making about

50,000 per acre. At first these plants usually wilt down in the daytime but in a few days they straighten up, the older leaves dying. At this time a field offers no shelter for the moth of the celery leaf tier and only under exceptional conditions is such celery infested.

The development of the young celery plant is rather slow at first. It scarcely increases in height for some time, but forms a semirosette type of structure. After about 2 months it is usually large enough to afford shelter for the moths and begins to have the celery odor, which is probably a factor in attracting them. In a few weeks more it has acquired a well-developed root system and is capable of utilizing the fertilizer that is now applied, and growth from this time on is very rapid. The length of time it is left in the

FIGURE 24.—End view of a row of celery, showing the canopy of leaves covering the secondary growth around the heart.

field depends upon weather conditions, and probably even more upon market price. In general, about 4 months is required for the crop to reach maturity.

A cross section of a fully developed celery row is illustrated in figure 24. This shows the perfect canopy of leaves over the top and the group of secondary leaves just above the heart of the celery. The leaves exposed to the sunlight become deep green and are not attractive to the worms of the leaf tier, although the celery looper feeds on them from preference. Extensive counts have shown that the eggs of the celery leaf tier may be deposited on the under side of the leaves, anywhere on the plant. The larger proportion, however, are deposited on the secondary leaves under the cover. The small worms hatching from the eggs on the outer leaves usually migrate within a few days to the more tender leaves in the cluster about the heart.

The almost complete canopy over the celery row (fig. 24) makes the thorough application of any liquid spray a very difficult matter. The celery stalks are very brittle and any attempt to draw them over will result in breakage, and without displacing the cover a proper distribution of spray material on the secondary leaves is very difficult. On account of the peculiar nature of this canopy it is probable that dusting will be more successful than spraying in the control of many celery pests.

THE PERCENTAGE OF ORIGINAL LEAVES OF THE CELERY PLANT USED AS FOOD

In order to determine at what time in the growth of the celery plant the application of remedies that would leave poisonous residues

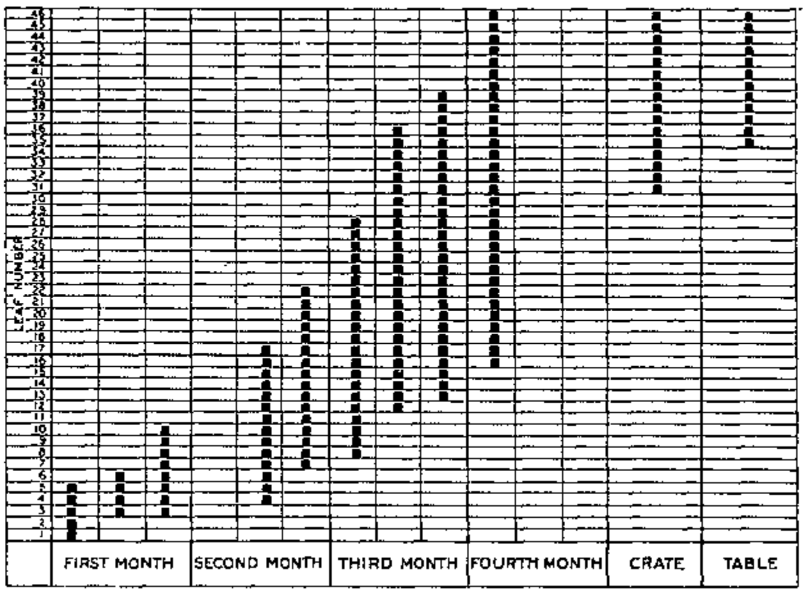

FIGURE 25.—Rate of development and death of successive leaves on a celery plant, and the number of leaves on the plant when in the crate and when prepared for the table. The first 15 leaves died before the plant was taken up, and 15 more were removed before it was placed in the crate.

on the plant must be discontinued, a careful and detailed study was made of the ultimate fate of each leaf that developed on the average celery plant from the time of transplanting to early maturity. The results are shown in figure 25, from which it is seen that the outside leaves are continually dropping off as new ones push up from within. Only 3 of the leaves produced in the first month survived after the second month, and only 7 produced in the second month survived after the third as functional leaves on the plant, and all of these and 8 more were stripped off in preparing this celery for the crate. This celery was harvested at the end of the first 10 days of the fourth month—really before it was ready for market. It would have been much larger in size and of much better quality had it been allowed to stand the normal period of 4 months, but even with this extremely early harvest not a single leaf that was aboveground on the plant at the end of the second month appeared in the crate; in fact only those leaves that had developed within 30 days were found in the crate, and it is probable that this would have been true had the celery been allowed to grow 20 days longer. In preparing the celery for the table a still further elimination of the outer leaves is made; therefore celery as served appears to be made up almost entirely of leaves that developed in the last 20-day period of normal growth.

From this study it is evident that any arsenical applied to the celery during the first or second month of growth will not be carried over into the harvested crop. Although of little importance in the control of the leaf tier, as that insect attacks the plants during the last 2 months of growth, this fact is of vast importance in pointing the way to a safe and satisfactory control of the cutworms and the southern armyworm, which attack early celery in the fall.

APPLICATION OF ARSENICALS

The standard remedy for the control of leaf-feeding caterpillars has long been the application of some arsenical compound, either in the form of spray or dust. When the worms first appeared in serious numbers in the fields at Sanford, applications of arsenicals were tried. The spray outfits in use in the fields were of the gear-driven type, excellently adapted for the application of bordeaux mixture or other fungicides, but lacking in power to drive an arsenical in through the leaf canopy of the nearly mature celery to the secondary leaves, where the worms were feeding. Growers who succeeded in reaching the celery hearts, either by increasing the power of the sprayer or by dropping the nozzles below the leaf canopy, were successful in control; but they found arsenical residues remaining on the celery at harvest time. In many instances these residues reduced the salability of the crop even more than damage by worms would have done. It was found later that the excess of arsenic could be removed by especially designed washing equipment.

In most of this work calcium arsenate was the arsenical used. A few growers mixed paris green with bran to form a poisoned bait which they scattered in the rows, but this tended to gather in the base of the stalks and, as the bran swelled in the washers, it was very difficult to remove. Others attempted to use paris green and molasses in a liquid spray, but in several instances this caused burning.

Some carefully conducted laboratory tests were made of the relative killing efficiency of calcium arsenate and paris green, and it was found that even where leaves were thoroughly dusted with calcium arsenate and larvae of the tier were compelled to feed upon them, it took a long time to kill them, whereas worms on leaves similarly treated with paris green died very quickly. For example, if worms feeding on leaves dusted with calcium arsenate were removed at the end of 4 days to foliage that had not been poisoned the worms all survived and matured, but those in the paris green experiment soon ceased feeding, began to die at the end of the second day, and by the fourth day most of them were dead—even those removed to fresh nonpoisoned foliage soon died. This may in part explain why such excessive quantities of calcium arsenate were required to bring about a control of the pest.

USE OF LIGHT TRAPS TO COLLECT MOTHS

R. H. Muirhead, who had experimented with light traps during previous outbreaks, stated that he had caught a large number of moths of the celery leaf tier. F. H. Lathrop was detailed by the Bureau of Entomology to make a study of the value of light traps during the winter season of 1925–26. Dr. Lathrop tested the relative value of different colored lights, but unfortunately there were few moths during the period of the test. When the moths began to be abundant in the spring of 1927 the writers induced Mr. Muirhead to start his trap lights again. Each light consisted of a 72-watt electric light suspended over a washtub placed about 4 feet from the ground. The tub was filled with water to within a few inches of the top, with a film of kerosene on the surface; then the light was lowered to within about 2 inches of the level of the water. Two trap lights were similarly placed in a 3-acre field of celery and the current was turned on at dusk and shut off in the morning. At first the two lights were of the same height. In order to test the value of different heights one light was lowered to within about 2 feet of the ground. From that time on the higher light always caught the larger number of moths. The moths apparently flew directly to the light and most of them, in attempting to pass under it, struck the kerosene film at once.

These two trap lights were operated on the favorable evenings over a 50-day period, from February 20 to April 10, when the celery was harvested. Not counting a few cold windy nights on which the lights were maintained in order to determine their value under such circumstances, there were 23 favorable nights during the period; and 49,600 celery tier moths were collected, or an average of a few more than 1,000 per night for each light. The maximum catch for one night was 4,500. A number of the major catches were sorted as to males and females. In one of the largest catches there were twice as many females as males; in some of the other catches 60 percent were females. The number of eggs in the females varied at different periods. At the end of a brood the majority of the females contained relatively few eggs; on the average, 20 percent appeared to have a full supply of eggs, 70 percent had one-half supply or more, and only 10 percent had laid all their eggs. The moths had apparently developed in this field at a rate ranging from 25,000 to 50,000 per acre; therefore, the total catch represented about one-half of the population. This result does not compare favorably with the effectiveness of pyrethrum dusting combined with the activity of swallows in eliminating the moths, but it might be found profitable in areas where boarded celery was becoming heavily infested from concentration.

CONTROL WITH PYRETHRUM DUST

Pyrethrum had been recommended by the Bureau of Entomology and was in use by a few of the celery growers prior to the season of 1925–26, but the post-war price of this material practically prohibited its use. By the time of the outbreak in the spring of 1927 the price had been reduced to about 32 cents a pound for the better grades. Careful tests were made of the killing efficiency of different quantities of the dust and of different times and methods of application. It was found that from 40 to 50 pounds per acre was required for satisfactory control of the worms. The ordinary horse-drawn dusters are capable of distributing only about 20 to 25 pounds to the acre in 1 application; therefore, the application to an area was repeated within 30 minutes or an hour. One double application, costing about $16 per acre for material, if applied under favorable conditions, would practically eliminate the worms for the time. The pyrethrum had no appreciable effect on the eggs or on the pupae, and its effect on the moths depended upon a number of variable factors and was hard to estimate. In most cases a small percentage of the moths were actually killed. Others were found on the ground or in the crotches of the plant, unable to fly, but these usually recovered later. About the time of this experiment it was discovered that if the dusting was done at a time when the swallows were in the field, the moths flying up to escape the pyrethrum fumes would be snapped up by the swallows; by keeping this factor in mind and timing the dusting, 80 or 90 percent of the moths could be eliminated within the day or two in which the dust appeared to remain sufficiently concentrated to be repellant to them. The most effective of these treatments left eggs in the field and often left pupae that would soon appear as moths; therefore, a second application within 10 days or 2 weeks was necessary in order to reduce the numbers permanently. In the latter part of the bad seasons the continual concentration of moths, owing to the decreasing acreage of celery, caused continuous reinfestation, and repeated applications of pyrethrum were necessary.

RELATIVE AMOUNT OF FOOD CONSUMED BY LARVAE AT DIFFERENT STAGES OF GROWTH

A careful study was made of the total amount of food necessary for the development of the average tier from the egg to the pupal stage. This amount appeared to be relatively constant, regardless of whether the worm grew rapidly under favorable temperatures or more slowly during the winter period. The striking thing was the relatively small amount of food consumed in the beginning and the proportionately large amount consumed in the last few days of growth. Figure 26 illustrates this graphically, showing that during the first week the total amount consumed was insignificant; the second week it was barely noticeable; during the third week the worm began to develop an appetite; and in the 5 days of the fourth week it consumed more food than it had done in all of its previous feeding. The total amount of celery leaf consumed by a worm was about 2¼ square inches. About 1 square inch of this was eaten in the first 3 weeks and the remainder in the last 5 days. A rapidly growing celery plant would not be materially affected by the loss of an inch of leaf surface in a 3-week period, but when the larger worms concentrate in the small group of leaves above the heart and destroy the leaves at the rate of 1 square inch per worm every 4 days, webbing and filling the remainder with an unsightly mass of frass, the situation becomes alarming, for the result of such feeding is disastrous.

WHY A VARIATION OF 1° OR 2° FROM NORMAL MEAN TEMPERATURE MAKES THE DIFFERENCE BETWEEN NO INJURY AND A SERIOUS OUTBREAK OF THE CELERY LEAF TIER IN FLORIDA

To anyone accustomed to working with insects during the summer season in the northern latitudes the statement that a variation of 1° or 2° in mean temperature will make all the difference between a serious outbreak and no commercial injury sounds incredible, and would be with respect to insects under northern conditions. In northern latitudes insects are working at temperatures fairly near optimum throughout a very large portion of the summer season. A variation of 1°, 2°, or even 4° or 5° would make no appreciable difference in their development under these conditions. But if these insects should be transferred to the winter season in Florida, they would be normally working very close to the minimum limit of their adaptation, and a permanent lowering of the temperature by 2° would usually result in their elimination; the raising of the temperature 2° would, on the other hand, tremendously increase the rapidity

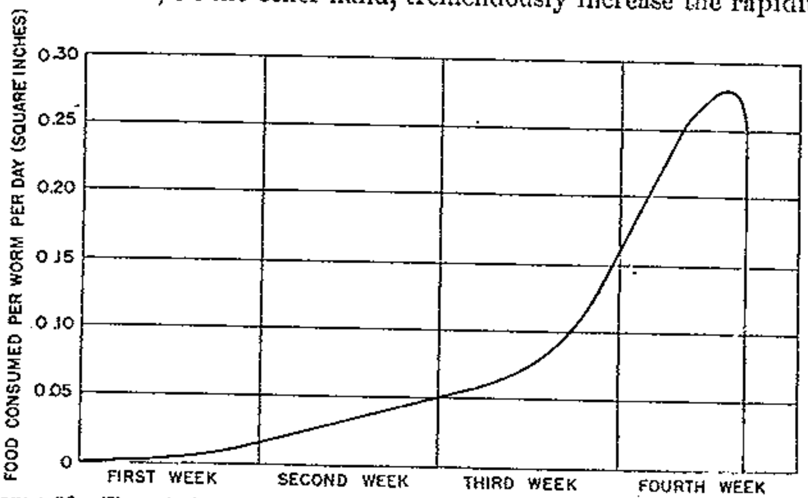

FIGURE 26.—The relative feeding capacity of a celery leaf tier worm at different ages.

of their development. Even so, such a statement would not be made with respect to the celery leaf tier if the truth of it had not been tested time and again and in very different ways. A difference of 2° in the normal mean winter temperature has invariably made the difference between an outbreak and no commercial injury. A similar difference in the mean temperature of different sections of the same area has meant the same in the sections affected. A mean temperature, especially in winter, is computed from widely fluctuating maxima and minima, which in themselves vary greatly from week to week, as successive northers sweep across the continent; they also vary from year to year. Yet the fact remains that a given mean temperature has produced a given result, whether the mean is obtained from a constant-temperature apparatus or is computed from a 40-degree range of variation.

There are, however, certain factors that contribute materially to the extreme sensitiveness of the celery leaf tier to temperature. First, there is the remarkable lengthening of the life period of the celery leaf tier as soon as the temperature drops appreciably below 60° F. (fig. 16). A drop of 20° from a temperature near 80° or 90° does not make half so much difference in the length of the life cycle as does a change of 2° near 55°. On the other hand, a change of 2° or even 5° near 55° makes comparatively little difference in the rapidity of growth of the celery plant. It has been noted that at the normal mean winter temperature of the celery areas the tier requires almost exactly 2 months to mature and that the moths rarely deposit eggs in the celery before it is half grown. Therefore the race between the celery and the tier as to which will mature first is almost even, with all the advantage to the celery as the temperature falls even 1° or 2°. If the tier matures before the celery is harvested, the moths will be able to fly to other fields and continue the infestation. If, on the other hand, they fail of maturity by even 2 or 3 days they will be shipped with the celery or shaken out in the field to be destroyed by the birds or plowed under with the leaves, and relatively few of them will survive to mature and reproduce. This almost hair-trigger balance between the rates of maturity of the celery and of the tier is the chief factor in producing this remarkable difference in the effect of slight variations in mean temperature.

The second and almost equally important factor is illustrated in figure 26. As the celery approaches maturity it may carry as many as 40 or 50 small worms to a plant without showing appreciable signs of injury. On celery harvested any time within 2 weeks of their appearance, the injury will be scarcely noticeable. On the other hand, celery boarded for bleaching in the middle of the third week after these worms appear and left the normal 10-day period might be entirely destroyed by these ravenous worms in their last few days of feeding. If the celery is harvested in the first 2 weeks, there will be no suggestion of an outbreak; but if harvested in the fourth week, with exactly the same number of worms of the same generation, the infestation would be serious. Whether or not the worms reach this final feeding stage depends entirely on the variation in temperature, and a difference of 2° is amply sufficient to make a difference of 10 days in their maturity.

This remarkable influence of so slight a temperature change cannot, therefore, be translated into general terms or made applicable to any other insect or condition. It is the result of a peculiar combination of factors strictly limited, so far as now known, to the growing of winter celery under Florida conditions.

SUMMARY AND CONCLUSIONS

The sudden and unprecedented increase in the numbers of the celery leaf tier in the Sanford, Fla., celery-producing area in 1923 and 1925 indicated that there had been a radical departure from the normal in one or more of the factors entering into the balance maintained by nature.

In a 3-year study of the problem the authors worked out an extremely complicated biological complex involving 2 host plants for leaf tiers, 3 parasites, several birds, 2 diseases, and a number of predators, all intimately associated in an unstable balance largely influenced by temperature factors. The detailed results of a number of these studies have been prepared for separate publication, and only their broader biological aspects are included in this bulletin.

The three most important factors, arranged in order of importance, were:

(1) Temperature. A fluctuation of 1° or 2° from the normal mean temperature of the 3 winter months (December, January, and February) was found to make the difference between serious infestation and no commercial injury. This almost hair-trigger reaction was the result of a number of interacting factors, the most important being the time required to mature a celery crop as compared with the time required to mature a brood of worms.

(2) The egg parasite *Trichogramma minutum*. This insect multiplied in the rising temperatures of the spring and materially reduced the numbers of the leaf tiers. After the celery tier disappeared, it parasitized the eggs of the amaranth tiers and, increasing in numbers during the late summer, was able to practically annihilate the eggs of the first brood of celery tiers to appear in the fall.

(3) The migratory birds wintering in the region, or on their way north in the spring, cleaned the worms and pupae of the celery leaf tier and celery looper from the isolated fields and those adjacent to woods or other favorable shelters. In the solidly planted areas where there were no shelters the birds were less numerous and did not hold the worms in check. The swallows encircled the machines that were distributing pyrethrum dust and skimmed over the dusted fields, capturing 80 or 90 percent of the moths as they flew up to avoid the fumes.

The factors entering into the natural balance were able to reduce the numbers of the celery tier to a minimum in normal seasons, but when one warm winter season followed another the tier was able to increase to injurious numbers. When there were three warm winter seasons in succession the damage was extremely severe. A study of winter temperatures indicated that such a combination would very rarely occur.

The proper use of pyrethrum dusts, with the applications so timed as to utilize the activities of the swallows in catching the moths, controlled even the worst outbreaks.

LITERATURE CITED

(1) BALL, E. D., BOYDEN, B. L., and STONE, W. E.
1932. SOME MAJOR CELERY INSECTS IN FLORIDA. Fla. Agr. Expt. Sta. Bull. 250, 22 pp., illus.

(2) BOLL, J.
1880. UEBER DIMORPHISMUS UND VARIATION EINIGER SCHMETTERLINGE NORD-AMERIKAS. Deut. Ent. Ztschr. 24: [241]-248.

(3) CAMPBELL, R. E.
1927. THE CELERY LEAF-TYER, PHLYCTÆNIA RUBIGALIS GUEN., IN CALIFORNIA (LEP). Pan. Pac. Ent. 4: 77-84, illus.

(4) COAD, B. R.
1915. RELATION OF THE ARIZONA WILD COTTON WEEVIL TO COTTON PLANTING IN THE ARID WEST. U.S. Dept. Agr. Bull. 233, 12 pp., illus.

(5) CORBETT, L. C., GOULD, H. P., ROBINSON, T. R., DARROW, G. M., HUSMANN, G. C., REED, C. A., SHOEMAKER, D. N., HUNN, C. J., BEATTIE, J. H., BEATTIE, W. R., and FLOHR, L. B.
1926. FRUIT AND VEGETABLE PRODUCTION. U.S. Dept. Agr. Yearbook 1925: 151-452, illus.

(6) FINCH, V. C., and BAKER, O. E.
1917. GEOGRAPHY OF THE WORLD'S AGRICULTURE. U. S. Dept. Agrl., Off. Sec., 149 pp., illus. Washington, D.C.

(7) MARSH, H. O.
1917. LIFE HISTORY OF PLUTELLA MACULIPENNIS, THE DIAMOND-BACK MOTH. Jour. Agr. Research 10: 1–10, illus.

(8) OSBORN, H., and BALL, E. D.
1897. CONTRIBUTIONS TO THE HEMIPTEROUS FAUNA OF IOWA. Iowa Acad. Sci. Proc. (1896) 4: 172–234, illus.

(9) STONE, W. E., BOYDEN, B. L., WISECUP, C. B., and TATMAN, E. C.
1932. CONTROL OF THE CELERY LEAF-TIER IN FLORIDA. Fla. Agr. Expt. Sta. Bull. 251, 23 pp., illus.

(10) THOMPSON, H. C.
1929. PREMATURE SEEDING OF CELERY. N.Y. (Cornell) Agr. Expt. Sta. Bull. 480, 50 pp., illus.

(11) WARD, R. DEC.
1921. SOME CHARACTERISTICS OF UNITED STATES TEMPERATURES. U.S. Monthly Weather Rev. 49: 595–606, illus.

(12) WEBSTER, F. M., and PARKS, T. H.
1913. THE SERPENTINE LEAF-MINER. Jour. Agr. Research 1: 59–88, illus.

(13) WEIGEL, C. A., BROADBENT, B. M., BUSCK, A., and HEINRICH, C.
1925. THE GREENHOUSE LEAF-TYER, PHLYCTAENIA RUBIGALIS (GUENÉE). Jour. Agr. Research. 29: 137–158, illus.

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