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G. W. Robertson

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SOME AGRO-METEOROLOGICAL PROBLEMS IN CANADA

by

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SOME AGRO - METEOROLOGICAL PROBLEMS IN CANADA

G. W. Robertson

THE CLIMATE OF CANADA

Canada embraces a range of climatic conditions as great as, and possibly greater than, any other major country in the world. In the far north there is permanent frost (12) on the Arctic Island. Farther south, in the northern fringe of the Northwest Territories and in Northern Quebec and Labrador there is a zone of Tundra. South of this Tundra zone is a vast region in which the climate, to some degree, is favourable for agriculture in one form or another. The climates in this vast area range from the cold, microthermal types in the northern fringes of the provinces to the moist, perhumid areas of the west and east coasts and the dry semi-arid regions of the prairie provinces. To be more specific, some record breaking meteorological data can be quoted. The coldest temperature ever recorded in Canada is -83°F at Snag, Yukon, in 1947. The highest temperature is 114°F at Weyburn, in the prairie region of Saskatchewan. Heaviest rainfalls occur along the west coast where, in some areas, over 16 ft. of precipitation occur each year. Just a few hundred miles inland, some of the valleys of interior B.C. have almost a desert climate, receiving less than 10 inches of precipitation annually.

Not only is Canada's climate variable from place to place, but in certain localities great extremes may occur from year to year. At Indian Head, in southern Saskatchewan, summer rainfall has varied from 6.57 inches in 1929, to 20.22 inches, over three times as much, in 1901.

In recent years another factor which varies greatly with latitude has been recognized as being important in agriculture. This is the duration and intensity of daylight. The length of the longest day of the year varies from about 15 hours at Pelee Island, the most southerly point in Canada to 24 hours at points north of the Arctic circle. Variations in daylength have a profound influence on the growth and development of certain crops when grown at latitudes other than that of their natural habitat (7) (9). Quantity and quality of natural daylight may also have an influence on plant or crop growth but little work has been done on this subject.

With such a great range in climatic conditions in Canada, the meteorological problems which face the agriculture industry as well as agricultural research are manifold. It would be impossible to do more than briefly list a few of the more important problems here. This appears pointless however, and it is proposed, instead, to tell you how one of these problems is being attacked by the Division of Field Husbandry, Soils and Agricultural Engineering, of the Experimental Farms Service, to which I have been seconded.

THE MAJOR PROBLEM

Phenomenal growth habits have been observed in certain crops grown in Northwestern Canada (11). Thatcher wheat matures 15 to 20 days earlier at Ft. Vermilion than at Lacombe. Early blue peas not only mature 5 days earlier at Ft. Vermilion than on irrigated land at Lethbridge, but produce a 60% greater yield at the more northerly location. Brome grass grown for hay at Beaverlodge outyields that at Lacombe by 22%. Most of the common varieties of vegetables grown in Canada can be grown at Beaverlodge, Ft. Vermilion and Ft. Simpson. Potatoes at Ft. Vermilion yield as good as, or better than, potatoes in New Brunswick. Cabbages will develop to the size of a washtub at Aklavik well beyond the Arctic circle in a relatively short growing season. Certain plants, on the other hand, show unfavourable growth habits. Root crops and lettuce, which are biennial plants in southern parts of Canada, bolt and produce seed in the first year on northern farms. What is the environmental factor which favours such phenomenal growth at high latitudes?

These abnormal growth habits in sub-arctic regions of western Canada pose one of the greatest problems in agro-meteorological studies in Canada today. It is estimated that there are over 18,000,000 acres of potentially arable land in northwestern Canada. As this land is brought into production, new varieties of grain, forage, and horticultural crops will have to be bred to be best adapted to the climate and day-length of that area. In order that plant breeders can develop suitable varieties it is necessary, first, to know in detail how and why present varieties respond to meteorological conditions, and second, to measure and study the meteorological conditions of the area in more detail than has been done in the past.

This second part of the problem can be partially answered by studying existing climatological records of the area taken over past years. The climatological data pertinent to agriculture is shown for a few representative stations in Table I. Data for Ottawa and Lacombe are also shown for comparative purposes. Compared with climatological data at more southerly stations, the outstanding features of the climate of northwestern stations are:

1. Relatively short vegetative and frost-free seasons.
2. Nearly normal rate of accumulation of day-degrees of growth in the early part of the vegetative season. Individual stations vary somewhat.
3. Rapid accumulation of daylight hours in the early part of the vegetative season.
4. Low rainfall.

The long hours of daylight undoubtedly are the major cause of unusual growth in the far north. Other factors may also be important, however. Unusual daily temperature distribution, light quantity as well as quality, low transpiration rates and possibly other factors not yet apparent may contribute to the unusual growth.

PRELIMINARY INVESTIGATIONS

In order to try to find the answer to these problems a preliminary investigation was started at Ottawa this past summer. The main purpose of this work was to develop a method or technique for studying the response of a crop to its meteorological environment. Details have to be worked out as to the best methods of measuring both the growth and development of the crop and the meteorological environment. Furthermore, methods of analyzing and relating plant response and the environmental factors have to be worked out.

Growth and development data were obtained from two different types of crops, crown proso millet and Redman wheat. In order to obtain data under a wide range of meteorological conditions, six plantings of each crop were made at about intervals of two weeks. Each planting was large enough so that a portion could be cut periodically to determine dry matter increase. A further measure of growth was determined by taking height measurements twice a week. Grain yields were also determined when the crop was harvested. Development was determined by noting the date at which the crops reached certain physiological states such as emergence, tillering, heading, flowering and maturity. Certain precautions were exercised to assure that soil type, fertility, and cultural practices were uniform for all six plantings of each crop. Replicates of each planting were made so that systematic errors, if any, could be removed.

In order to measure the meteorological environment, a weather observing station was set up near the experimental plots. Standard measurements of temperature, dew point, wind, sunshine and rainfall were made once or twice daily according to standard climatological procedure.

Soil moisture and soil temperature at several depths as well as evaporation were also measured. Total daily solar and sky radiation data were available from the meteorological station at the Uplands airport, about four miles away.

No microclimatological observations were made this first season. It was felt that where possible standard meteorological observations should be used. This would facilitate duplication of the experiment at other stations. Also , any conclusions arrived at could be applied to existing climatological data to determine the possible response of a crop to the climate of other regions.

The data collected during the first year have been partially analysed. Many of the results are questionable because of the limited number of observations. There were two interesting studies made, however, the conclusions of which may have considerable bearing on future work of this nature.

CROP DEVELOPMENT AND DAY LENGTH

It was found that the interval from date of emergence to date of heading became progressively shorter for the later plantings of millet. For wheat the reverse held true, the later plantings had a longer period between date of emergence and date of heading. Several relationships involving temperature and day-length were attempted. It was finally found that the number of accumulated hours of daylight during the period was closely related to the length of time it took the crops to head. Since this accumulation depends upon the day-length at time of emergence as well as after, the variation is real and not merely a result of the length of the period. The relationships are shown in Figure I. A regression equation was calculated for the best fit line. The equation was put in the form:

$$\text{for wheat} \quad \sum_{o}^{H} (L - 10.7) = 194$$

$$\text{for millet} \quad \sum_{o}^{H} (L - 18.3) = -147$$

Where $\sum_{o}^{H}$ signifies the sum of daily values from date of emergence to date of heading and L is the daily duration of daylight.

It appears that, for Redman wheat at Ottawa, 194 hours of daylight over and above 10.7 hours per day are required by the crop during the period of development from emergence to heading. A similar interpretation of the equation for millet cannot be made since at no time at Ottawa was the duration of daylight as great as 18.3 hours. If, however, the equation is expressed in terms of hours of darkness, there is a physical interpretation. The equation becomes:

$$\sum_{o}^{H} (D - 5.7) = 151$$

where D = length of night from sunset to sunrise.

It appears from this relationship that crown proso millet at Ottawa requires a constant number of hours of darkness over and above a threshold value of 5.7 hours per night during the period of development from emergence to heading. The physiological reason for these differences in response of wheat and millet to light is as yet unexplainable although the phenomena have been observed in many plants (7). Nevertheless, they are real and further studies with different types of crops at different locations should aid in developing a relationship which will make it possible to predict how a crop will react to day-length at different latitudes.

Temperature undoubtedly may have an influence on this effect of day-length on the development of a crop. Investigations at Ottawa during the past summer, however, failed to reveal any influences which were significant. Investigations under cooler conditions may show a temperature influence (9).

In terms of crop response at different latitudes, the results of this investigation indicate that wheat should develop seed earlier and easier in northern Canada where the days are long, whereas millet should do best in southern areas where days are shorter and nights longer. This is exactly what agronomists have observed. Wheat and other related cereal crops mature early and yield well at Ft. Simpson and Ft. Vermilion, whereas millet sets seed only with the greatest of difficulty. Similar relationships between day or night-length and vegetable crops may help to explain bolting or the initiation of reproduction in such crops as lettuce, beets, spinach, etc., at northern stations.

THE EFFECTIVE GROWTH TEMPERATURE OF A CROP

The second investigation, using growth measurements made during the past summer, was to determine the part played by sunshine and other meteorological factors in controlling the effective growth temperature of a crop.

The idea of "heat units" or day-degrees of growth was used in 1834 by Boussingault (1). Today canneries and market gardeners (2) (8) use the idea extensively and with fair success in predicting the time required for various crops to reach maturity. The heat units are based entirely on daily mean air temperatures measured according to standard meteorological practice. It appears only too logical that if such methods give fair-to-good results, better results should be attained if temperatures close to the plants were used, or better still, if plant tissue temperatures were used. Such measurements, however, though possible to make, are not practical as a general procedure because of technical difficulties (6).

It is here proposed that a "heat balance equation" can be set up for a crop and by using only standard meteorological measurements the effective crop temperature can be determined. Then by relating this effective crop temperature with growth, it should be possible to evaluate the importance of this total heat balance to crop growth. An investigation along somewhat similar lines was recently reported by Waggoner and Shaw (13). In their research, however, they worked with individual leaves rather than the crop as a whole.

The role of solar and sky radiation in warming plant tissue is adequately demonstrated in Figure II (5). Here it is shown that leaves exposed to sunlight may be 13°F warmer than air temperature. Further, a wilted leaf is warmer than a turgid leaf and a leaf edgewise to the solar beam is cooler than one normal to it.

By considering the crop as a whole rather than as individual plants, it is assumed that it acts as a horizontal flat surface which absorbs, reflects, and reradiates energy as a unit. The heat balance of this unit can be calculated and ultimately the crop temperature. This temperature will not be the same as the air temperature, but generally will be somewhat higher, depending upon the meteorological conditions which govern the total heat balance of the crop. Since the crop will respond to its own temperature and not necessarily to the air temperature, measurements of growth will be indicative of the effective crop temperature. Thus from observations of crop growth it should be possible to solve the heat balance equation of the crop.

THE RADIATIVE HEAT BALANCE OF A CROP

A schematic representation of the radiant heat balance of a crop is shown in Figure III. Sun and sky radiation, H_s, is the energy measured by means of a pyroheliometer. Part of this energy, rH_s, is immediately reflected by the crop. The reflectivity, r, of growing plants varies considerably but averages about 20%. Thus only 80% of the solar and sky radiation is available to the crop.

The crop, because of its temperature, radiates long wave radiation, H_B, according to the Stefan-Boltzman law. The water vapour of the atmosphere absorbs a large percentage of this radiation and reradiates it both upwards and downwards. That part which is reradiated downwards, H_M, is available to the crop. Thus the radiant heat balance of the crop can be given by:

$$H_R = H_s - rH_s - H_B + H_M$$

Cloudiness affects the net long-wave radiation received by the crop, and Penman (5) gives an empirical correction for cloudiness. Thus

$$H_R = (1-r)\, H_s + (H_M - H_B)\, (0.10 + 0.90\, \frac{n}{N})$$

where n = hours of bright sunshine

N = total possible hours of bright sunshine and the ratio $\frac{n}{N}$ is therefore a measure of the cloudiness which affects the net incoming long wave radiation.

The outgoing radiation, H_B, can be evaluated by the Stefan-Boltzman law:

$$H_B = \sigma T_p^4$$

where T_p is the crop temperature in degrees Kelvin. The radiation from the moisture vapour in the atmosphere (4),

$$H_M = \sigma T_a^4 (a + b \sqrt{e_d})$$

where T_a = air temperature in degrees Kelvin

e_d = vapour pressure in inches of mercury

and a and b are constants.

The radiant heat balance then becomes

$$H_R = 0.80\ H_s - 0.117 \times 10^{-6}\ T_a^4 \ (0.56 - 0.46\sqrt{e_d})\ (0.10 + 0.90\frac{n}{N})$$

where numerical constants have been introduced and it is assumed that $T_p = T_a$ which is in keeping with other assumptions in the equation.

THE TOTAL HEAT BALANCE OF A CROP

The radiative heat balance is only a part of the total heat balance of the crop. There are two other important processes by means of which heat is gained or lost by the crop. These are by means of the turbulent flow of the wind and by the process of transpiration.

In the absence of radiation, wind, and transpiration, the initial heat content of the crop is assumed to be

$$H_o = CMT_a$$

where C = specific heat of the crop

M = mass of the crop affected per unit area.

It is further assumed that the initial temperature of the crop in this case is equal to the air temperature, T_a.

The total heat content of the crop after its thermal balance has reached an equilibrium condition in the presence of radiation, wind and transpiration, is:

$$H_T = H_o + H_R - H_E - H_W$$

where H_E = heat used in the transpiration process to convert water to vapour

H_W = heat carried away by turbulence.

The heat used for transpiration is the most doubtful to evaluate. Under conditions of optimum soil moisture where ample water is always available to the root system, it can be assumed that transpiration is approximately equal to evaporation. Thus H_E can be evaluated from measurements of evaporation or can be calculated by Penman's evaporation equation (10). Where there is a deficiency of soil moisture, transpiration may be less than the measured evaporation. Under such conditions other methods must be found for determining the rate of transpiration. Because of copious and frequent rainfall (Figure IV) during the past summer at Ottawa, it appears that soil moisture should have been readily available to the crops at all times and so it was assumed that transpiration was equal to evaporation as calculated by Penman's Equation (10).

The term involving the heat carried away by the turbulence of the wind can be calculated by means of an empirical relationship:

$$H_W = CM\ (T_p - T_a)\ kW$$

where W = wind speed in miles per day at 6ft. above the surface
k = a constant involving the co-efficient of eddy conductivity of the air.

Thus the total heat balance equation for the crop becomes:

$$H_T = CMT_a + H_R - H_E - CM\ (T_p - T_a)\ kW = CMT_p.$$

Solving for crop temperature:

$$T_p = T_a + \frac{H_R - H_E}{CM\ (1+kW)}$$

If k = 0.01, Penman (10), it is possible to calculate all factors excepting CM.

Now, if it is assumed that growth, G, is proportional to crop temperature (van't Hoff rule):

$$\text{i.e.}\quad G \propto T_p$$

$$\text{or}\quad G = AT_a + B\ \frac{H_R - H_E}{1 + 0.01W}$$

The constants A and B will fix the relative importance of air temperature and the radiative and conductive heat balance of the crop. Since all factors can be calculated or measured it will be possible to solve for A and B by the method of partial regression.

Before solving the equation, however, it is necessary to express growth and heat balance in terms which can be correlated.

RELATIVE GROWTH

It was mentioned previously that six crops of millet were planted at two-week intervals throughout the early part of the summer of 1952. Height measurements made of these six crops every 3 or 4 days provided the necessary growth data to solve the heat balance equation.

It is characteristic of plants to grow slowly while young, then go through a rapid period of grand growth, then grow more slowly while nearing maturity.

This variation of growth is illustrated in Figure V. Since temperature influence on growth will be masked by these physiological variations in growth, they must be removed or allowance made for them. This was done by dividing the interval from date of emergence to date of heading, for each crop, into 8 equal periods and the interval from date of heading to date of maturity into 2 equal periods. The mean daily average growth for each of the 10 periods was calculated for the 6 crops. Then the daily average growth for each period was expressed in terms of the mean growth for that period. This was called relative growth. The relative growth of the first three plantings is shown in Figure VI. Note that on certain dates there is a similarity in the relative growth of different plantings. This similarity suggests that there is some common environmental factor operating on certain dates to affect the relative growth of the three plantings in the same manner.

Relative mean daily temperature and relative mean daily heat balance were calculated in a similar manner for the 60 periods. Thus there were 60 sets of triple values from which the constants of the heat balance equation could be solved.

SOLUTION

The total correlation co-efficients were found as follows; the prime (') indicates relative values:

G' vs T'_a : $r = 0.390$ significant at 1% level.

G' vs $\frac{(H_R - H_E)'}{(1 + 0.01W)}$: $r = 0.244$ significant at 5% level

T'_a vs $\frac{(H_R - H_E)'}{(1 + 0.01W)}$: $r = 0.167$

These show that the relative mean daily growth is more closely related to mean daily relative temperature than to mean daily relative heat balance, although the latter is a significant factor in crop growth. Solving the equation,

$$G' = 0.83\,T'_a + 0.22\,\frac{(H_R - H_E)'}{(1 + 0.01W)} - 0.049.$$

Mean daily air temperature was calculated above a base of 50°F. This threshold value for millet was determined from previous investigations. The small co-efficient 0.049 confirms this choice of 50°F for a threshold temperature.

The multiple correlation co-efficient, $R = 0.430$, is significant at the 1% level. The regression equation can be converted to terms of actual growth, temperature and heat balance. There will be 10 such equations, one for each period. The ratios of the constants of these 10 equations, B, were found to be nearly equal and they averaged 0.18. This factor gives A the average effective growth temperature equivalent of the heat balance term $\frac{H_R - H_E}{1 + 0.01W}$. Thus the effective crop temperature

$$T_p = T_a + 0.18\,\frac{H_R - H_E}{1 + 0.01W}$$

From this equation the daily effect of radiation, conduction and transpiration on the effective crop temperature can be calculated.

Calculations show that the net heat balance of the crop contributed considerably to the effective crop temperature. On the average, the mean daily effective temperature of the six millet crops grown at Ottawa was calculated to be 4.5°F. warmer than the mean daily air temperature. Calculations of the effective crop temperature on individual days yielded some interesting results. Calculations for four cases are shown in Table II. The case on May 11th. is an example of the heat balance under cloudy and windy conditions when solar and sky radiation are very low. Under these conditions more than the available radiant energy was used for transpiration with the result that heat is taken from the crop. Consequently the crop temperature was 2° lower than the actual air temperature. June 12th was a case of high solar and sky radiation on a clear day. Because of this high available energy and a large vapour pressure deficit, transpiration was high. Thus most of the heat was used for transpiration with only enough left over to increase the crop temperature by 8° over the air temperature. Had there been no available soil moisture so that the crop could not transpire, its temperature, according to calculation, would have been 42°F. above the air temperature! On July 8th the highest daily mean temperature of the summer occurred. Wind and radiation were also high so that again transpiration was great. Most of the available energy was therefore used in the transpiration process and consequently the crop temperature was raised only 4°F. above air temperature. The case of Sept. 8th is one where transpiration was low because of light winds and a small vapour pressure deficit. Radiation was greater than average and so sufficient energy was available to heat the crop 15°F. above the air temperature.

These calculated differences between crop temperature and air temperature are in line with direct observations made by other investigators on leaf temperature (13) (5), and air temperature in the immediate vicinity of the crop (3).

To further indicate the importance of this heat balance in crop growth and development, a comparison was made between the accumulated heat units based on mean daily air temperature alone and that based on calculated effective crop temperature. The base or threshold temperature for these calculations was 50°F. The difference between the rate of accumulation of heat units is shown in Figure VII. Accumulated heat units based on calculated effective crop temperature are 23% greater than those based on air temperature alone.

IMPLICATIONS

Results of this study suggest that serious errors may ensue when air temperature alone is used in certain studies of environmental factors. When temperature is used:

(1) as an indicator of crop development to determine date of maturity;
(2) in climatic zonation problems;
(3) in the study of insect pests and pathological problems;

the effect of radiant energy, transpiration and wind on the heat balance of the crop may be important factors and should not be overlooked.

FUTURE PROBLEMS AND RESEARCH

This is only a beginning. No definite or far-reaching conclusions can be drawn from only one year's work. Although certain crops appear to respond to light very closely, the effect of temperature still has to be investigated and undoubtedly will be found important. If all crops will yield to this type of mathematical analysis a lot of work can and should be done to determine the response co-efficient of various crops and varieties. Such co-efficients should be of great value to plant breeders who are attempting to select varieties for specific climatic conditions.

The calculation of the heat balance of a crop shows some promising results. Still there is much to be done. Instruments should be perfected for measuring terrestrial radiation so that recourse to an empirical formula does not have to be made. Methods have to be developed for measuring or calculating transpiration when there is a deficiency of soil moisture.

Two big problems in plant growth have not been mentioned. These are the effect of the water balance within the plant itself and the effect of light quality and quantity on photosynthesis. These studies will involve the design of new equipment and techniques for observing crop and environmental factors, and new methods of relating these factors.

Yes, the problems are many and the field in Canada is wide open. We are on a track — our only hope is that it is the right one.

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FIGURES

Figure I:	Elapsed time from date of emergence to date of heading of millet and wheat plotted against accumulated daylight hours during the period. The numbers refer to dates of seeding of wheat: (1) May 8, (2) May 24, (3) June 5, (4) June 19, (5) July 5, (6) July 17; of millet: (1) May 9, (2) May 30, (3) June 13, (4) July 3, (5) July 15, (6) July 25.
Figure II:	Temperature of apple leaves in sun and shade as influenced by the angle of exposure and water supply (5).
Figure III:	The radiative heat balance of a crop.
Figure IV:	Daily rainfall amounts during the summer of 1952 at Central Experimental Farm, Ottawa.
Figure V:	Growth (elongation) curves for six dates of seeding of crown proso millet at Ottawa, 1952. The arrows indicate the first appearance of heads.
Figure VI:	Relative growth of three crops of crown proso millet planted on May 9th, May 30th, and June 13th.
Figure VII:	The seasonal accumulation of day-degrees above a threshold of 50°F. using (1) air temperature, (2) calculated effective crop temperature.

Table I - Agro - Climatological Data for Some Northern Canadian Stations with Comparative Data For Some Southern Stations

Station	Latitude	Elevation A.S.L. Ft.	Length of Record yr.	Vegetative period Daily mean temperature above 42°F.		Mean Frost-Free (period (32°) Days	Accumulated day degrees above 42°F		Accumulated hours of daylight		Precipitation	
				Beginning Mean Date	Mean Duration Days		First 40 days of V.P.	Total for V.P.	First 40 days of V.P.	Total for V.P.	During V.P. ins.	Total Annual ins.
Aklavik	68°14'	30	24	June 2	99	65	350	860	900	1970	3.65	9.05
Ft. Simpson	61°52'	415	42	May 12	135	84	360	1725	720	2360	6.81	12.96
Ft. Vermilion	58°23'	950	40	May 5	143	68	350	1735	680	2340	7.67	12.05
Beaverlodge	55°10'	2484	32	April 24	171	92	270	1915	820	2620	10.07	17.36
Lacombe	52°28'	2783	41	April 21	171	79	235	2000	600	2610	13.09	17.92
Ottawa	45°24'	260	59	April 18	190	143	390	3330	580	2660	19.10	34.52

Table II - Examples of the Breakdown of the Heat Balance of a Crop

Date	Daily Mean Air Temp.	Dew Point	Wind	Solar Sky Energy	Radiant Heat Balance	Heat Used for Transpiration.	Net Available Heat	Contribution To Crop Temperature
	°F.	°F.	MPD	gm.	cal. /	cm^2 /	day	°F.
May 11	50	45	177	53	20	120	-13	-2
June 12	60	45	84	825	433	357	42	8 (42)
July 8	77	71	144	670	425	373	22	4 (31)
Sept. 8	49	48	53	556	299	173	82	15

DAYS TO HEAD
VS
ACCUMULATED DAYLIGHT

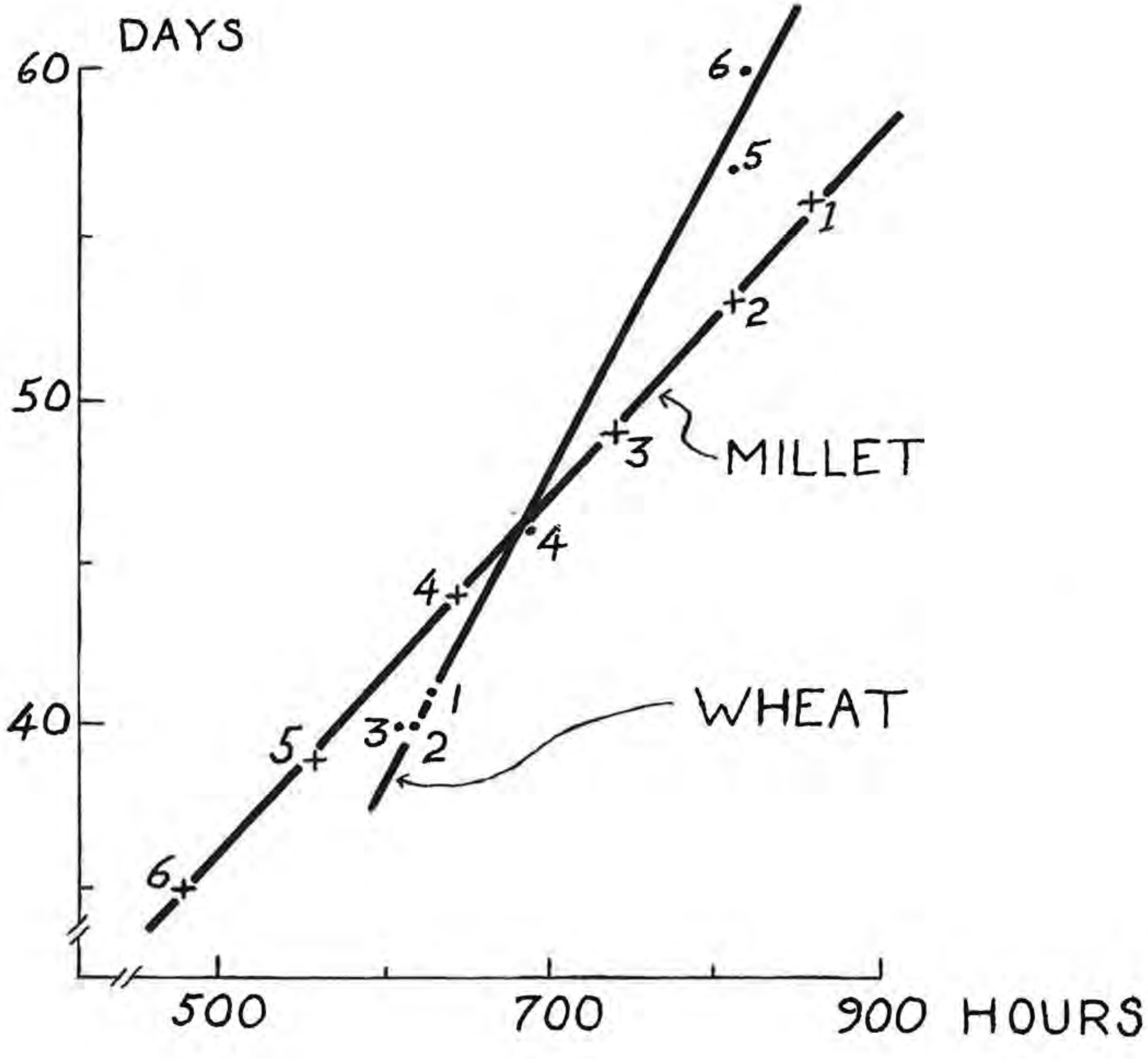

FIGURE I

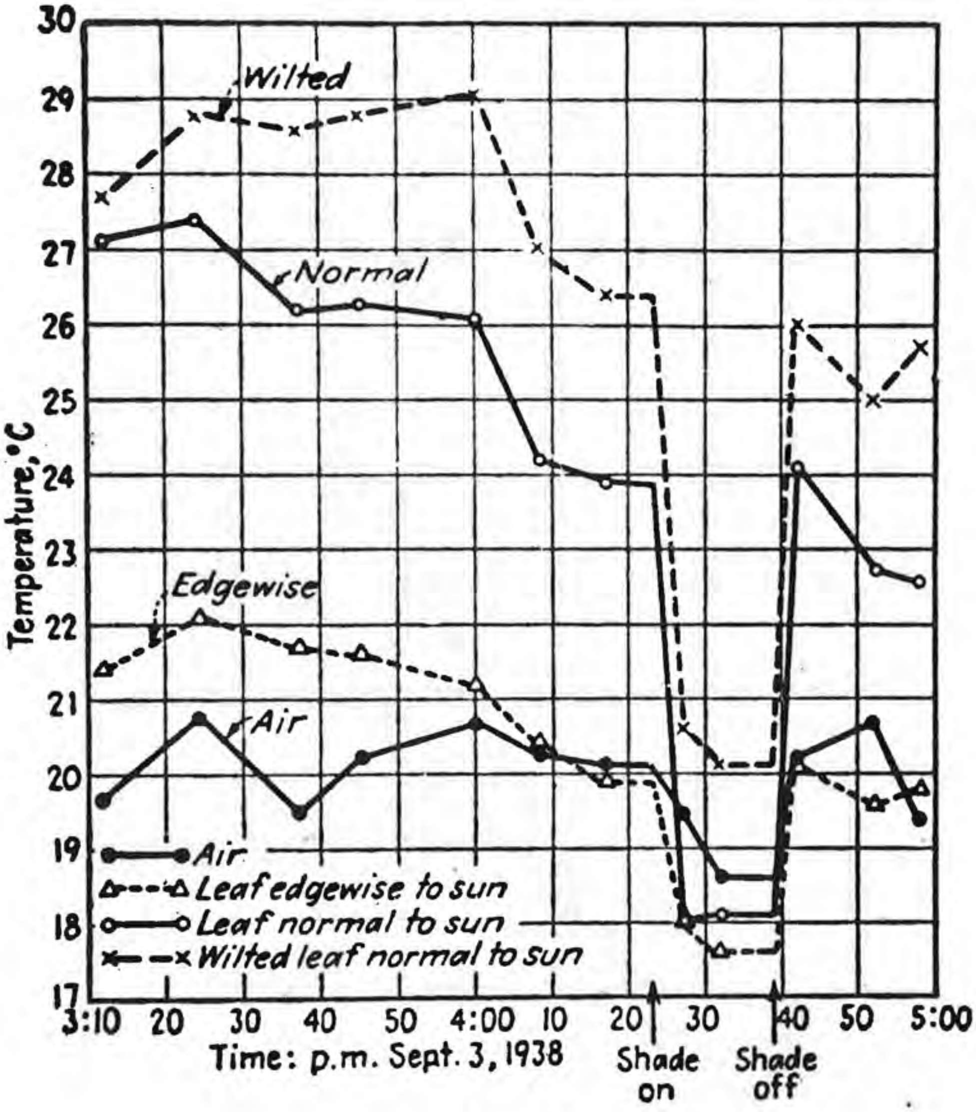
Temperature, °C
30
29
28
27
26
25
24
23
22
21
20
19
18
17
Wilted
Normal
Edgewise
Air
Air
Leaf edgewise to sun
Leaf normal to sun
Wilted leaf normal to sun
3:10
20
30
40
50
4:00
10
20
30
40
50
5:00
Time: p.m. Sept. 3, 1938
Shade on
Shade off

FIGURE II

RADIANT HEAT BALANCE OF A CROP

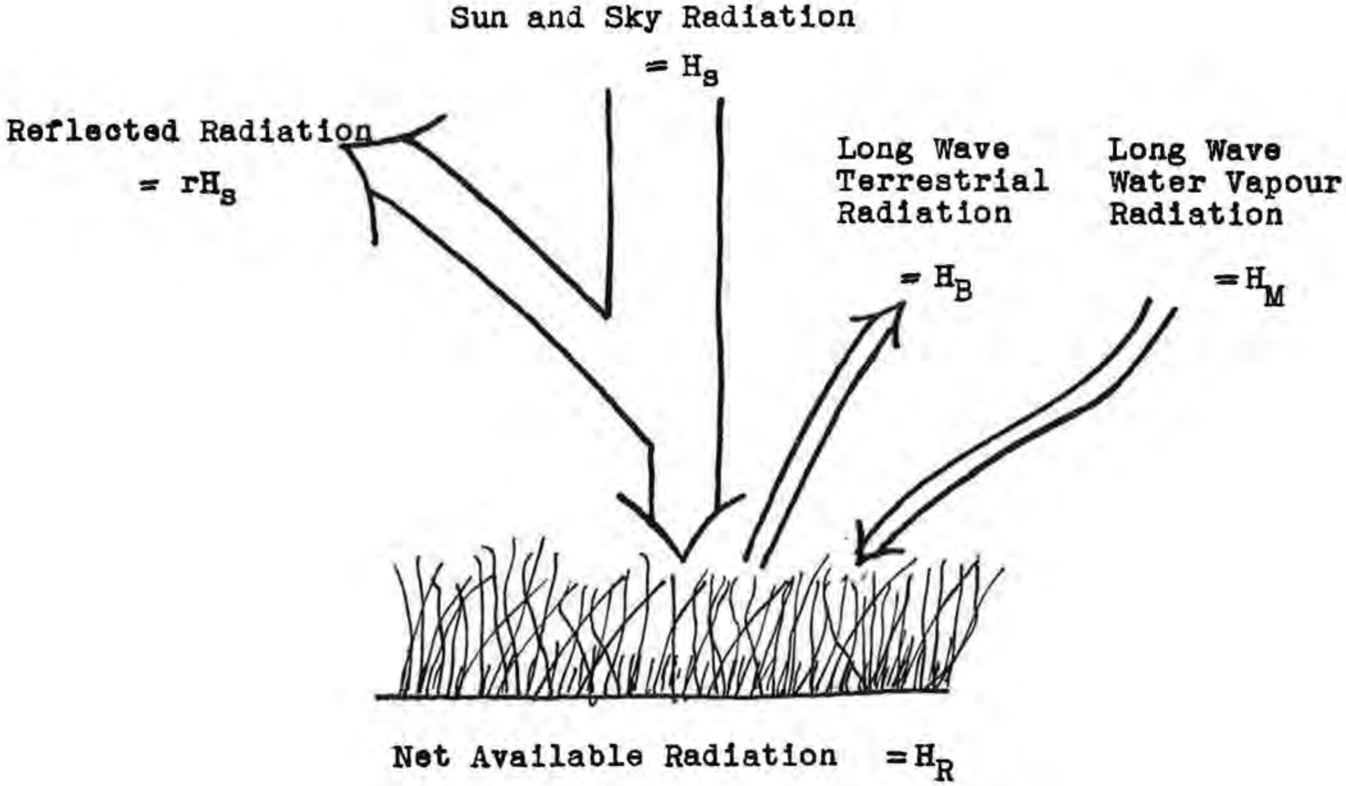

FIGURE III

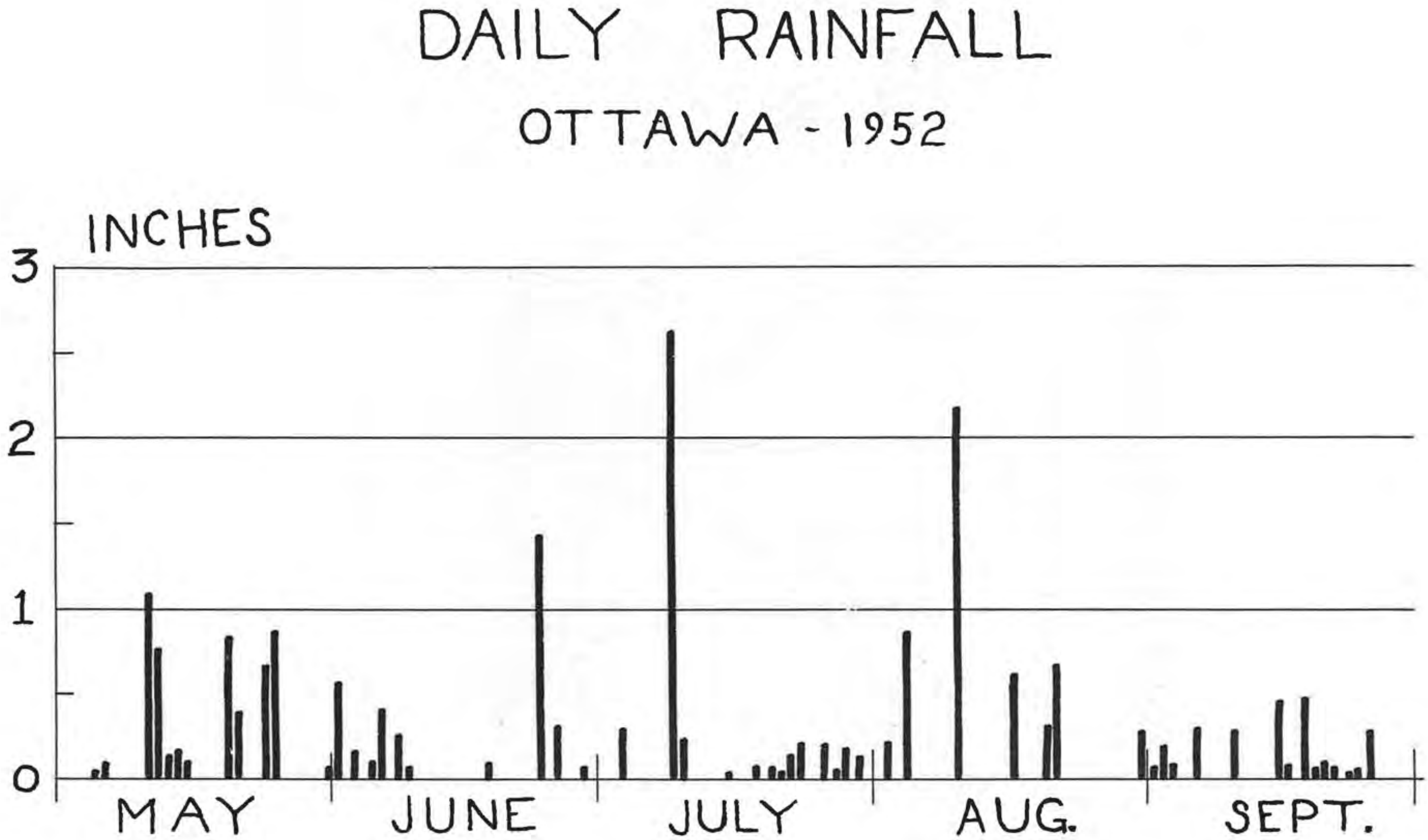
DAILY RAINFALL
OTTAWA - 1952
INCHES
3
2
1
0
MAY
JUNE
JULY
AUG.
SEPT.

FIGURE IV

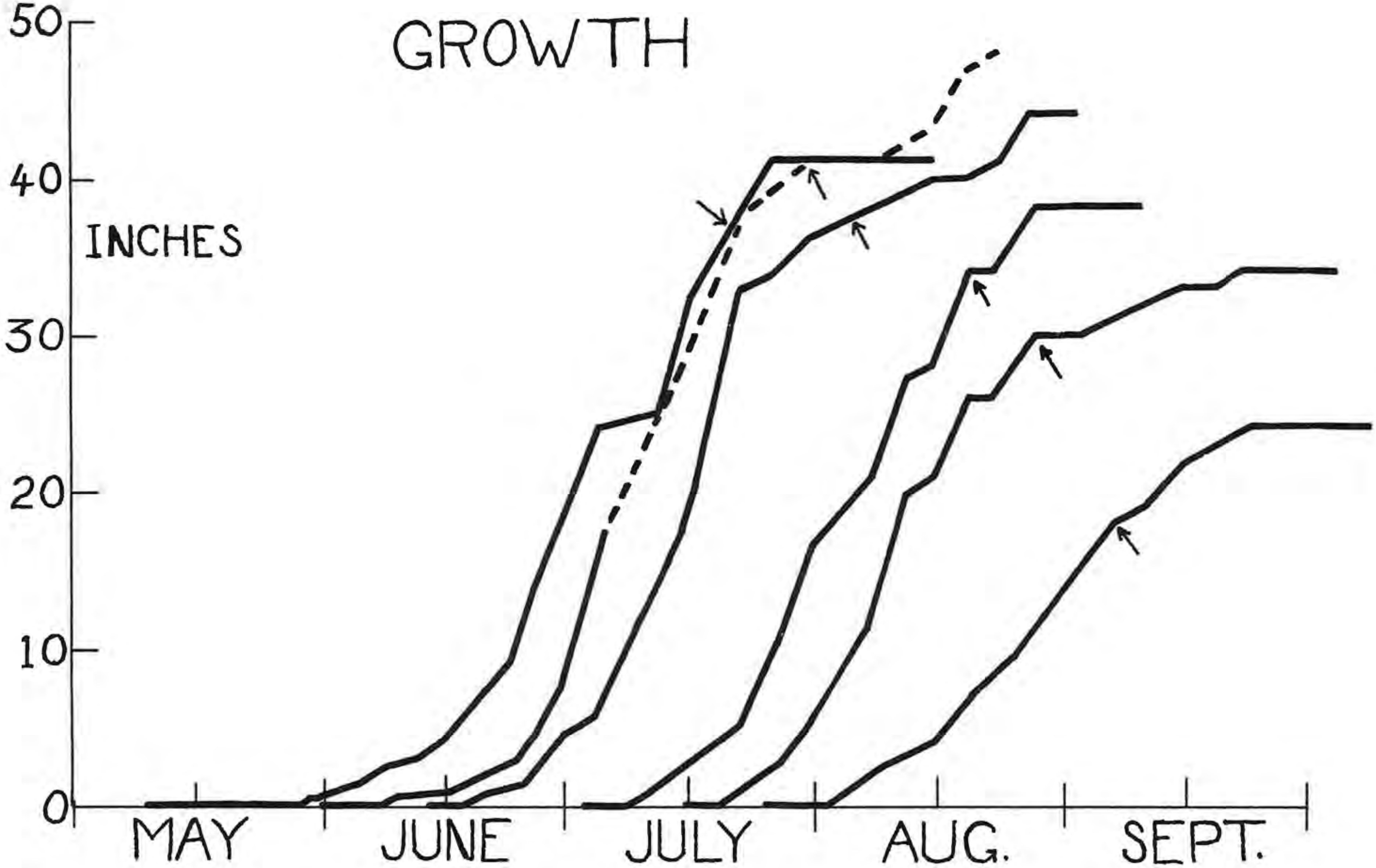

FIGURE V

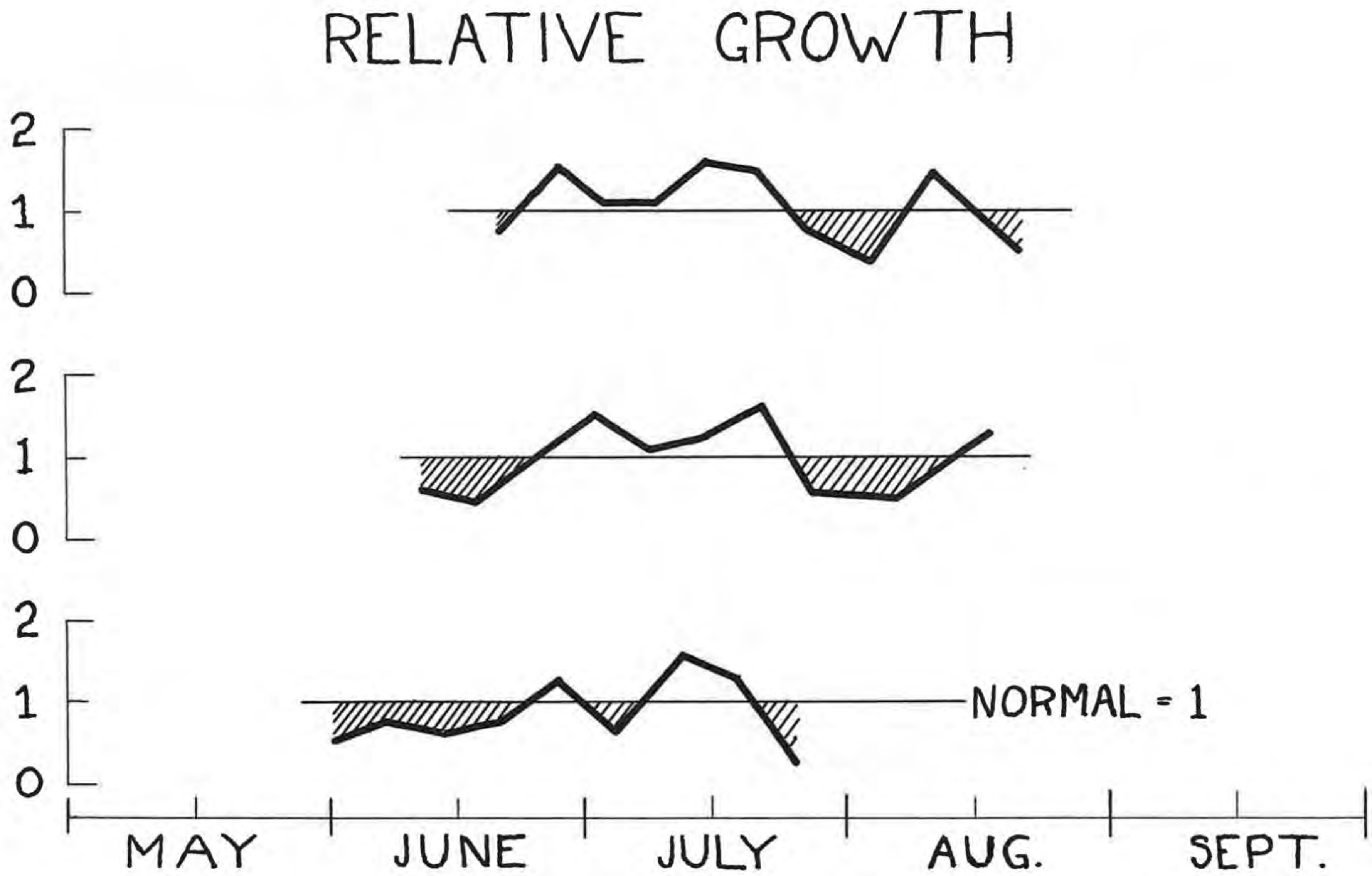

FIGURE VI

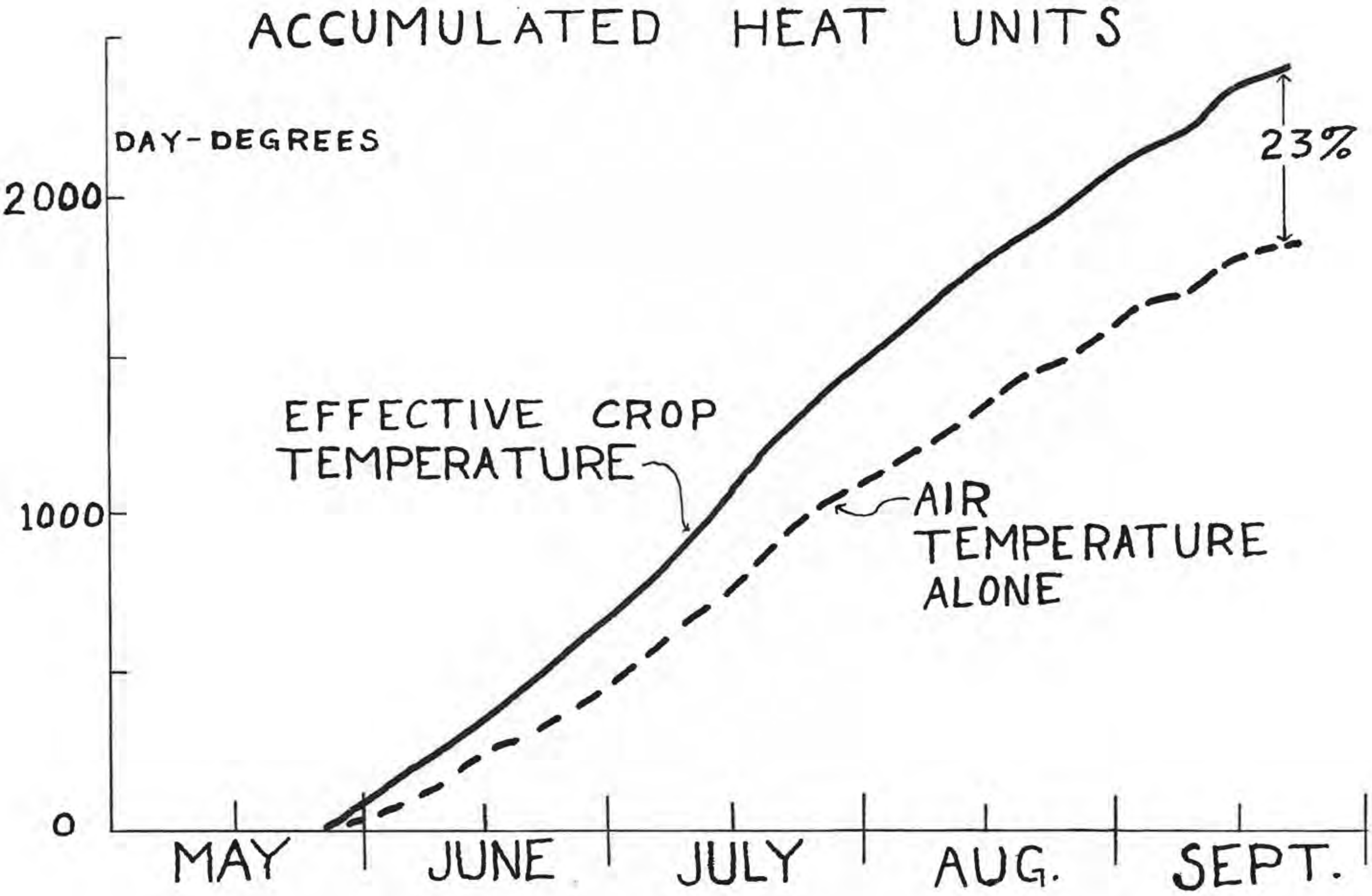
ACCUMULATED HEAT UNITS
DAY-DEGREES
2000
1000
0
EFFECTIVE CROP TEMPERATURE
AIR TEMPERATURE ALONE
23%
MAY
JUNE
JULY
AUG.
SEPT.

FIGURE VII