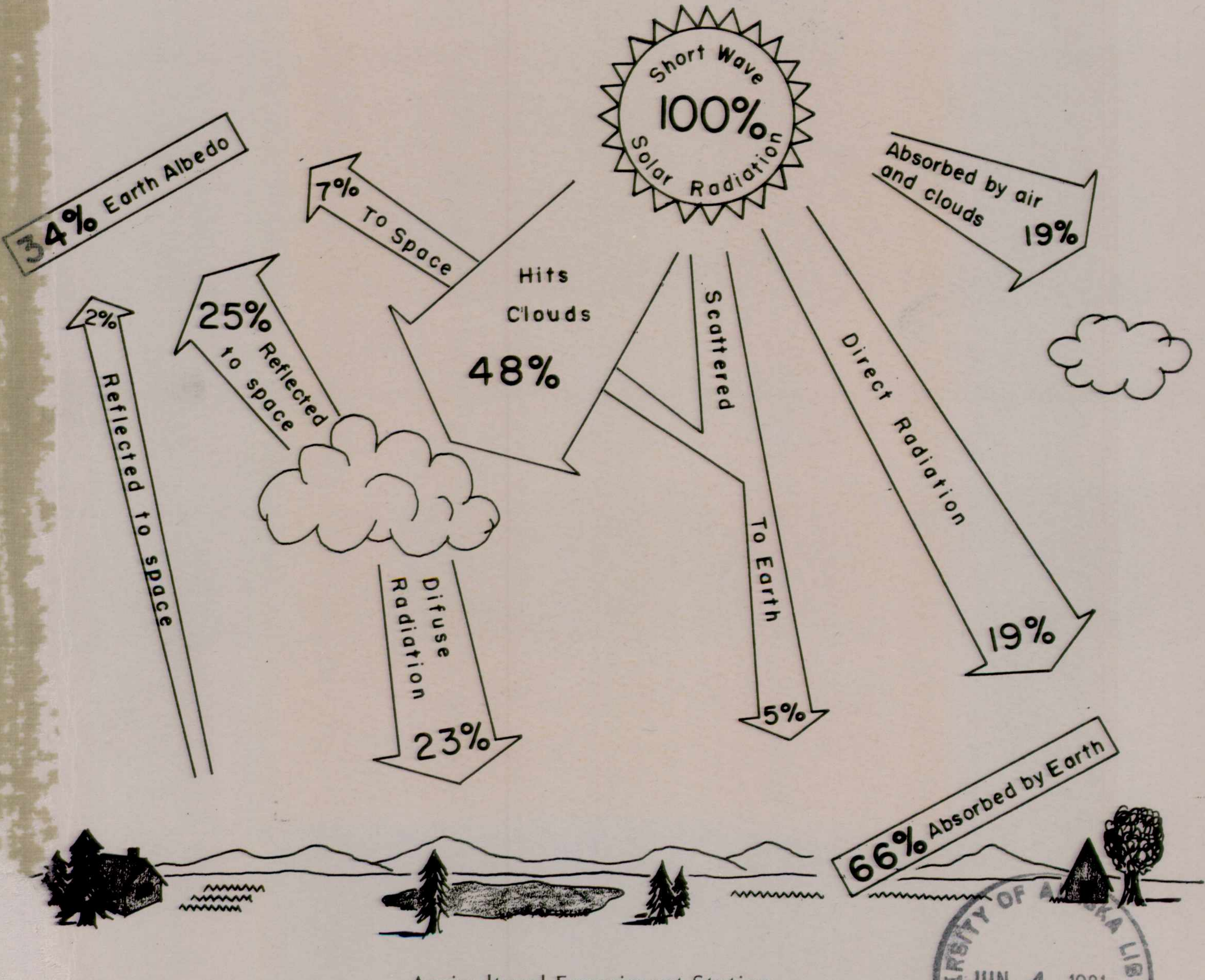
TIME, TEMPERATURE, AND SOLAR ENERGY RECEIVED BY CROPS at PALMER, ALASKA

Lee D. Allen



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Worldwide commercial agriculture strives to find and grow plants which are uniquely adapted to the existing climatic regime of each particular area. Finding suitable varieties has been assisted by assembling world grain and vegetable collections which can then be grown and evaluated under the various climatic conditions. This evaluation of many crops can determine a general range of suitability, but until crops are put in commercial production, growers cannot be sure of the relative desirability of a particular variety.

For many years seed companies have been rating some crops by the length of growing season. An example would be 60- 70- or 80-day sweet corn. The prediction of probable harvest dates using a measurement system which only counts days from planting to harvest becomes increasingly unreliable when unusual conditions occur, such as the reduced maximum daytime temperatures or the increased number of daylight hours encountered in northern latitudes. A more advanced rating system of time and temperature summations, using a unit called "growing degree-day" (GDD) is now widely used (Madariaga and Knott, 1951) for an increasing number of crops grown in the United States. The system is based upon the amount the avearge daily temperature exceeds a selected "base temperature". As the daily air temperature climbs above the base temperature, the method predicts that the plants will develop faster and therefore require fewer days to reach a harvestable stage. The base temperature subtracted from the average of the maximum and minimum daily air temperature is the GDD accumulation for that day.

$$\text{Degree-days} = (\text{average temp}) - (\text{base temp}) = \frac{(\text{Max} + \text{min})}{2} - 40$$

For daily temperature extremes of 50° and 70° the average temperature would be 60°, and degree-day accumulation would be 20 degree-days.

$$\text{Degree-days} = \frac{70 + 50}{2} - 40 = \frac{120}{2} - 40 = 60 - 40 = 20$$

The green pea industry in the Pacific Northwest has successfully used this heat unit accumulation system to aid in the commercial production of peas for freezing or canning. Experience has shown that each variety of peas has a fairly constant degree-day requirement for any geographical area. By keeping track of the GDDs received during the season for each individual planting, harvesting machinery and plant facilities can be used most efficiently while obtaining the highest yields consistent with good quality.

The GDD requirement for individual crops varies with latitude for several reasons, perhaps the most obvious is day length. GDD data developed for crops in Alaska will more closely coincide with other Alaskan locations, than would data developed for an area further south. A summary of mean, weekly GDD accumulations for eighteen selected Alaskan locations is available (Watson, Branton, and Newman, 1971). These data provide some idea of the heat available for crop growth at Alaskan sites. A more complete analysis of GDD accumulation, including probabilities of obtaining certain values (Branton and Shaw, 1973) enables degree-day predictions to be made for the six Alaskan locations covered. GDD accumulations have recently been shown (Branton and Searby, 1973) to be as great in some agriculturally undeveloped areas of Alaska as in the Matanuska and Tanana valleys where farming is practiced.

SOLAR ENERGY IS REAL FORCE

While the GDD method offers a practical solution for some crops, it is still only an indirect measure of solar energy, which is the real activating force on the plant. This energy from the sun has a direct effect on daily temperature, and thus, also logically correlates somewhat with GDD measurements. The total incoming energy consists of two distinct types, direct solar radiation from the sun and diffuse radiation from the sky and clouds (Geiger, 1965). Collectively, all of this incoming radiation is called global hemispheric radiation (GHR). Not all of the GHR is effective in heating the earth or producing plant growth, however. A certain portion is reflected back into space, and some is reradiated away from the earth towards space. The difference between the incoming GHR and the reflected and reradiated energy is called net radiation (NR). NR can be positive or negative depending upon whether the incoming or outgoing component is larger. Generally on sunny days the NR will be positive (incoming component larger) and on clear nights it will be negative; in summer the daily NR balance will be positive and in winter it will be negative. Positive NR produces heating while negative radiation results in surface cooling.

Since net radiation is directly affected by the amount of reflected radiation, it stands to reason that the nature of the reflecting surface has considerable effect on the readings. NR then, is not a uniform value from one type of surface cover to another; it varies in relationship to the presence of vegetative cover, bare ground, water, or snow. The ratio of reflected radiation to GHR at the time is called the "albedo." Since the albedo of bare soil is not very different from that of most kinds of green vegetation, it can be assumed that only small errors are introduced by measuring NR over clipped grass in attempting to relate this to growth of crops nearby. NR measurements reported here were observed over a clipped grass surface.

Researchers interested in studying the amount of energy required for various crops have been hampered by a shortage of radiation records. GHR has been recorded throughout the United States for a number of years by the National Oceanic and Atmospheric Administration using Epply-type pyranometers. These records are available for a number of locations, and many are near research farms. NR records are much more restricted as they have been routinely recorded for only a few locations in the world. Since NR is essentially a measure of the amount of solar energy retained at the earth's surface, it is generally considered a better index to evaporation from a free water surface than is GHR. At the present time, however, there is insufficient data to establish whether NR is as efficient for indicating plant growth as GHR. In this publication, the data for both are presented.

This publication reports upon the number of days required for crops to reach harvestable maturity, the calculated GDD accumulation, and the amount of GHR and NR received by the crops over several seasons in the Matanuska Valley near Palmer, Alaska. Radiation is measured in *langleys*, a quantity equal to one calorie per square centimeter. Methods and procedures that were used in making these solar measurements are explained in detail in University of Alaska Technical Bulletin No. 3 (Branton, Shaw, and Allen, 1972).

In considering these data, it must be kept in mind that some of the vegetable plants were grown using transplants. In such cases a greenhouse or hotbed is required and field production can be obtained with a shorter growing season and less energy accumulation than if the plants were started from seed in the field.

USE OF DATA

This publication presents the available accumulated data for persons who may be concerned with the climatic requirements of plants grown in a northern environment.

Land resource planners will find many areas of Alaska with short, hot summers that can be developed for vegetable production. The limited number of measuring sites may make some interpolation necessary.

To evaluate the effectiveness of the four climatic characteristics studied, a series of computations was made to determine the values of standard deviation (SD), arithmetic mean ($\bar{x}$), and coefficient of variation (C.V.). The arithmetic mean is the average level accumulated for the season of the characteristic in question. The standard deviation is the average variation from this mean value. The coefficient of variation is the standard deviation expressed as a percentage of the arithmetic mean,

$$\frac{\text{SD} \times 100}{\bar{x}}$$

and can be thought of as the percentage variation of each value from the mean annual accumulation. Climatic characteristics having a low C.V. exhibit the least variation for the crops studied, and, therefore, are most likely the best predictors of the climatic requirements for future crops. The "n" shown in the tables is the number of observations used in the calculations.

Both vegetable and grain crops have been observed. Planting and harvest dates of grains were obtained from Dr. Roscoe L. Taylor, USDA Agronomist of the Alaska Agricultural Experiment Station, Palmer, for crops raised at the Matanuska Farm, 5 miles west-southwest of Palmer.

Growth habits of the grain crops are such that a quite precise maturity date can be determined by observing the moisture content of the kernels. The growing seasons reported here for grains are the length of time from planting until the average moisture content of the seed has reached a predetermined value. Crops like carrots or celery are harvested only once, giving a specific length of growing season for each row or plot. Since these crops do not usually spoil if left in the field longer, slightly more energy might have been utilized in some years to produce larger yields. Lettuce and cauliflower reach maturity and must be harvested to preserve quality, but not all of the plants will reach maturity at the same time. In crops like broccoli, multiple harvests usually occur because each plant keeps producing new heads for a period of a few weeks. These growth characteristics have resulted in the growing season data being presented as a single date for grains, and a harvest season for vegetable crops. Harvest season was judged to start the first time commercial quantities of the product could be taken from the field, and end when quality or quantity was no longer at commercial levels, even though small harvests may have occurred before or after the dates listed.

Since it is expected that these energy-requirement measurements and comparisons will be used in determining which crops might be adapted to production in certain areas of Alaska, the comparisons are made for the accumulation at the time of the first harvest. Areas contributing slightly larger accumulations of the selected climatic characteristic should experience a "harvest season" in addition to a "first crop". Areas having smaller accumulations of the climatic characteristics than the requirement reported here can expect to experience partial or complete crop failures in years when accumulations are below those shown.

LETTUCE

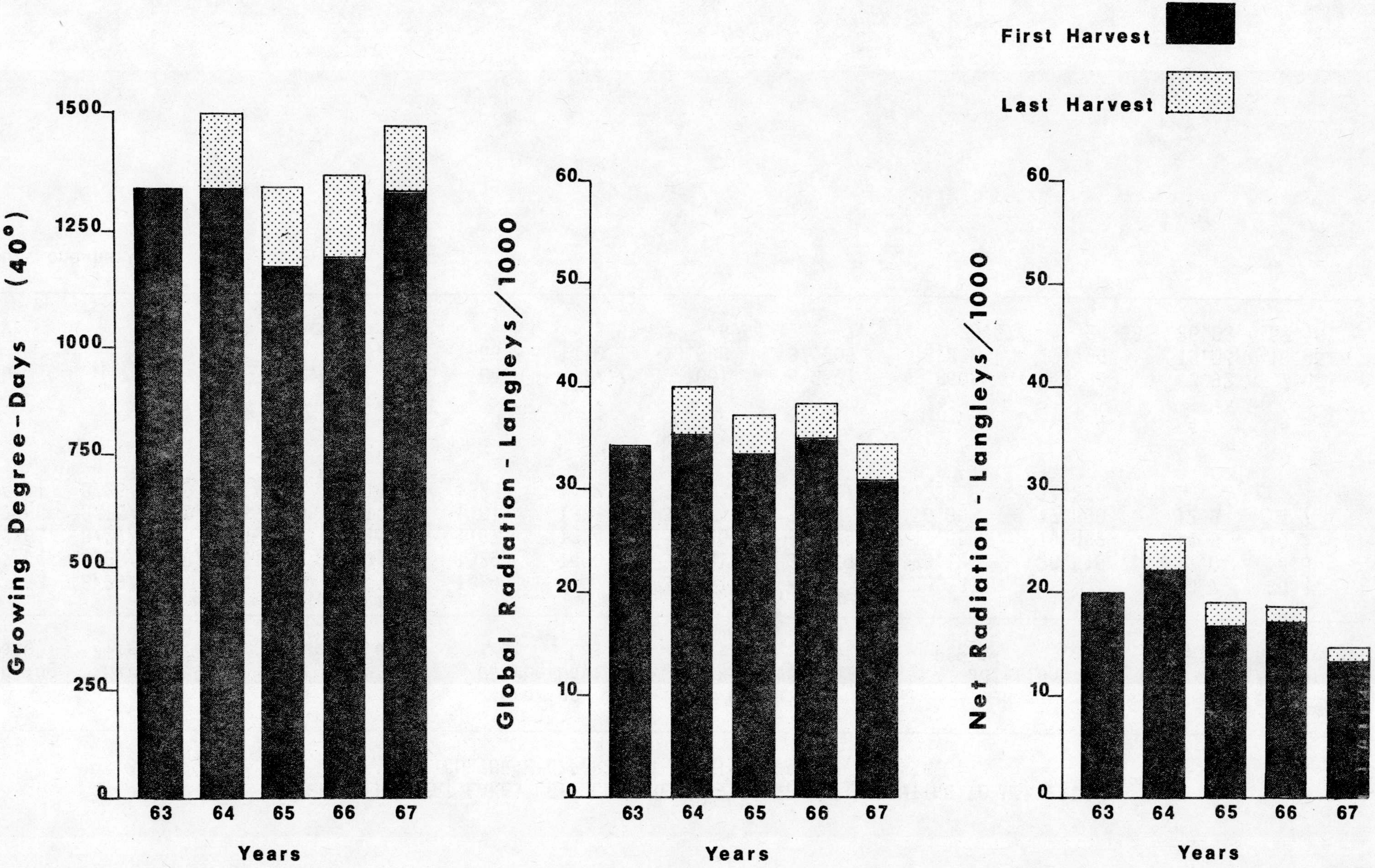
A single planting of Premier Great Lakes variety may be harvested over a three-week period, or the crop may be uniform enough that only one cutting is required. Data for five annual lettuce harvests are shown in Table 1 and Figure 1. In years where the harvest consisted of two or more cuttings, the data bars in the figures show two patterns, the first representing the climatic characteristic accumulation at the earliest significant harvest, and the second pattern the accumulation at the last harvest. Unless the season was terminated by frost, some small harvests may have occurred at a later date.

TABLE 1: PREMIER GREAT LAKES LETTUCE, ENERGY REQUIREMENT, PLANTING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting Date	Harvest Date First	Harvest Date Last	Days First	Days Last	Growing Degree-Days First	Growing Degree-Days Last	Global Radiation First	Global Radiation Last	Net adiation First	Net adiation Last	Yield Tons/Acre Irrig.	Yield Tons/Acre Nonirrig.
5/27/63	8/29/63	*	94		1329		33,991		20,333		20.7	20.4
5/27/64	8/25/64	9/09/64	90	105	1329	1490	35,061	39,749	23,126	25,516	12.0	6.5
5/27/65	8/27/65	9/10/65	92	106	1167	1334	32,730	36,229	17,536	19,082	14.6	10.2
5/17/66	8/15/66	8/30/66	90	105	1181	1353	35,374	38,435	16,808	17,890	12.9	4.7
6/26/71	8/25/71	9/07/71	91	104	1323	1462	30,833	33,607	13,358	14,292		
n			5	4	5	4	5	4	5	4	4	4
SD			1.67	0.82	84.0	77.7	1861	2691	3696	4680	3.92	7.02
$\bar{x}$			91.4	105.0	1266	1410	33,598	37,005	18,232	19,195	15.05	10.45
C.V.			1.83	0.77	6.63	5.51	5.54	7.27	20.27	24.38	26.03	67.15

* Only one harvest.

Figure 1. **PREMIER GREAT LAKES HEAD LETTUCE.** Growing Degree-Days and Energy Required in Growth, Matanuska Valley, Alaska.



From this tabular material it would appear that the temperature and energy received during the 1963 crop year were more favorable for lettuce production than 1964, 65, and 66. With and without irrigation the crop developed uniformly and only one harvest was needed. Considering all years, production with irrigation was much more consistent than production without irrigation.

For the years reported in Table 1, GHR is slightly better than GDDS as an indicator of the climatological requirements to first harvest. The C.V.s for the first cutting are respectively 5.54 and 6.63. Unfortunately, the NR sensing instrument was changed in 1964 and 1969, and the amount of variation between years that might be caused by this change is not known. NR was not closely related to plant growth for the years shown.

For lettuce planted at various dates in a single season (Table 2), the accumulated langleys of either NR or GHR appear to be a much better measure of maturity than GDDs, the C.V. being 5.36 for GHR, 4.05 for NR, and 10.11 for GDDS. These low values for C.V. for the energy-related characteristics indicate the seasonal energy requirements for lettuce growth are quite consistent within a single year. By keeping track of accumulated radiation, accurate prediction of successive harvest dates may be made.

Figure 2 shows a trend for an increased requirement of GDDS as the season progresses, both in Premier Great Lakes and Calmar lettuce. The GHR, on the other hand, shows a slight decrease with successively later plantings. This may be due to cloudiness in the latter part of the season in the Matanuska Valley. The NR required is surprisingly uniform throughout the season.

CARROTS

Carrots generally utilize the full length of the growing season available in the Matanuska Valley, and rarely is it necessary to harvest the crop before the end of the growing season in order to prevent a further increase in size. Production increases at a faster rate in the late summer, so that growth obtained the last few days of the season may be critical. Observations of carrots for six seasons are shown in Table 3 and Figure 3.

A statistical study of these data determined the C.V. to be least for GDDS, 6.29, intermediate for GHR, 8.73 and highest for NR, 17.26. Compared to the requirement for production of the final crop of Premier Great Lakes head lettuce in the four years that both crops were grown, Royal Chantenay carrots required 22.9% more days, utilized 15.9% more GDDS, 12.2% more GHR, and 7.7% more NR.

TABLE 2: PREMIER GREAT LAKES LETTUCE, ENERGY REQUIREMENTS, PLANTING TO HARVEST FOR SIX CROPS PRODUCED IN 1971 BY ONE COMMERCIAL GROWER.

Crop and Planting Date	Harvest Date		Days		Growing Degree-Days		Global Radiation		Net Radiation	
	First	Last	First	Last	First	Last	First	Last	First	Last
(1) 5/07/71	8/05/71	8/09/71	90	94	1070	1128	34,885	35,239	14,119	15,076
(2) 5/16/71	8/10/71	8/25/71	86	101	1133	1367	31,129	35,434	13,119	15,076
(1) 5/16/71	8/09/71	*	85		1117		30,983		13,032	
(3) 5/23/71	8/20/71	8/29/71	89	98	1270	1390	31,037	33,598	13,329	14,322
(4) 5/30/71	8/27/71	8/31/71	89	93	1326	1376	30,177	31,157	13,153	13,516
(2) 5/30/71	8/30/71	*	92		1365		30,844		13,371	
n			6	4	6	4	6	4	6	4
SD			2.59	3.70	122.6	125.2	1689	1979	543	659
$\bar{x}$			88.5	96.5	1214	1315	31,509	33,857	13,416	14,390
C.V.			2.92	3.83	10.11	9.52	5.36	5.85	4.05	4.58

* Calmar variety with only one harvest.

Figure 2. PREMIER GREAT LAKES HEAD LETTUCE from one commercial grower. Growing Degree-Days and Energy Required in Growth, Palmer, Alaska.

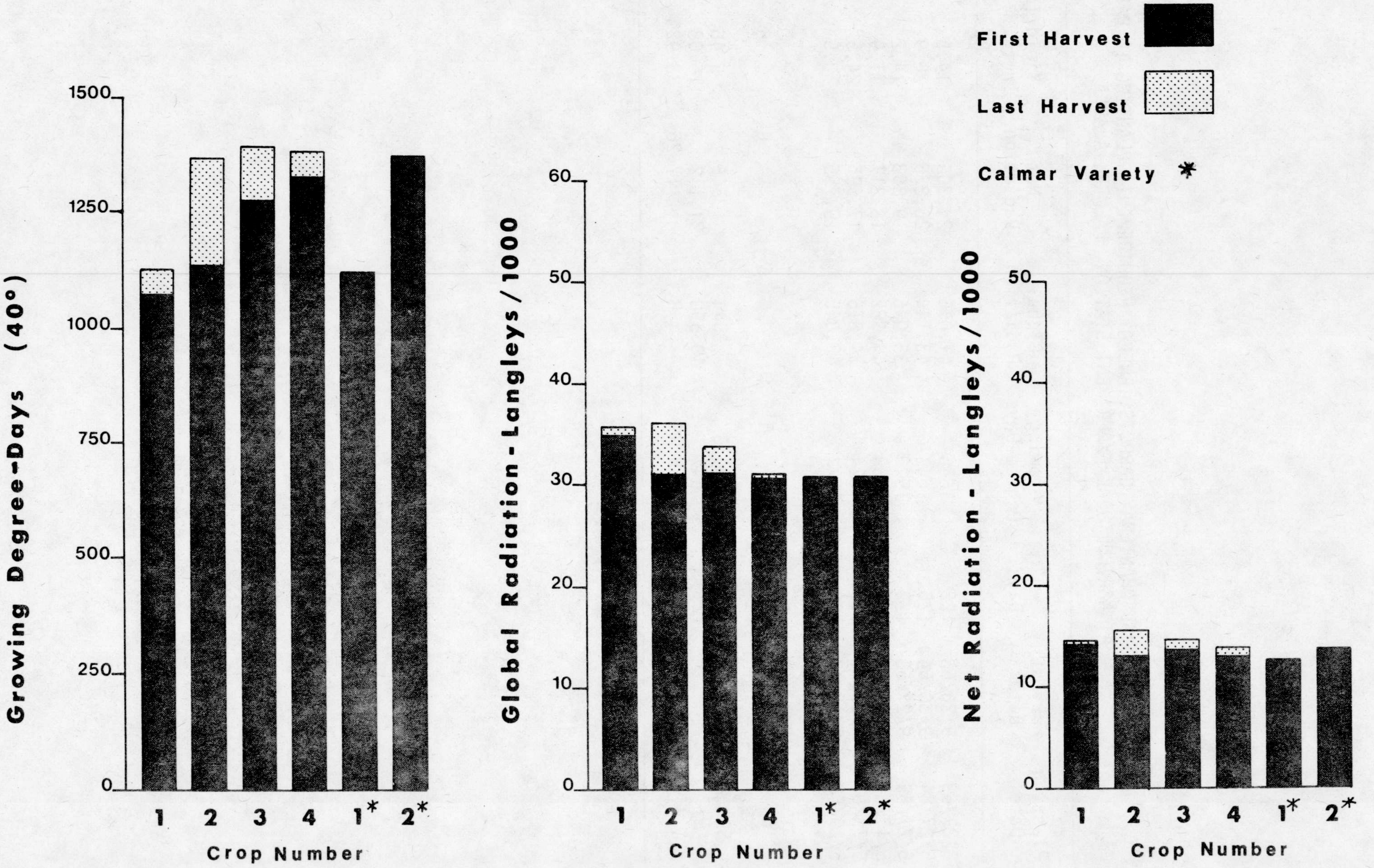
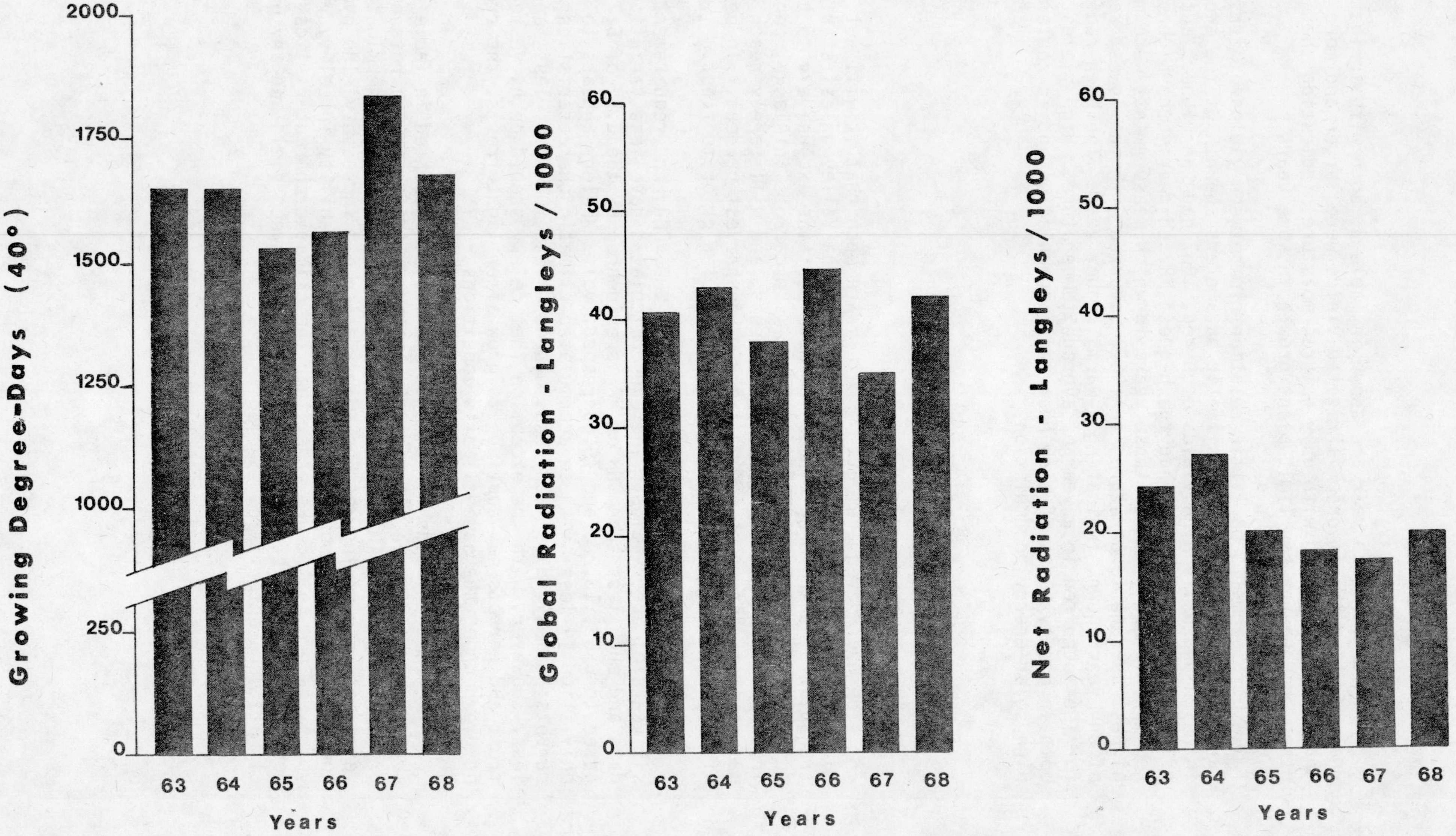


TABLE 3: ROYAL CHANTENAY CARROTS, ENERGY REQUIREMENT, PLANTING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting Date	Harvest Date	Days	Growing Degree-Days	Global Radiation	Net Radiation	Yield Tons/Acre Irrig.	Yield Tons/Acre Nonirrig.
5/27/63	9/26/63	122	1646	41,056	24,306	14.5	14.4
5/27/64	9/30/64	126	1647	43,144	26,836	20.9	11.8
5/27/65	9/27/65	123	1523	38,096	19,863	14.2	12.1
5/17/66	9/27/66	133	1568	44,382	18,217	11.9	2.8
5/25/67	9/20/67	118	1824	34,816	17,695	24.5	1.6
5/29/68	9/12/68	106	1672	42,045	19,755	10.5	2.6
n		6	6	6	6	6	6
SD		9.03	103.5	3544	3645	5.45	5.80
$\bar{x}$		121.3	1647	40,590	21,112	16.08	7.55
C.V.		7.44	6.29	8.73	17.26	33.92	76.81

Figure 3. ROYAL CHANTENAY CARROTS. Growing Degree-Days and Energy Required in Growth, Matanuska Valley, Alaska.



Yields for each year are shown in Table 3, both with irrigation and under dryland conditions. Irrigated yields were larger and more uniform than yields obtained with only natural moisture, indicating that factors other than energy can limit plant growth in some years.

There seems to be little relationship between yields of irrigated carrots and any one of the climatic parameters shown. Of the two years in which unusually high yields occurred, 1967 had the highest accumulation of degree-days, and 1964 had the highest NR and nearly the highest total hemispheric radiation of those years in which measurements were made. The highest average temperature, in 1967, occurred with the lowest radiation of any year shown, indicating a warm, cloudy year. The high radiation for 1964 occurred in a year of average temperature. High yields occurred both in cloudy years of high heat-unit accumulation and in cooler years of high solar-energy accumulation.

CELERY

The energy requirements of celery are such that it will not reach a marketable stage of maturity in the Matanuska Valley unless started from transplants, therefore, discussion here pertains exclusively to transplanted celery of the 52-70 Variety. Celery, like carrots in Alaska, continues to increase in size as the season progresses, and will rarely reach an overmature state before chance of frost makes harvest prudent. To be certain of market quality, celery should be harvested prior to frost.

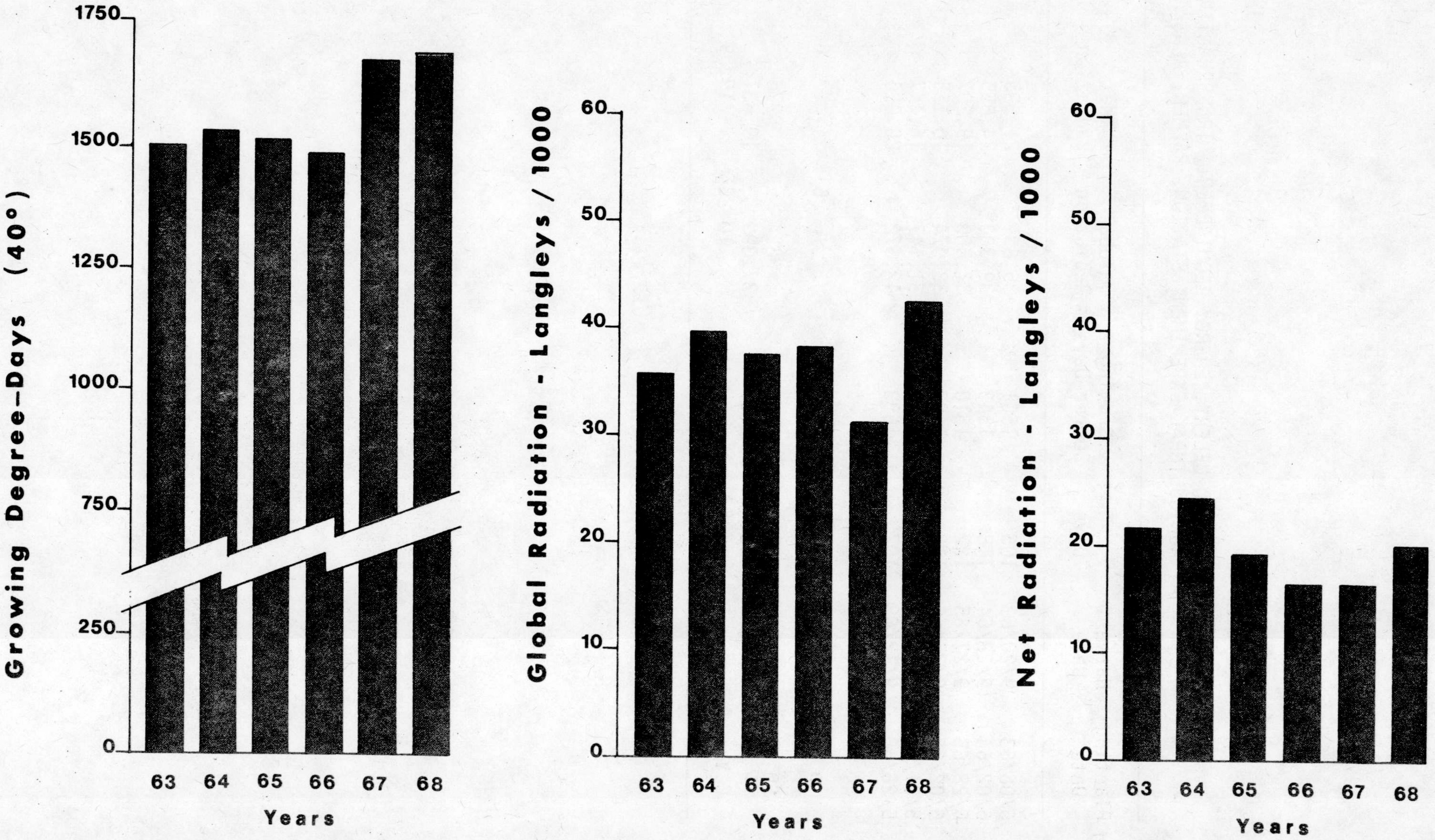
Table 4 and Figure 4 give the day, GDD, GHR, and requirements for the six years of observation. The GDDs calculated have less variation than days and much less than GHR or NR as evidenced by the C.V. of 5.71 as compared to 6.53, 10.22, and 19.69 respectively. Celery appears to require only slightly less of these accumulated climatic characteristics than carrots; namely, days 7.3% less, GDD 4.9% less, GHR 7.9% less, and NR 7.0% less. However, with the exception that celery should be harvested before frost and carrots may continue to grow after light frosts, the crops can be grown under the same climatic conditions.

The celery yields for six years are also presented in Table 4. Non-irrigated yields were not as variable for celery as for carrots or lettuce, primarily due to elimination of the problem of poor seed germination in years with dry spring weather. Irrigation did increase yields by over 15 tons per acre, or about 60%. Some of the variability in celery yield between years was due to factors other than the climatic characteristics studied here; there appears to be no relationship between yield and any of the climatic characteristics studied.

TABLE 4: UTAH 52-70 CELERY, ENERGY REQUIREMENT, TRANSPLANTING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting Date	Harvest Date	Days	Growing Degree-Days	Global Radiation	Net Radiation	Yield Tons/Acre	
						Irrig.	Nonirrig.
6/06/63	9/20/63	106	1501	35,631	21,595	22.6	20.5
6/02/64	9/28/64	118	1543	39,300	24,655	38.6	23.3
5/28/65	9/27/65	122	1510	37,669	19,207	39.2	35.3
6/02/66	9/27/66	117	1488	38,074	16,155	51.2	28.7
5/31/67	9/13/67	105	1677	31,147	16,147	59.6	25.6
5/28/68	9/12/68	107	1683	42,572	20,026	34.0	19.5
n		6	6	6	6	6	6
SD		7.34	89.4	3824	3276	13.01	5.87
$\bar{x}$		112.5	1567	37,399	19,631	40.87	25.48
C.V.		6.53	5.71	10.22	19.69	31.84	23.02

Figure 4. UTAH 52-70 CELERY. Growing Degree-Days and Energy Required in Growth, Matanuska Valley, Alaska.



CRUCIFERS

As a group, crucifers, the members of the mustard family, are suited to cool weather and do well in Alaska. Data presented here are limited to one or two well-adapted varieties of broccoli, cauliflower, and Brussels sprouts. Other varieties may have different requirements, but the varieties used were typical of those in commercial production in Alaska.

Soil moisture deficiencies change growth rate. Where differences in maturity between irrigated and unirrigated crops occurred, the values for irrigated crops are used. Under some conditions, the effect of drought may be to slow plant growth resulting in later harvest while under other conditions drought may speed flowering, resulting in earlier harvest. No attempt is made here to evaluate the effect of moisture stress on the energy requirements of the crop. Serious moisture stress did not occur in the plants upon which these energy requirements were made.

While certain of the crucifers can be produced either from seed or transplants, all of those discussed here, except one broccoli variety, were produced from transplants. Since these experiments were designed for purposes other than the study of solar energy and temperature on plant growth characteristics, no special attempt was made to be sure that the transplants used each year were exactly the same size and age as those used in other years. Likewise, no uniform method was used to determine when to sow the seeds. However, the practices employed are probably representative of those used in commercial practice, or that might be used for home gardens throughout the state. Normal cultural practices were employed to prevent undue competition or stress. Weeds were controlled by cultivation and some hand weeding. Root maggots were controlled by insecticide sprays at seven- or eight-day intervals. Plant spacing was about 18 inches in the row with space between rows of 36 to 42 inches.

Broccoli: Broccoli has a modest energy requirement, and can be produced in the Matanuska Valley either as a seeded crop or by using a transplanting technique. The time and energy values shown in Table 5 and Figure 5 show transplanted Gem broccoli has the lowest time and energy requirement to reach a harvestable stage of maturity of any crop evaluated. When compared to lettuce, transplanted broccoli required 44.7% fewer days, 37.9% less GDDs, 37.3% less GHR, and 44.3% less NR. Transplanted broccoli is more responsive to GHR received than to air temperature, as indicated by the C.V. of 8.35 for GHR and 15.12 for GDDs.

The Harvester variety of broccoli, developed for mechanical harvest, was direct seeded. This small-headed, early variety was thinned to 3- or 4-inch plant spacing, except in 1971, when 18-inch spacing was used. Harvester is an early variety, so time and energy requirements should not be taken as an indicator of those of the larger, later, standard varieties of broccoli, should they be direct seeded.

TABLE 5: GEM BROCCOLI, ENERGY REQUIREMENT, TRANSPLANTING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting	Harvest Date		Days		Growing Degree-Days		Global Radiation		Net Radiation		Yield Tons/Acre	
Date	First	Last	First	Last	First	Last	First	Last	First	Last	Irrig.	Nonirrig.
5/23/69	7/11/69	8/11/69	49	80	869	1369	23,413	36,248	9,895	15,392	7.46	4.79
6/01/70	8/02/70	9/02/70	62	93	904	1317	21,096	30,779	11,321	15,048	6.86	4.99
5/27/71	7/13/71	8/23/71	47	88	658	1292	19,223	30,268	7,747	13,152	-	2.82
6/06/72	7/20/72	8/11/72	44	75	714	1133	20,469	30,884	11,636	17,446	4.97	5.05
n			4	4	4	4	4	4	4	4	3	4
SD			7.94	8.04	118.9	101.7	1757	2811	1772	1759	1.30	1.07
$\bar{x}$			50.5	84.0	786	1278	21,050	32,049	10,150	15,260	6.43	4.41
C.V.			15.72	9.57	15.12	7.96	8.35	8.77	17.46	11.53	20.21	24.19

Figure 5. GEM BROCCOLI. Growing Degree-Days and Energy Required in Growth, Transplanting to Harvest, Matanuska Valley, Alaska.

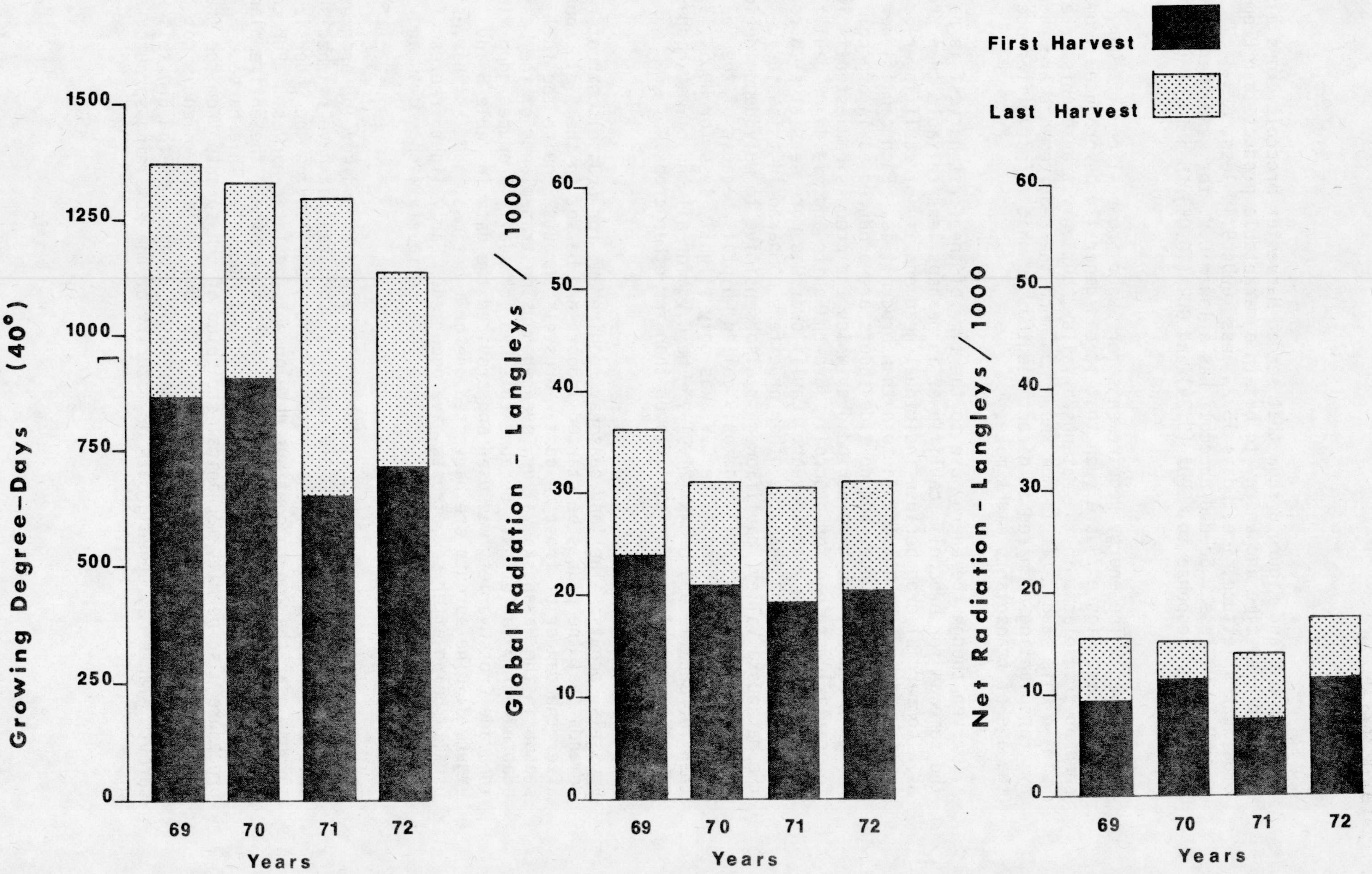


Table 6 and Figure 6 show that seeded Harvester broccoli crops also required less time and energy to obtain a marketable product than Premier Great Lakes lettuce, i.e., days 15.2% less, GDDs 9.4% less, GHR 14.7% less, and NR 19.9% less. Seeded broccoli has a lower C.V. for, and therefore shows better response to, GDDs (5.29) and GHR (10.05) than to NR (19.89).

Cauliflower: The energy requirements for Super Snowball cauliflower (Table 7 and Figure 7) are such that it can generally be produced from seed or transplants in the Matanuska Valley, but only transplants were used in this study. It is not known how much the requirements are reduced by transplanting compared to direct seeding, or what effect difference in the age of transplants might make.

Even though the energy use to the time of the first harvest is nearly the same as for broccoli, cauliflower is perhaps less reliable than broccoli as a commercial crop because individual head quality of cauliflower is influenced by more outside factors than broccoli is. Each cauliflower head is harvested only once, and no side shoots are produced as in broccoli. For this reason, the time period over which the crop is harvested is less for cauliflower than for broccoli. Growth habits and yields of cauliflower were variable from year to year. Cauliflower was more sensitive to root maggots and drought than the other crucifers compared in this study. In the Matanuska Valley, cauliflower is also sensitive to molybdenum deficiency (Allen and Laughlin 1967), commonly called whiptail because of the leaf abnormalities exhibited. The C.V. was only slightly less for GDDS (17.31) than for GHR (19.99) or NR (21.91). The C.V. for all the climatic characteristics was higher for cauliflower than for other crops.

Brussels sprouts: The long seasonal requirement for Brussels sprouts demands that the plants be started indoors and be set in the field soon after the danger of frost is past. Brussels sprouts require the full season in the Matanuska Valley, even when using transplants of the best-adapted early varieties. Because this hybrid usually produces good yields, the Jade Cross variety was used and provided the data in Table 8 and Figure 8. The sprouts are harvested one or two times, the last harvest usually being after some frosts have occurred. Early light freezes of 32°F do not injure the sprouts or interfere seriously with growth and development.

Sprouts first form at the bottom of the plant, and develop progressively up the stem. For multiple harvests, sprouts that have reached suitable size are broken from the bottom of the stem, leaving the undersized sprouts near the top to continue development for later harvest. For the final harvest, which may occur during freezing weather, the entire plant may be harvested and taken inside for sprout removal. This harvest procedure also permits mechanical stripping of the sprouts from the stalk for the final harvest, with a resultant savings in labor which is not possible for the first of multiple harvests. Topping of the Brussels sprouts plants may speed growth or maturity of the remaining sprouts, and

TABLE 6: HARVESTER BROCCOLI, ENERGY REQUIREMENT, DIRECT SEEDING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting	Harvest Date		Days		Growing Degree-Days		Global Radiation		Net Radiation		Yield Ton/Acre	
Date	First	Last	First	Last	First	Last	First	Last	First	Last	Irrig.	Nonirrig.
5/20/70	8/05/70	8/26/70	77	98	1069	1343	27,226	33,258	14,505	17,105		
6/04/70	8/26/70	9/09/70	83	97	1182	1332	26,697	30,175	13,654	15,115		
5/28/71	8/13/71	9/13/71	77	108	1131	1496	27,750	34,451	11,687	14,621		1.48*
6/02/72	8/14/72	8/21/72	73	90	1206	1452	32,918	38,395	18,592	21,536	4.49	4.70
n			4	4	4	4	4	4	4	4	1**	2**
SD			4.12	7.41	60.7	81.0	2879	3400	2905	3150		
$\bar{x}$			77.5	98.2	1147	1406	28,648	34,070	14,610	17,094		
C.V.			5.32	7.54	5.29	5.76	10.05	9.98	19.89	18.43		

* 18-inch plant spacing.

** Insufficient data for analysis.

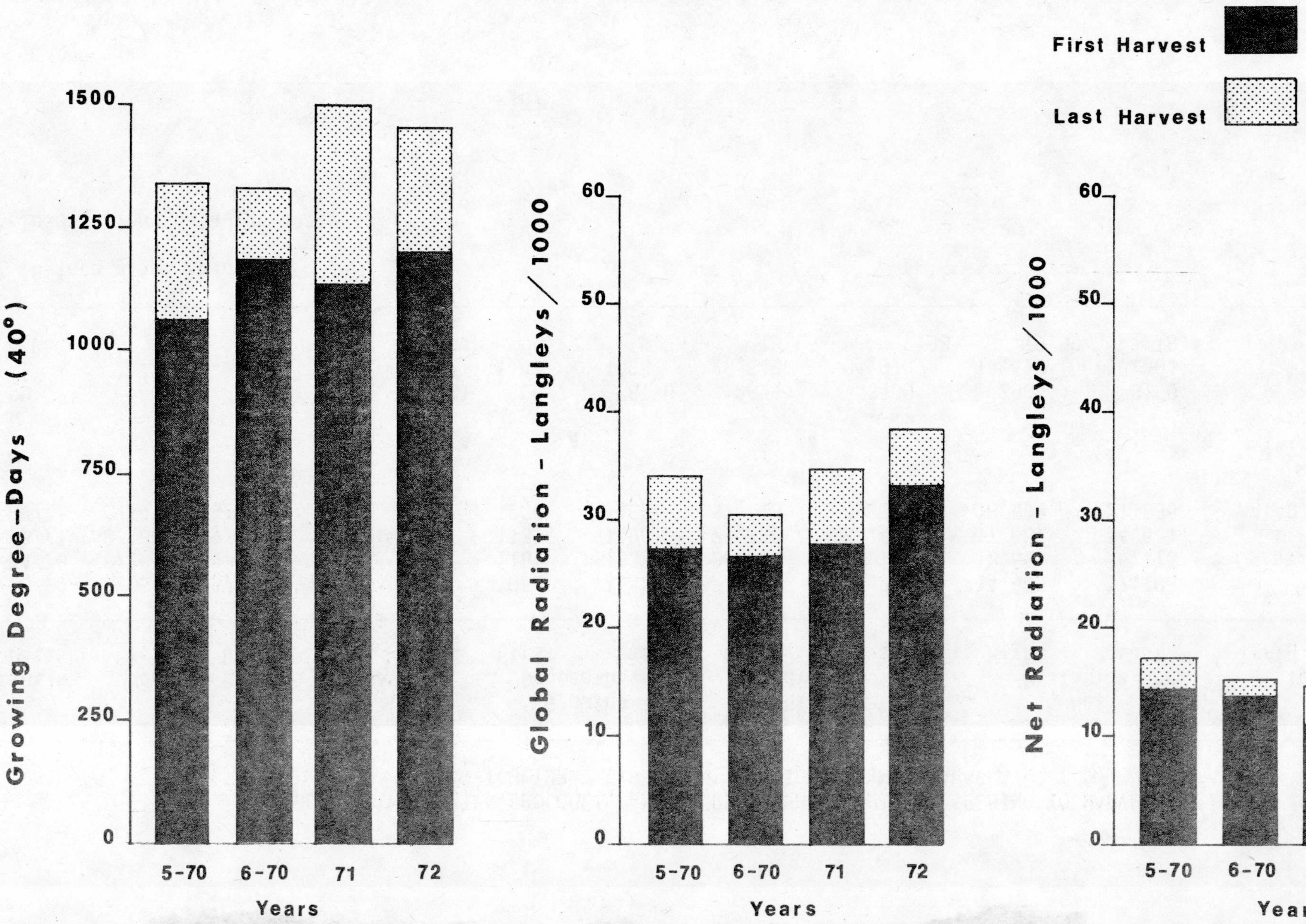


Figure 6. SEEDED HARVESTER BROCCOLI. Growing Degree-Days and Energy Required in Growth, Matanuska Valley, Alaska.

TABLE 7: SUPER SNOWBALL CAULIFLOWER, ENERGY REQUIREMENT, TRANSPLANTING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting Date	Harvest Date First	Harvest Date Last	Days First	Days Last	Growing Degree-Days First	Growing Degree-Days Last	Global Radiation First	Global Radiation Last	Net Radiation First	Net Radiation Last	Yield Tons/Acre Irrig.	Yield Tons/Acre Nonirrig.
5/31/66	8/04/66	8/18/66	65	79	963	1167	26,584	30,362	12,766	14,337	6.53	1.37
5/24/67	7/06/67	7/24/67	43	61	630	985	16,110	22,858	7,872	11,355	4.75	2.48
5/23/68	7/15/68	7/31/68	53	69	768	1075	22,724	30,060	11,626	15,178	4.29	3.92
5/27/69	7/11/69	7/22/69	45	56	800	990	21,273	25,994	9,028	11,402	5.90	2.66
n			4	4	4	4	4	4	4	4	4	4
SD			9.98	10.05	136.8	85.8	4333	3579	2262	1981	1.03	1.04
$\bar{x}$			51.5	66.3	790	1054	21,673	27,319	10,323	13,068	5.37	2.61
C.V.			19.9	15.16	17.31	8.14	19.99	13.10	21.91	15.16	19.17	40.06

Figure 7. SUPER SNOWBALL CAULIFLOWER. Growing Degree-Days and Energy Required in Growth, Matanuska Valley, Alaska.

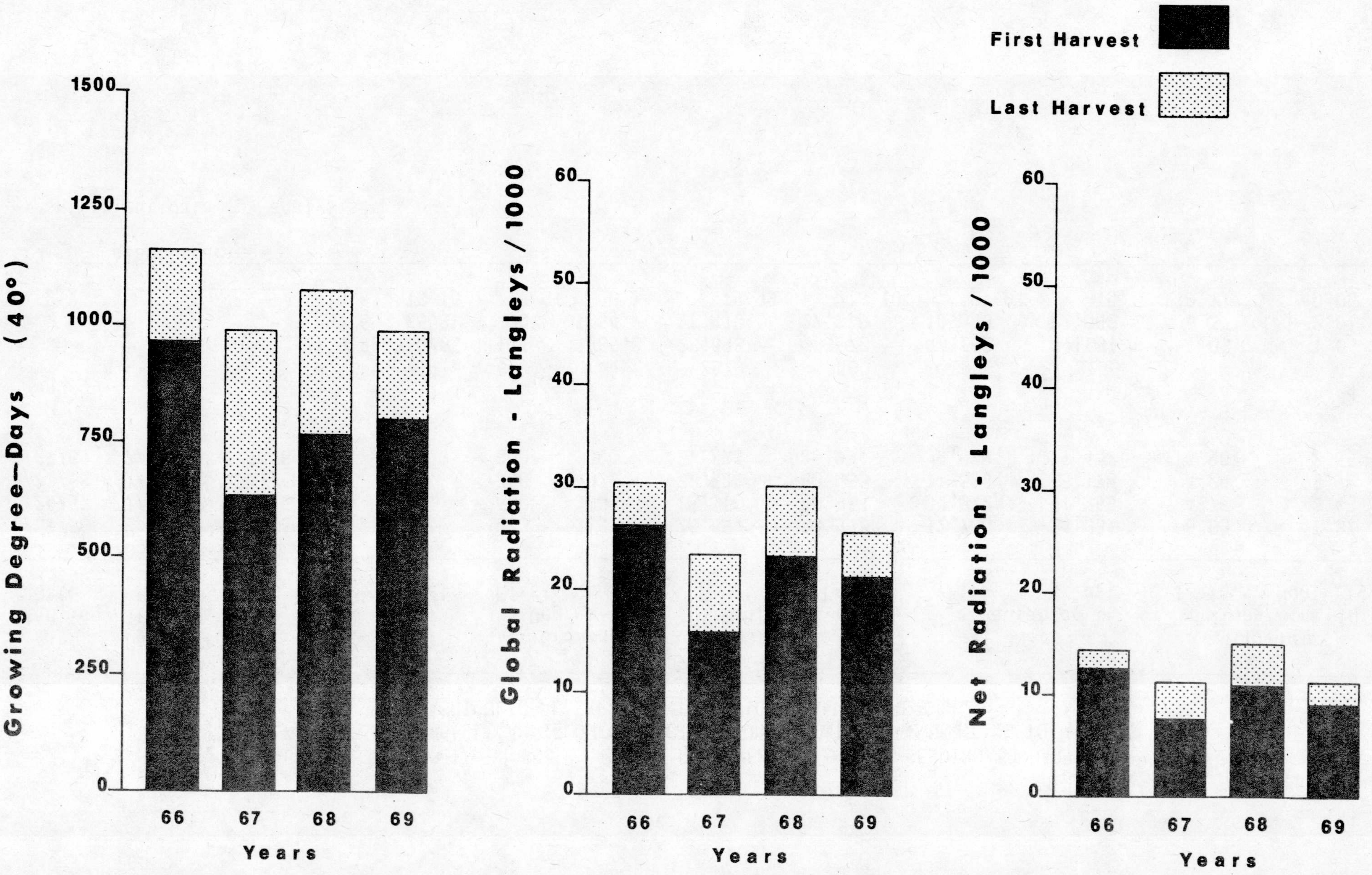
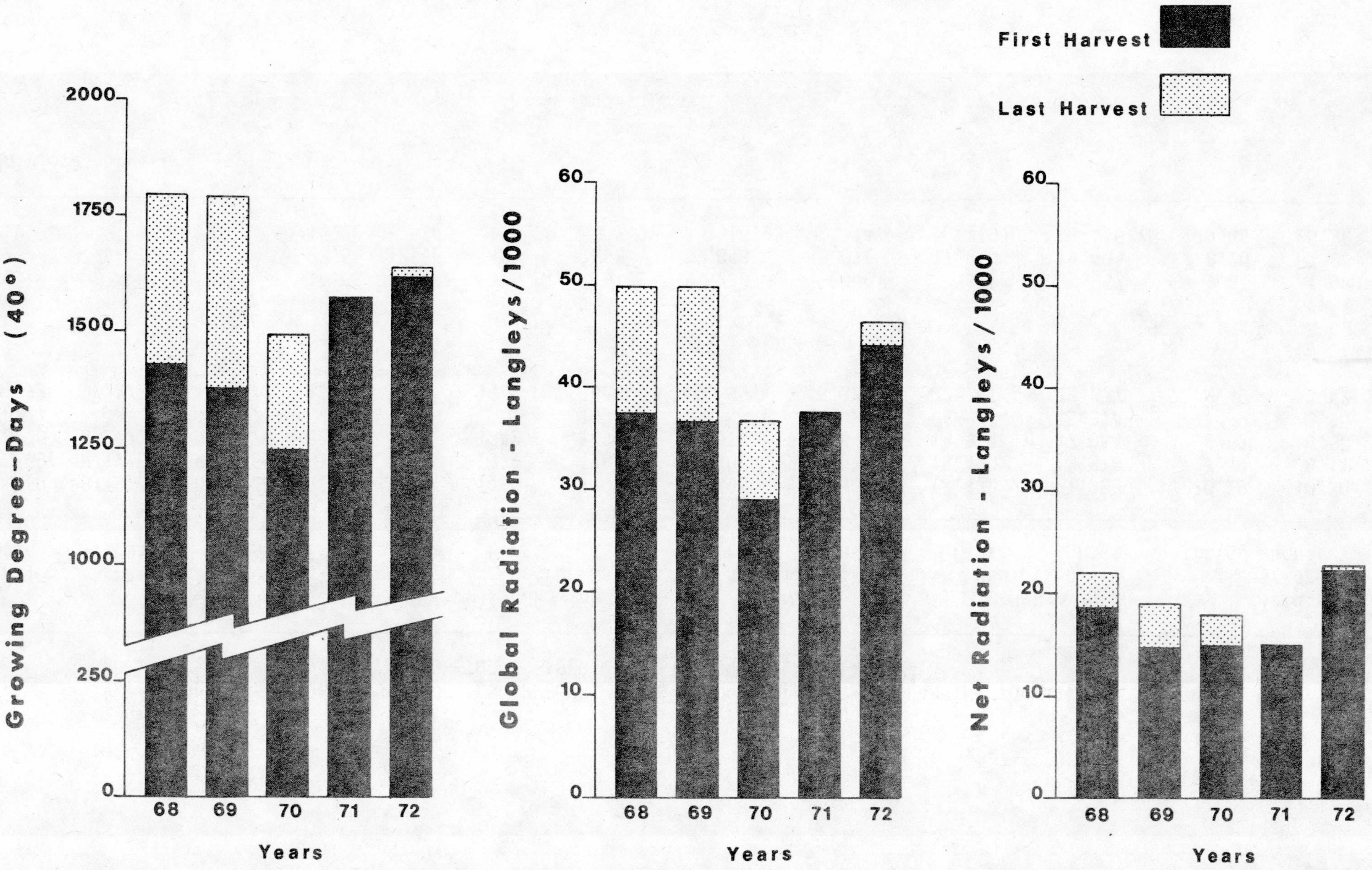


TABLE 8: JADE CROSS BRUSSELS SPROUTS, ENERGY REQUIREMENT, TRANSPLANTING TO HARVEST AT AGRICULTURAL EXPERIMENT STATION, PALMER, ALASKA.

Planting Date	Harvest Date		Days		Growing Degree-Days		Global Radiation		Net Radiation		Yield Tons/Acre	
	First	Last	First	Last	First	Last	First	Last	First	Last	Irrig.	Nonirrig.
5/23/68	8/19/68	10/07/68	88	137	1430	1792	37,495	49,608	18,472	21,983	10.29	10.30
5/23/69	8/12/69	9/22/69	81	122	1379	1788	36,608	49,511	15,490	18,818	7.49	6.11
5/28/70	8/24/70	9/24/70	88	119	1242	1490	29,013	36,513	14,954	17,964	6.52	5.55
5/28/71	*	9/30/71		125		1578		37,429		15,374		8.90
6/01/72	9/22/72	10/04/72	113	125	1664	1666	44,255	46,320	22,741	22,877	8.49	8.42
n			4	5	4	5	4	5	4	5	4	5
SD			14.06	6.84	175.8	131.8	6238	6449	3571	3057	1.61	1.98
$\bar{x}$			92.5	125.6	1429	1663	36,843	43,876	17,914	19,403	8.20	7.86
C.V.			15.20	5.45	12.30	7.92	16.93	14.70	19.93	15.75	19.64	25.26

* Only one harvest.

Figure 8. JADE CROSS BRUSSELS SPROUTS. Growing Degree-Days and Energy Required in Growth, Matanuska Valley, Alaska.



is a technique which might be used to produce sprouts in gardens receiving even less solar energy than is received in the Matanuska Valley. Some additional accumulation of energy might be obtained and utilized in the spring by earlier plantings than these, since Brussels sprouts are quite frost tolerant, or by the use of larger transplants.

The C.V. (Table 8) of the climatic characteristics accumulated up to the time of final harvest was as variable as the seasons involved since Brussels sprouts utilize the entire growing season available in Alaska. Very few GDDs or NR were accumulated at the time of harvest, and daily GHR values were low. The GDDs have a lower C.V. than GHR or NR, indicating, not necessarily that Brussels sprouts growth is better correlated with GDDs, but that in the years studied a more uniform accumulation of GDDs occurred between planting time and freeze-up than was the case for the other climatic characteristics.

SMALL GRAINS

Calculations concerning the GDD and solar-energy requirements for production of Edda barley, Golden Rain oats, and Gasser wheat have been based on crops grown in experimental plots by United States Department of Agriculture researcher Dr. Roscoe L. Taylor. Cereals were planted in the spring as soon as soil and weather conditions were most favorable. This resulted in a different planting date each year, but all the small grains were planted on the same date each year. Crops were harvested when the grain matured to a predetermined proper moisture content.

The GDDs and GHR were comparable as predictors of maturity for small grains as shown in Tables 9, 10, and 11. Days to maturity were less reliable, and, as indicated by the highest C.V., the accumulated NR proved the least reliable of the climatic characteristics studied.

Each year barley matured earliest. In six out of the nine years, oats matured before wheat, and the required growing season for oats averaged three days shorter than for wheat. This indicates that for the varieties studied, oats are more likely to reach maturity during short growing seasons than wheat. Also, immature oats are more suitable as a forage crop than immature wheat, so oats are a better crop choice where the growing season may be limited.

A comparison of the mean time, temperature, and solar-energy requirements of the three grains (Table 12) can be used to determine which of the grains can be expected to produce mature crops in any particular area of the state, when the climatic characteristics can be predicted. Since Edda barley always required less energy to mature the crop than oats or wheat, it is used as a standard.

TABLE 9: EDDA BARLEY, ENERGY REQUIREMENT, PLANTING TO HARVEST AT THE AGRICULTURAL EXPERIMENT STATION, MATANUSKA FARM, PALMER, ALASKA.

Planting Date	Harvest Date	Days	Growing Degree-Days	Global Radiation	Net Radiation
5/18/64	8/29/64	103	1361	38,893	25,176
5/10/65	9/02/65	115	1294	42,520	22,214
5/17/66	9/09/66	115	1435	42,461	18,938
5/08/67	8/21/67	105	1619	35,997	18,129
5/17/68	8/13/68	88	1407	38,347	18,856
5/14/69	8/19/69	97	1537	43,842	18,116
5/18/70	9/04/70	109	1476	36,927	18,782
5/12/71	8/31/71	111	1450	39,263	14,370
5/24/72	8/25/72	93	1448	39,518	22,249
n		9	9	9	9
SD		9.64	94.3	2665	3128
$\bar{x}$		104.0	1447	39,752	19,648
C.V.		9.27	6.51	6.70	15.92

TABLE 10: GOLDEN RAIN OATS, ENERGY REQUIREMENT, PLANTING TO HARVEST AT THE AGRICULTURAL EXPERIMENT STATION, MATANUSKA FARM, PALMER, ALASKA

Planting Date	Harvest Date	Days	Growing Degree-Days	Global Radiation	Net Radiation
5/18/64	9/06/64	111	1483	42,243	26,929
5/10/65	9/19/65	132	1514	45,460	23,598
5/17/66	9/24/66	130	1529	44,238	19,364
5/08/67	9/01/67	116	1785	38,936	19,601
5/17/68	8/24/68	99	1603	42,047	20,506
5/14/69	8/20/69	98	1549	44,358	18,254
5/18/70	9/08/70	113	1507	37,675	19,153
5/12/71	9/12/71	123	1552	41,670	15,177
5/24/72	9/08/72	107	1639	43,942	24,227
n		9	9	9	9
SD		12.27	92.9	2594	3562
$\bar{x}$		114.3	1573	42,285	20,757
C.V.		10.73	5.91	6.14	17.16

TABLE 11: GASSER WHEAT, ENERGY REQUIREMENT, PLANTING TO HARVEST AT THE AGRICULTURAL EXPERIMENT STATION, MATANUSKA FARM, PALMER, ALASKA.

Planting Date	Harvest Date	Days	Growing Degree-Days	Global Radiation	Net Radiation
5/18/64	9/16/64	121	1583	44,960	28,142
5/10/65	9/13/65	126	1441	44,871	23,375
5/17/66	9/26/66	132	1553	44,592	19,424
5/08/67	8/31/67	115	1768	38,698	19,476
5/17/68	8/13/68	106	1497	44,488	21,534
5/14/69	8/25/69	103	1602	45,551	18,700
5/18/70	9/13/70	118	1535	38,847	19,594
5/12/71	9/21/71	132	1623	43,482	15,749
5/24/72	9/01/72	101	1542	42,072	23,580
n		9	9	9	9
SD		11.86	91.8	2632	3592
$\bar{x}$		117.1	1572	43,062	21,064
C.V.		10.18	5.84	6.11	17.05

TABLE 12: ENERGY REQUIREMENT OF EDDA BARLEY, GOLDEN RAIN OATS, AND GASSER WHEAT WITH PERCENTAGE REQUIREMENT OF EDDA BARLEY.

	Days		Growing Degree-Days		Global Radiation		Net Radiation	
Grain Variety	Mean	Percent of Edda	Mean	Percent of Edda	Mean	Percent of Edda	Mean	Percent of Edda
Edda barley	104.0	100.0	1447	100.0	39,752	100.0	19,648	100.0
Golden Rain oats	114.3	109.9	1573	108.7	42,285	106.4	20,757	105.6
Gasser wheat	117.1	112.6	1572	108.6	43,062	108.3	21,064	107.2

ANALYSIS OF DATA

Agricultural land use planning processes in Alaska require the assessment of the climatic characteristics of areas not now used for agriculture. This publication relates the accumulation of certain climatic characteristics to the growth and maturity of selected agricultural crops. The day, GDD, GHR, and NR accumulation requirements of these crops can be used as a basis for prediction of the performance of the crops studied in any area where the climatic characteristics can be estimated.

The predictor that has shown the least variation in previous years is likely to be the most useful one. Table 13 lists C.V. for the observations of days, GDDs, GHR, and NR. Variation in yields produced with and without irrigation are also included.

Caution must be exercised in drawing conclusions, especially for single crops exhibiting very low C.V. values for only four to six readings. An example would be "days" to maturity for the lettuce crops. The day requirement would be less likely to transfer from one geographic location to another than the temperature or solar energy-based measurements.

Table 13 displays the C.V. of all the crops in a manner permitting selection of the overall most influential climatic factor on plant maturity. Single harvest crops are listed in the first harvest column rather than with the last harvest because, generally, the time of first use would be the determining factor in whether or not these varieties of vegetable crops had potential for production in a geographic area.

The climatic factors which appear to be most promising as a predictor of plant maturity are GDDs and GHR. These appear to be about equally effective when considering all crops, because the C.V. values are nearly the same.

The uniform conditions under which the grain crops were produced and the greater number of production years make this data worthy of special consideration. The grain crops, in particular, bear out the contention that GDD and GHR are more closely related to plant growth than growing days or NR accumulations.

Since GDD and GHR are the superior climatic characteristics for prediction purposes, the minimum, mean, and maximum values for annual accumulation by each crop are presented in Table 14. These values should allow reasonable predictions of the suitability of the various crops to areas in Alaska for which probable GDD or GHR values can be established. The single harvest crops will have suitable production most years if the accumulated values for the area are equal to or exceed the mean values shown in the table. The multiple harvest crops will usually produce a first crop at accumulations listed in the "mean" column of the table, and will produce additional yield if greater temperature or solar-energy accumulations occur before frost.

TABLE 13: COEFFICIENT OF VARIATION (C.V.) OF THE ENERGY REQUIREMENTS FOR THE PRODUCTION OF CROPS AT PALMER, ALASKA.

Crop	No. of Crops	Days		Growing Degree-Days		Global Radiation		Net Radiation		Yield	
	(1)	(2) First	(3) Last	(2) First	(3) Last	(2) First	(3) Last	(2) First	(3) Last	Irrig.	Nonirrig.
Lettuce (Premier Great Lakes)	5-4	1.83	0.77	6.63	5.51	5.54	7.27	20.27	24.38	26.03	79.22
Lettuce (1971)	6-4	2.92	3.83	10.11	9.52	5.36	5.85	4.05	4.58		
Carrots (Chantenay type)	6	7.44		6.29		8.73		17.26		33.92	76.81
Celery (Utah 52-70)	6	6.53		5.71		10.22		16.69		31.84	23.02
Broccoli (Transplants)	4-4	15.72	9.57	15.12	7.96	8.35	8.77	17.46	11.53	20.21	24.19
Broccoli (Seeded Harvester)	4-4	5.32	7.54	5.29	5.76	10.05	9.98	19.89	18.43		
Cauliflower (Snowball type)	4-4	19.39	15.16	17.31	8.14	19.99	13.10	21.91	15.16	19.17	40.06
Brussels sprouts (Jade Cross)	4-5	15.20	5.45	12.30	7.92	16.93	14.70	19.93	15.75	19.64	25.26
Barley (Edda)	9	9.27		6.51		6.70		15.92			
Oats (Golden Rain)	9	10.73		5.91		6.14		17.16			
Wheat (Gasser)	9	10.18		5.84		6.11		17.05			
Average of 6 (4)		10.06	7.05	11.13	7.47	11.04	9.95	17.25	14.97	25.14	44.76
Average of 11		9.51		8.82		9.46		17.05			

(1) For each harvest listed.

(2) C.V. of accumulation at first significant harvest.

(3) C.V. of accumulation at last significant harvest.

(4) Crops with two harvests or moisture levels.

TABLE 14: RANGE AND MEAN GROWING DEGREE-DAYS (40°F BASE) AND GLOBAL HEMISPHERIC RADIATION (LANGLEYS) REQUIREMENT TO FIRST HARVEST FOR CROPS PRODUCED AT PALMER, ALASKA.

Crop	Growing Degree-Days			Global Hemispheric Radiation		
	Min.	Mean.	Max.	Min.	Mean	Max.
Lettuce (Premier Great Lakes)	1167	1266	1329	30,833	33,598	35,374
Lettuce (1971)	1070	1214	1365	30,177	31,509	34,885
Carrots (Chantenay type)	1523	1647	1824	34,816	40,590	44,382
Celery (Utah 52-70)	1488	1567	1683	31,147	37,390	42,572
Broccoli (Transplant)	714	786	904	19,223	21,050	23,413
Broccoli (Seeded Harvester)	1069	1147	1206	26,697	28,648	32,918
Cauliflower (Super Snowball)	630	790	963	16,110	21,673	26,584
Brussels sprouts (Jade Cross)	1242	1429	1664	29,013	36,843	44,255

CONCLUSIONS

GHR and GDDs have been shown to be better indicators of when crops will reach a useable stage of maturity than days or NR. At first glance, NR might seem to be the climatic characteristic most closely associated with plant growth, since it approximates the amount of solar energy actually retained at the earth's surface.

One possible reason for the poor correlation between NR and date of first harvest is the large negative component of NR at night, especially during the latter part of the season. In the fall as the days begin to shorten, it is possible for the incoming positive component of NR for bright sunny days to be practically offset by the outgoing negative component during clear nights. This results in very low average daily accumulation of NR during some excellent growing days in the fall. Both GHR and NR tend to be near a maximum during the first part of the growing season when less cloudy weather occurs, rather than later in the season in the Matanuska Valley.

The spring season in the Matanuska Valley is characterized by long clear days and cool nights. Transplanting cannot typically be performed before the last week in May because of the danger of frost, but daily radiation accumulation is at its highest at this time of year. The temperatures of soil and air are cool, and plant growth is slow. Several days earlier planting date in the spring results in only a few days earlier harvest, but a disproportionately larger radiation accumulation. Average daily values of GHR and NR listed in Technical Bulletin 3 (Branton, Shaw, and Allen, 1972) for the last week in May are 448 and 225 langleys while by mid-September are reduced to 203 and 82 langleys. Some of the days in mid-September will even have negative totals for daily NR values.

Recent additions to instrumentation for the study of the quality of solar radiation at the Agricultural Experiment Station, Palmer Research Center, permit the measurement of reflected solar radiation and the diffused component of incoming solar radiation. Planned additions will permit the easy measurement of the positive portion of the NR which occurs during the daylight hours. These additional measurements may permit the breaking down of solar radiation into components more closely related to plant growth. Future experiments can be designed to incorporate multiple plantings, uniform-aged transplants, and other factors to eliminate variation not associated with incoming energy levels.

Until these refined procedures yield additional information, it appears that reasonably accurate predictions of plant performance can be made from either GHR or GDD based on the requirements presented here.

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