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Seasonal Variation of Degree-Day Accumulation in Relation to Phenology of Western Spruce Budworm, Douglas-Fir Tussock Moth, and Host Trees in Northeastern Oregon

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Abstract

The annual variation of degree-days and early summer phenology of Douglas-fir tussock moth, western spruce budworm, and their host trees was monitored over five to six seasons at two locations in the Blue Mountains. Accumulated degree-days and the phenology of bud burst and larval development were consistent and comparable at the two sites. Either degree-days or shoot elongation can be used to time simultaneous larval sampling of these two insects.

Keywords: Phenology, grand fir, Douglas-fir tussock moth, western spruce budworm.

Introduction

The phenology of Douglas-fir tussock moth *(Orgyia pseudotsugata* (McDunnough)) and the apparent synchrony of egg eclosion with host bud burst was described for northeastern Oregon by Wickman (1976). Recently, Beckwith and Kemp (1984) developed shoot growth models for Douglas-fir *(Pseudotsuga menziesiivar. glauca* (Beissn.) Franco) and grand fir *{Abies grandis* (Dougl. ex D. Don) Lindl.). This work led to development by Kemp and others (1986) of a stochastic phenology model for the western spruce budworm *{Choristoneura occidentalis* Freeman). Earlier phenology studies of western spruce budworm and host trees in northeastern Oregon were conducted by Wagg (1958). None of these studies considered phenological variation over five or six seasons or the comparative larval development of Douglas-fir tussock moth and western spruce budworm in the same host trees.

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The use of lower crown sampling techniques for Douglas-fir tussock moth and western spruce budworm larvae on the same host trees in northeastern Oregon by Mason (1987) and Mason and others (in press) depends on proper timing to coincide with the desired phenological stage of both insects and the two host trees. Seasonal variation provides an additional factor to consider when sampling dates for this technique are being predicted.

Variation of phenological events over a five-season period was studied for Douglas-fir tussock moth and white fir *(A. concolor(*Gord. and Glend.) Lindl. ex Hildebr.) in southern Oregon (Wickman 1981). In that location, little variation in degree-days for particular phenological events was found for the seasons of 1976-80, but there was a range of 154 degree-days (Fahrenheit) and 7 calendar days for development to Douglas-fir tussock moth egg eclosion and larval dispersal.

This note describes the relations among the phenology of Douglas-fir tussock moth, western spruce budworm, and their host trees and the accumulation of degree-days in the late spring-early summer period. The data are based on measurements at the same sites from 1982 to 1987.

Methods

Monitoring Plots

Monitor sites were located northwest and west of La Grande, Oregon, near the crest of the Blue Mountains. Each site was also the location of an insect population study-impact plot. Two locations were sampled:

Y-Ridge—8 air miles northwest of La Grande; Wallowa Whitman National Forest; 4,150-foot elevation; slight western exposure (flat); young, open-grown mixed-conifer, logged stand.

Bally Mountain (Starkey Experimental Forest)—24 air miles west of La Grande; Wallowa Whitman National Forest; 4,716-foot elevation; slight eastern exposure (ridgetop); well-stocked, all-age mixed-conifer, logged stand (mostly grand fir).

Temperature Records

Air-temperature-recording stations consisted of a 31-day battery-operated hygrothermograph or an Omnidata TA51 biophenometer in a weather shelter located in small openings in each plot.[1] The biophenometers were tested for comparability with hygrothermographs and were slightly more accurate for accumulating degree-days in forest environments (Wickman 1985). The biophenometers measured the temperature and calculated the degree-day total every 10 minutes by the sine wave method (Allen 1976). The results of each 10-minute calculation were then stored in a random-access memory. The total could be displayed as a liquid crystal display readout when the instrument was visited.

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

A threshold temperature of 42 °F (5.5 °C) was used for comparability with previous Douglas-fir tussock moth phenology studies (Wickman 1976, 1977, 1981). In many biological studies, 42 °F has been used as the "base temperature for onset of vegetative growth" (Taylor 1967). Heat units were accumulated by subtracting 42 °F from the mean daily temperature; each degree above 42 °F was termed a degree-day. The few instances where temperatures were low enough to result in negative values were assigned zero.

Biophenometers were placed on the plots as soon as they were accessible. At Y-Ridge, the earliest placement was March 17 in 1983; the latest was April 14 in 1982 and 1984. At Bally Mountain, the earliest placement was March 27 in 1986; the latest was April 12 in 1983 and 1985. The starting date for accumulating heat units was during the first period when the average temperature exceeded the threshold. This varied from April 5 to April 20 at Y-Ridge and April 6 to May 3 at Bally Mountain. The instruments were in place and capturing most of the early spring degree-days each year of the study.

Foliage and Insect Sampling

At each plot, five open-grown grand fir and five open-grown Douglas-fir trees, 16-33 feet (5-10 m) in height, were selected and used for foliage measurements. Each tree had four tagged primary branches on the four cardinal sides of the midcrown for small trees and lower crown for larger trees.

At Y-Ridge, the terminal bud on each tagged branch was examined for bud burst and measured at 3- and 6-day intervals from mid-May through the period of bud development. For this study, bud burst occurred when the transparent sheath encasing expanding buds split, exposing new needles to young larvae for feeding (Wickman 1976). Shoot elongation was measured three to five times during the season. At Bally Mountain, tagged shoots were not used because heavy western spruce budworm populations destroyed tagged buds. Instead, visual estimates were made of bud burst at midcrown on 10 open-grown grand fir trees.

First- and second-instar Douglas-fir tussock moth are the usual stages sampled during annual population monitoring by lower crown sampling (Mason 1987). At this time, western spruce budworm larvae are usually fourth or fifth instar. Because the two species of defoliating insects can inhabit the same tree and branch, both insects can be sampled simultaneously. This is usually timed for about 600 degree-days when shoots are estimated to be elongated 50 percent or more (Wickman 1976, 1977, 1981). Simultaneous sampling by the lower crown method was done only at Y-Ridge where both insects were present. At Bally Mountain, only western spruce budworm were sampled at a nominal fifth instar (a mix of larval instars, but mostly fifth) by a conventional midcrown technique (Carotin and Coulter 1972).

Results

Spring Degree-Days

The degree-day values by year and calendar date for each plot are shown in table 1. When accumulated degree-days were graphed for each plot for the 5 and 6 years of measurements, they showed a similar pattern of heat-unit development through the seasons (fig. 1). The degree-days were averaged for 6 years at Y-Ridge and 5 years at Bally Mountain by date. Annual variations by date are indicated by standard errors of the mean (fig. 2). The five and six seasons monitored show a range of degree-day development, mostly because of a cooler than usual season in 1984 and an abnormally early and warm season in 1987. But based on coefficients of variation

Table 1—Accumulated degree-days (°F) from April 15 through July 10 on 2 monitoring plots in

Location and date		1982 (4/14)	1983 (3/17)	1984 (4/14)	1985 (4/3)	1986 (3/27)	1987 (4/2)	x̄	C.V.[a]	S.E.[b]
Y-Ridge:										
April	20	—	33	—	62	41	76	53.0		
	25	—	47	9	62	60	—	44.0		
	30	—	66	—	103	60	—	76.0		
May	5	52	67	16	139	88	273	105.8	86.4	37.3
	10	70	110	35	149	90	383	139.5	89.8	51.1
	15	100	138	71	176	94	440	169.8	80.9	56.1
	20	129	210	84	252	152	490	219.5	66.2	59.3
	25	193	283	124	348	198	530	279.3	52.1	59.4
	30	211	386	200	378	328	559	343.7	38.6	54.1
June	5	245	456	243	426	455	627	408.7	35.7	59.6
	10	289	498	260	505	505	695	458.7	35.1	65.8
	15	385	541	303	612	610	764	535.8	31.3	68.4
	20	502	596	343	710	664	860	612.5	29.1	72.7
	25	610	665	438	774	743	943	695.5	24.4	69.3
	30	691	734	532	870	836	1120	797.2	24.9	80.9
July	5	744	804	638	998	914	1252	891.7	24.3	88.6
	10	821	—	744	1144	992	1280	996.2	21.3	87.2
Bally Mountain:										
April	20	—	34	—	43	21	77	44.0		
	25	—	37	—	43	21	—	34.0		
	30	—	42	15	79	32	—	42.0		
May	5	—	48	19	138	40	217	92.4	90.1	37.2
	10	—	48	37	154	41	382	132.4	103.1	71.6
	15	—	60	54	172	43	414	148.6	105.8	70.3
	20	—	83	66	260	93	447	189.8	86.2	73.2
	25	—	185	91	348	132	490	249.2	66.7	74.4
	30	—	325	151	373	270	508	325.4	40.4	58.8
June	5	—	393	165	448	414	527	389.4	34.8	60.6
	10	—	462	180	493	473	640	449.6	37.1	74.7
	15	—	501	206	587	589	705	517.6	36.4	84.4
	20	—	532	260	706	641	770	581.8	34.4	89.6
	25	—	589	274	792	748	835	647.6	35.3	102.2
	30	—	643	376	892	845	1044	760.0	34.0	115.4
July	5	—	708	479	1067	932	1113	859.8	30.8	118.4
	10	—	760	582	1219	1007	1182	950.0	28.9	122.7

■— no measurements.

[a] Coefficient of variation.

[b] Standard error.

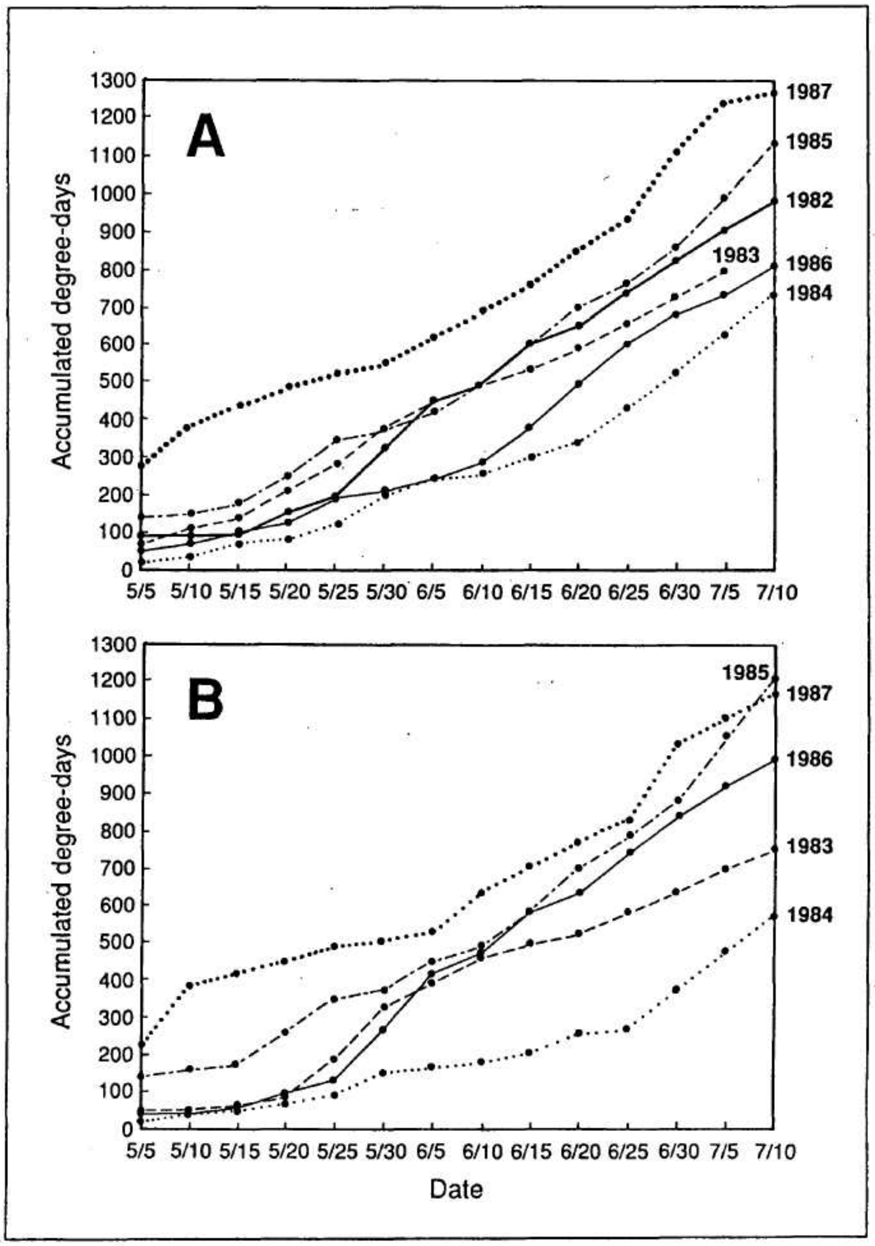

Figure 1—Accumulated degree-days, May 5 through July 10.
A. 1982-87, Y-Ridge. **B.** 1983-87, Bally Mountain.

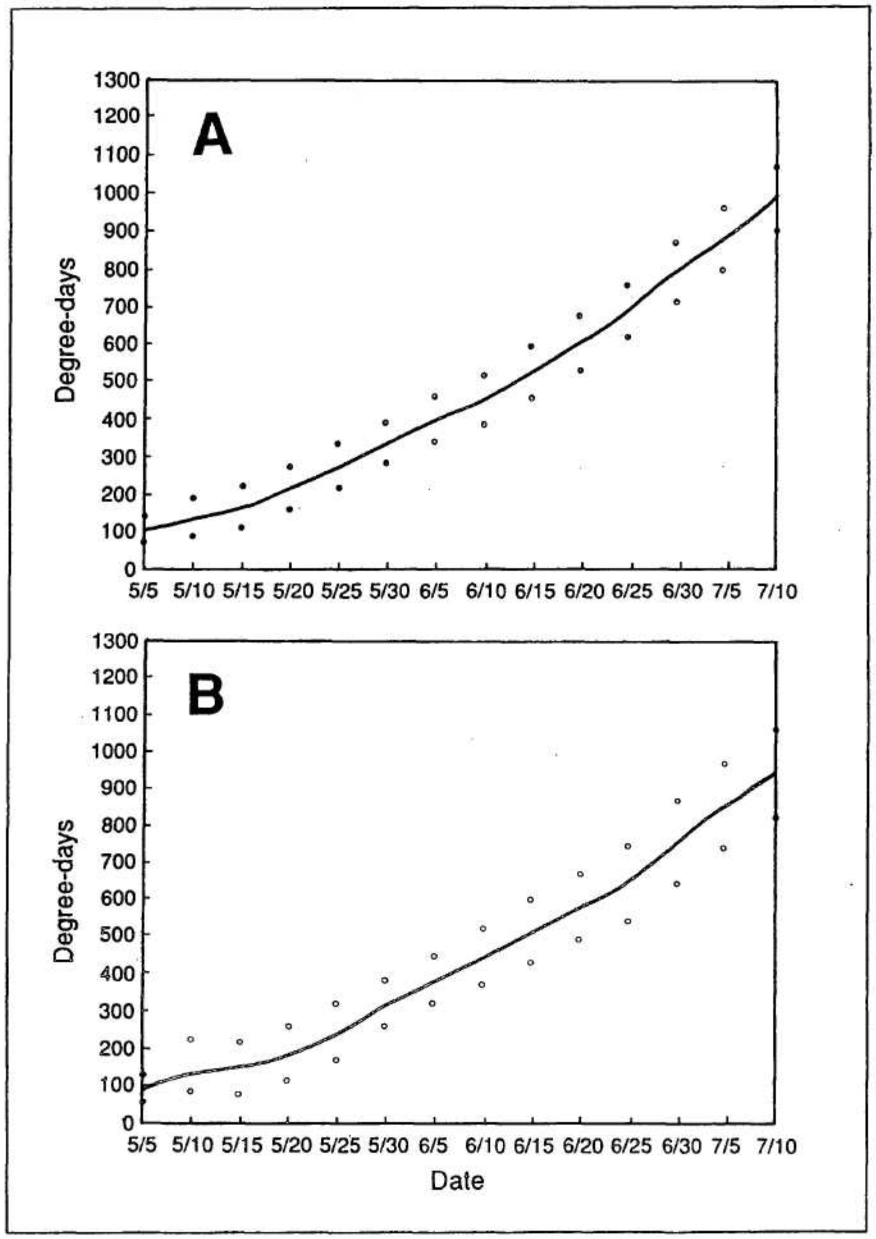

Figure 2—Average degree-days, May 5 through July 10.
A. 1982-87, Y-Ridge. §, 1983-87, Bally Mountain.

(table 11), the annual variation for *live* and six seasons is consistent for both areas. Accumulated degree-days related to differences in elevation during the 1987 season (fig. 3). conform to findings in other studies (Wickman 1976,1981)'. As expected, degree-days on the higher elevation plot at Bally Mountain. lags, slightly behind the Y-Ridge site after *May* 10 and through the entire season.

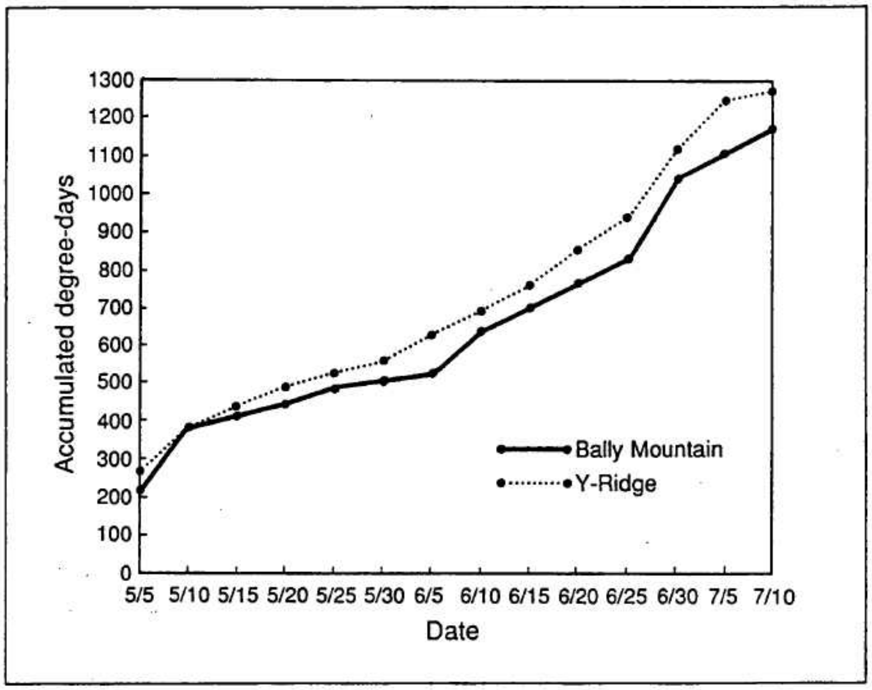

Figure 3—Accumulated degree-days, May 5 through July 10, 1987, Y-Ridge and Bally Mountain.

Bud Burst and Shoot Elongation

The Y-Ridge plot has the most complete record of bud burst and shoot elongation because heavy western spruce budworm feeding at Bally Mountain destroyed terminal buds on the tagged branches, making impossible the use of marked trees. Only visual estimates were made of bud burst at Bally Mountain after 1984, resulting in the gaps shown in table 2. The destruction of host buds during the western spruce budworm outbreak made monitoring of host development extremely difficult at both locations. Complete shoot growth could be monitored for only 1982-85 at Y-Ridge.

When accumulated degree-days were averaged for all years at each location for comparison, the phenology of bud burst at the two sites was in close agreement. Shoot elongation at the two sites, however, could not be compared because of the destruction of marked shoots by western spruce budworm at Bally Mountain (table 2).

Larval Sampling Dates

Larval sampling dates for Douglas-fir tussock moth and western spruce budworm . were determined partially by degree-day and host bud and shoot development and partially by work schedules and availability of people. The dates and instar shown for each insect, therefore, may not be the ideal targeted period, but every effort was made to sample at the optimum time, especially at Bally Mountain because of the intensive western spruce budworm population dynamics studies at that location. Table 3 shows that the samples through the seasons of 1982-87 at Y-Ridge ranged from June 1 to 25, and degree-days from 438 to 764. Sampling for western spruce budworm at Bally Mountain was timed for nominal fifth instars by periodic field examinations of developing larvae. The range of dates and degree-days for western

Table 2—Phenology of bud burst and shoot elongation on the Y-Ridge plots,

Location and year	First bud burst		75 percent > bud burst		50 percent > shoot elongation	
	Date	Degree-days	Date	Degree-days	Date	Degree-days
Y-Ridge:						
1982	6/2	241	6/10	289	6/22	600
1983		[b]	5/30	386	6/14	541
1984	6/11	260	6/15	303	6/25	438
1985	5/15	176	5/25	348	6/13	574
1986	5/26	226	5/30	328		[c]
1987	5/4	227	5/10	383		[c]
Average[d]		226 ± 13.9		340 ± 16.5		538 ± 35.5
Bally Mountain:						
1983	5/25	185	5/30	325		[e]
1984		[b]	6/15	206		
1985		[b]	5/30	373		
1986		[b]		[e]		
1987	5/7	280	5/15	414		
Average[d]		232 ± 47.5		330 ± 45		

[a] Averages of grand fir and Douglas-fir combined.

[6] No visit to plot at bud burst

[c] Many buds and shoots on tagged trees destroyed by western spruce budworm.

[d] ± standard error.

[e] All marked shoots at Bally Mountain destroyed by western spruce budworm.

Table 3—Dates, degree days, and larval instar for combined Douglas-fir

Year	Date	Degree-days	Larval instars	
			Douglas-fir tussock moth	Western spruce budworm
1983	6/20	596	1st	[a]
1984	6/25	438	1st [b]	4th
1985	6/24	764	[a]	5th-6th
1986	6/17	640	[a]	4th-6th
1987	6/1	559	1st	3d-5th
Average[c]		599 ± 53.1		

[a] No larvae found.

[b] 1 larva found on nearby plot, same elevation.

[c] ± standard error.

Table 4—Dates and degree days for nominal 5th western spruce budworm larval Instar

Year	Date	Degree-days
1983	6/15	501
1984	7/3	[a]
1985	6/10	493
1986	6/15	589
1987	6/9	640
Average[b]		556 ± 35.5

[a] Biophenometer not read at sampling time.

[b] ± standard error.

spruce budworm fifth-instar sampling at Bally Mountain was June 9 to July 3 and 493 to 640 degree-days (table 4). Average accumulated degree-days required to sample nominal fifth-instar western spruce budworm (or first-instar Douglas-fir tussock moth at Y-Ridge), were similar for Y-Ridge and Baily Mountain (tables 3 and 4). The sample dates and degree-day accumulation for 1983 agreed closely with those found at a lower elevation on the Starkey Experimental Forest (Kemp and others 1986).

Discussion

The variation in degree-day accumulations calculated as standard errors of the mean for five and six seasons of monitoring in northeastern Oregon was slightly greater than that reported for five seasons in southern Oregon (Wickman 1981). Much of the variation of the northeastern Oregon degree-day accumulation, however, appears to be due to the exceptionally early and warm season before May 10,1987. The consistency of degree-day development between the two areas was especially good from early May to early June when degree-day accumulations set the stage for bud burst in host trees and Douglas-fir tussock moth and western spruce budworm larval dispersal and feeding. More degree-days were accumulated early in the season in southern Oregon, however, and this resulted in higher degree-days in relation to phenological development (Wickman 1981). The differences relate to earlier temperature and phenological development in more southerly latitudes as is generalized by Hopkins bioclimatic law (Hopkins 1918). Accumulation of degree-days can be used as a general predictor of both host foliage development and desired sampling date for larvae during most seasons. Over the long run, average accumulation of degree-days may be comparable between locations based on host and insect phenology results reported here.

The use of degree-days to predict sampling dates for a simultaneous sampling of early instar Douglas-fir tussock moth larvae and late instar western spruce budworm larvae seems feasible. These data also demonstrated the delay in phenological development associated with higher elevation (Wickman 1976, 1977,1981). If temperature-recording instruments are not available for onsite monitoring, then sampling can be timed so that it is synchronous with an estimated 50-percent shoot elongation. This technique is practical and has been used extensively in our population-monitoring activities. This would not be feasible if most buds and shoots were destroyed by dense populations of western spruce budworm.

Ideally, biophenometers should be placed in a variety of elevations and environments and the accumulated degree-day measurements used to predict site-specific phenology. This may be feasible only on intensive study sites or some insect treatment projects.

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