LIMITED DISTRIBUTION

A STUDY OF PHYTOMETEOROLOGICAL EFFECTS ON THE GROWTH AND DEVELOPMENT OF PEAS

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A STUDY OF PHYTOMETEOROLOGICAL EFFECTS
ON
THE GROWTH AND DEVELOPMENT OF PEAS

CHAPTER I

INTRODUCTION

In the present paper emphasis is placed upon a review of previous work as well as on the establishment of methods of phytometeorology. Not too many works have been done in the past on the weather-pea relationship, but over 200 articles have been collected relating to cultural practice and phytopathological problems. Those who worked on the meteorological requirements of peas, (most of them) used the heat unit system, with modification to some extent. As a matter of fact, almost all of the canning companies in this country use the heat unit system.

CRITICISMS OF THE HEAT UNIT SYSTEM.-- Criticisms of the use of the heat unit system have been developed in ~~the~~ recent years, (11,34,41,60)* by various investigators including those who work in the canning pea companies.** The flaws of the heat unit system are:

A. The heat sum for a process is constant only for that range within which there is direct proportionality between growth rate and temperature. Lack of such proportionality is

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*All figures in parentheses refer to Literature Cited.
**Personal talks with several workers in different pea companies.

usually found near both the upper and lower limits of tolerance.

B. The heat sums are usually based on average daily temperature. They do not take into account the possible special effects of the maximum and minimum daily values, night temperature, interdiurnal temperature and the difference between day and night temperatures, etc.

C. The heat sums do not include many other factors which influence the plant growth or development, such as precipitation, intensity of light, (as well as duration and quality), soil moisture and temperature, etc. Went (60) pointed out that no heat sum can account for the ripening of the tomato.

D. Over the growing season the growth of a plant is a continuous function, thus the growth versus time (say in days) is a near-linear function. This function is similar to the summation of heats units versus time. In view of the photosynthesis-respiration relationship these two physiologically unrelated factors sometime happen to be coincident because of their linearity. This does not prove that the heat sum is a determining factor of growth.

PHYTOMETEOROLOGY AND RELATED SUBJECTS.— There exists considerable confusion between the study of Plant Ecology, Phenology, Agricultural Climatology and Phytometeorology. The main difference is their method of approach, even though they are related. The differentiation of the above subjects are as follows:

A. PLANT ECOLOGY (both Autecology and Synecology) : (a) Much larger scope of environmental factors are considered, such as habitat of plants; nutrients (mode of, influence of, decomposition and regeneration of); biological factors (reproduction, population, symbiosis, antagonism); the community, succession and fluctuation as well as dynamics of the ecosystem. (b) Interest in spatial distribution, especially related to geographical study. (c) It is interested in describing the existed biological event related to its environment as well as the inter-relationship of all biological things. (d) It is a combination study in the development of plants relative to soil, air, fertilization, etc. Hence, the central tast of ecology is to delineate the general principles under which the natural community and its components parts operate. Modern ecology is concerned with the fundamental inter-dependencies between living things and their surroundings.

B. PHENOLOGY (phytophenology) : (a) It is a horizontal science so that meteorological, agricultural, geographical and biological sciences are all related to the phenological approach; (b) It is also the science of appearance. It emphasizes the date of appearance of certain events of plant life cycles, such as date of planting, of germination, of emergence, number of leaves (ripeness-to-flower), of floral primordia, of blossoming, of fruit setting, of maturity, of the color of leaf, of the falling of leaf and the death of annuals, etc. (c) It is also an auxiliary science for the ultimal aim of phenological study is to be used for all the related sciences. (d) It concerns primarily in the study of weather and native plants rather than cultivated plants.

C. AGRICULTURAL CLIMATOLOGY (or agricultural ecology): (a) It studies the geographical distribution, migration, and origin of agricultural crops. (b) It concerns biological relationships with the yield and quality of agricultural crops, such as relationships of developmental physiology; hormones and growth and reproduction; photoperiodism; breeding and analyses of environmental requirements; manipulation of developmental physiology on economic crops, etc., (c) It is also an ecological approach of agricultural crops.

The Study of PHYTOMETEOROLOGY is (a) from the standpoint of the pure meteorological approach, of course, techniques relative to micrometeorology, such as soil moisture and soil temperature, etc., are included. Emphysis is placed upon analytical and mathematical methods as used in meteorology; (b) with the average value of yield, of quality, of growth and development and with the average technique of cultural practice, such that the factors other than meteorological factors influencing the growth and development of plants are eliminated; (c) special meteorological observation, instrumentation, and analytical techniques are required for the phytometeorological approach; (d) It deals more with historical data rather than observational data of plants.

PURPOSES OF THE PRESENT PAPER. --(a) To study the development and growth of peas, particularly yield and quality, in relation to weather, including micrometeorology, microclimatology and the edaphic factors; (b) To predict the quantity and quality of pea production as well as the blossoming and harvesting dates; (c) To aid in farm planning-- the location of the most appropriate farm for pea growing in a region (a study of microclimate, isophene-chart analyses, especially slope climate) as well as in any other regions; (d) To facilitate the cultural practice - including: (i) Time and method of planting and harvesting, (ii) time and method of irrigation, (iii) time and method of fertilization, pruning, if necessary, etc.; (e) To control pest and disease by means of spraying, etc.; (f) To avoid weather hazard, such as frost -- freezing temperature, wind, flood, etc.; (g) To select correct weather conditions for transportation, storage, farm-processing, etc., if needed.

To the best of our knowledge, a review of this subject on a world-wide base and an approach from the pure phytometeorological method for the growth and development of peas has not previously been carried out. In other words, it is a new line of investigation, therefore, its theoretical set up and its methodology should be thoroughly explained, discussed as well as verified. More volume of that paper will be occupied by the description of methodology. While this is only a preliminary study on this subject, in our opinion it is of value in furthering the study of the methods of phytometeorology.

CHAPTER II

PEAS AND CLIMATE IN GENERAL

ORIGIN AND MIGRATION - The pea is the only vegetable that can with certainty be traced back to the Stone Age, as has been pointed out by James S. Shoemaker. It was found among the relics at Morssedorf, Switzerland (2000 - 2400 B.C.), known as the Swiss Lake region. Ethiopia is probably the main center of origin in growing the garden types now known as canning peas (Pisum sativum L.).

Ethiopia has an average altitude of 5000 feet above sea level, and the highest peak rises to 14,760 feet, around 10° north of the equator. Glancing at the mean monthly daily temperature (°F) and the mean rainfall (inches) of Addis Ababa (8005 ft.) and Harar (6089 ft.), it is obvious that the fluctuation of temperature is small, for the annual range of monthly temperature is only 7.1°F at Addis Ababa and 4.1°F at Harar. The annual temperature is 62.1°F for the former and 67.5°F for the latter. Addis Ababa has an annual rainfall of 49.6 inches, while Harar receives 35.3 inches. All these environmental factors are seemingly favorable for the production of peas, even though Ethiopia is located in the subtropical belt. In this latitude "the duration of daylight" or the interval between sunrise and sunset has its lowest interval from December 17 to 25, of 11 hours and 32 minutes, and its highest interval from June 21 to 29, of 12 hours and 43 minutes. The changes of civil twilight* throughout the year is quite uniform also. A maximum change in the year is two minutes only,

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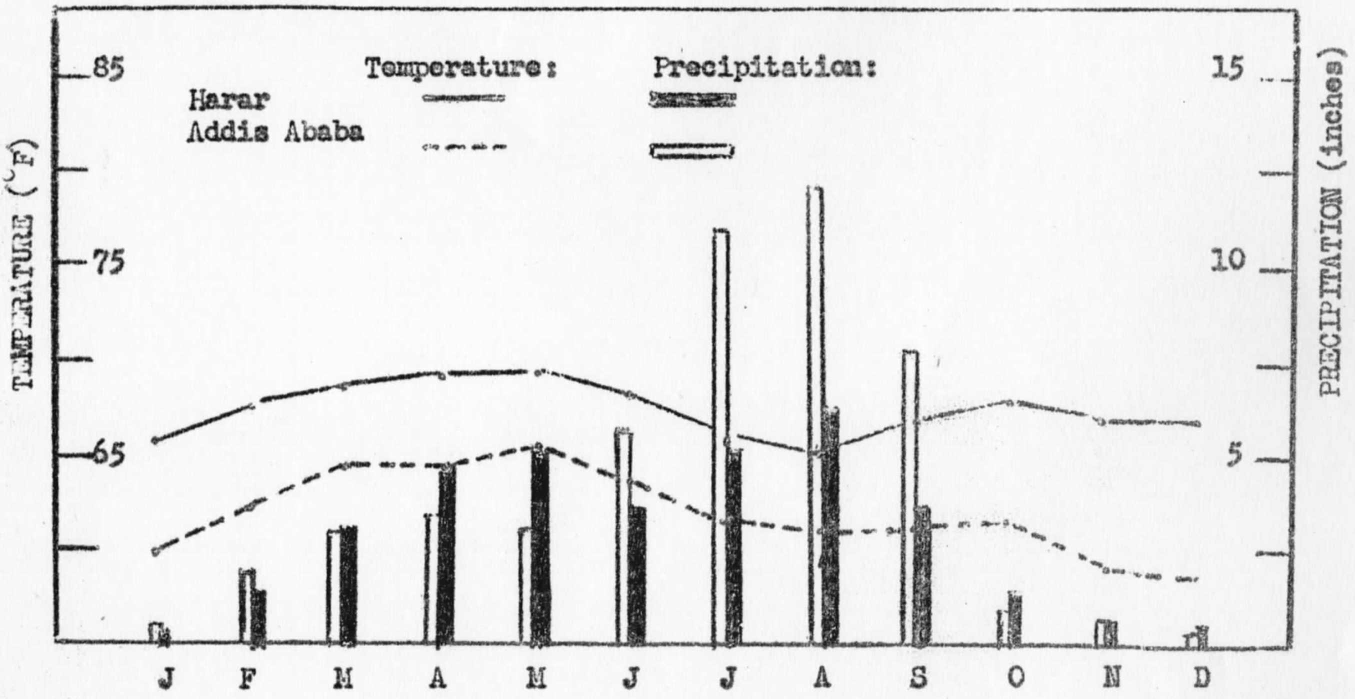
*It is defined as interval between sunrise or sunset and the time when the true position of the center of the sun is 6° below the horizon at which time stars and planets of the first magnitude is just visible.

namely 21 to 23 minutes. Thus the variation of daylength in the growing period of peas is too small to be of significance. The uniformity of daylength throughout the growing season may be significant to the weather-pea relationship. Reath (34) has shown experimentally that most varieties of garden peas will respond as day-neutral, if night temperature is 60°F or above. The monthly daily mean temperature for Ethiopia, throughout the year is about 60 to 68°F, (see Chart 1 below). With these two factors, limited change of daylength and a few degrees difference in temperature from month to month, one might assume that the peas grown there was day-neutral. From the concept of direct adaptation, one can further assume that garden peas originated in a day-neutral stage. Moreover, garden peas do well in humid, cool climates, with sufficient rainfall, but they are independent of latitude and altitude as far as solar intensity, duration and qality are concerned. (Since the detailed record of the varieties, yield, qualities, and cultural practices, etc., of garden peas grown in this ancient pea producing center are unavailable, therefore only general climatological features can be described). Chart 1 gives the average monthly daily mean temperature and the monthly rainfall of Addis Ababa and Harar to represent the general climatic conditions of Ethiopia.

Chart 1

Monthly daily mean temperature and monthly precipitation of Addis Ababa and Harar, Ethiopia, Africa. (Data obtained from Kendrew: The Climates of the Continent, 1941).



Peas were known for centuries in Rome and Greece, as well as ancient China. References to it are frequently found in their literature. One Lydgate, a writer in the time of Henry VII, mentioned peas being peddled about the streets of London. They were brought to America by the earliest colonists. In recent years, the United States and Canada have lead the world in the pea industry.

REGION OF PRODUCTION. Average pea (*Pisum sativum* and *Pisum arvense*) of production of the world in the recent 19 years (1934 to 1952) was as follows:

Table 1*

The Acreage, Production and Yield of Dry Peas in Different Continents of the World (1934-52).
(various types)

CONTINENT	AREA (1000 hectares)**	PRODUCTION (1000 metric ton)	YIELD (1000 kg/ha.)**
EUROPE	527	650	12.3
NORTH & CENTRAL AMERICA	135	169	12.5
SOUTH AMERICA	106	93	8.8
ASIA	5349	3844	7.2
AFRICA	308	198	6.4
OCEANIA	33	39	11.8
WORLD TOTAL	6458	4993	9.8

In the United States, Wisconsin leads in the production of peas for canning, and California in fresh peas. Peas can be grown as far north as Maine and Washington and as far south as Texas and Florida. They can also be grown through a wide range of altitudes, as well as latitudes, However, the canning pea region in North America is nearly the same as the Hay and Dairy Belt, which is in accord with the known preference of peas for cool temperatures.

The yield and acreage of Green Peas in U.S.A. by states (1951 to 1953) was as follows:

Table 2***

The Yield and Acreage of Green Pea Production in the 28 States in U.S.A. (1951-53)

STATE	YIELD IN TONS PER ACRE 1951	1952	1953	AVERAGE	ACREAGE (Acre) (Mean 1951-53)
MAINE	1.07	.69	.97	.91	7,627
NEW YORK	1.06	.77	.89	.91	24,633

* Data computed from F.A.O. of the United Nations: 1953 Yearbook of Food and Agricultural Statistics Vol. VII, Part 1, pp. 59-60.

** One hectare (or ha.) equals 2.471 acres.

***Data from "Agricultural Statistics", USDA (1954), p. 232.

	YIELD IN TONS PER ACRE				ACREAGE
STATE	1951	1952	1953	AVERAGE	(Mean 1951 - 53)
PENNSYLVANIA	1.25	.86	1.20	1.10	14,400
OHIO	.93	.76	.76	.82	2,400
INDIANA	.84	.88	.94	.89	2,553
ILLINOIS	1.16	.90	.99	1.02	28,233
MICHIGAN	.90	.61	.69	.73	5,913
WISCONSIN	1.24	1.00	1.01	1.09	127,667
MINNESOTA	1.01	.87	.87	.72	55,267
IOWA	.87	.72	.76	.78	4.133
DELAWARE	1.10	.97	1.24	1.10	2,467
MARYLAND	1.25	1.05	1.07	1.12	8,500
VIRGINIA	.94	.82	.90	.89	2,200
IDAHO	1.00	1.34	1.19	1.18	9,033
COLORADO	1.24	.98	.74	.99	3,400
UTAH	1.51	1.02	1.44	1.32	8,233
WASHINGTON	1.20	1.24	1.39	1.28	6,133
OREGON	.95	1.15	1.19	1.10	5,087
CALIFORNIA	1.32	1.53	1.27	1.37	9,967
OTHER STATES*	1.34	1.13	1.24	1.24	7,557

The above table illustrates that the highest yield of peas in United States from 1951 to 1953 was Utah (average height 3000 feet above sea level), however Wisconsin had the highest acreage for pea production. This may be caused by the cooler inter-mountain climate, particularly low night temperatures of Utah as compared with Ethiopia, as well as by the benefits of irrigation, which is common in the state of Utah. Again, looking at the two general climatological parameters, namely temperature and precipitation, we can choose the significant month** for these parameters for qualitative correlation with the yield in pounds per acre. This is shown in Chart II and III as follows:

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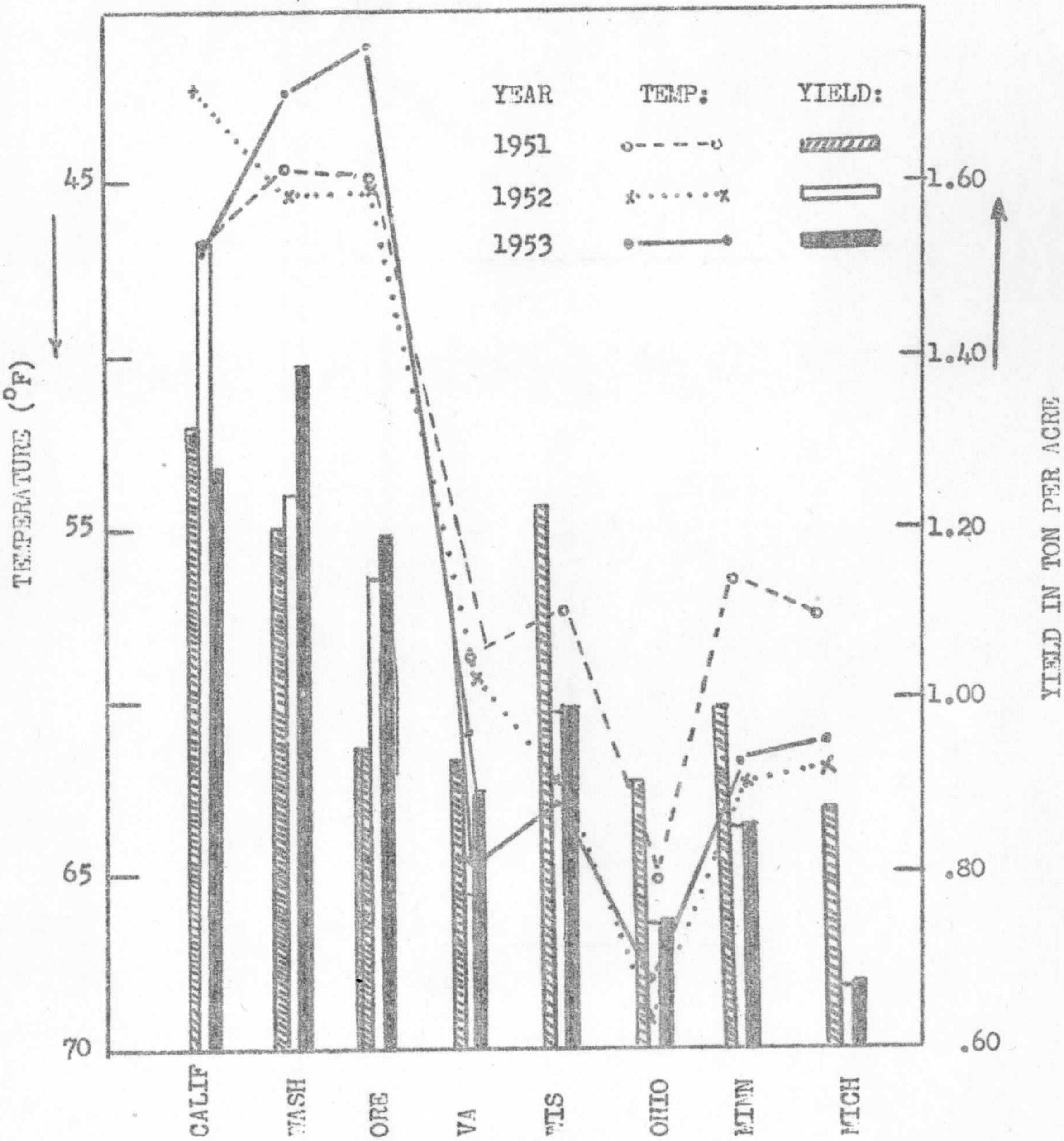
*Other states include: Arkansas, Kansas, Missouri, Montana, Nebraska, New Jersey, Oklahoma, Tennessee and Wyoming.

**Significant month designates the month whose climatological conditions are important to the growth and development of plants in general.

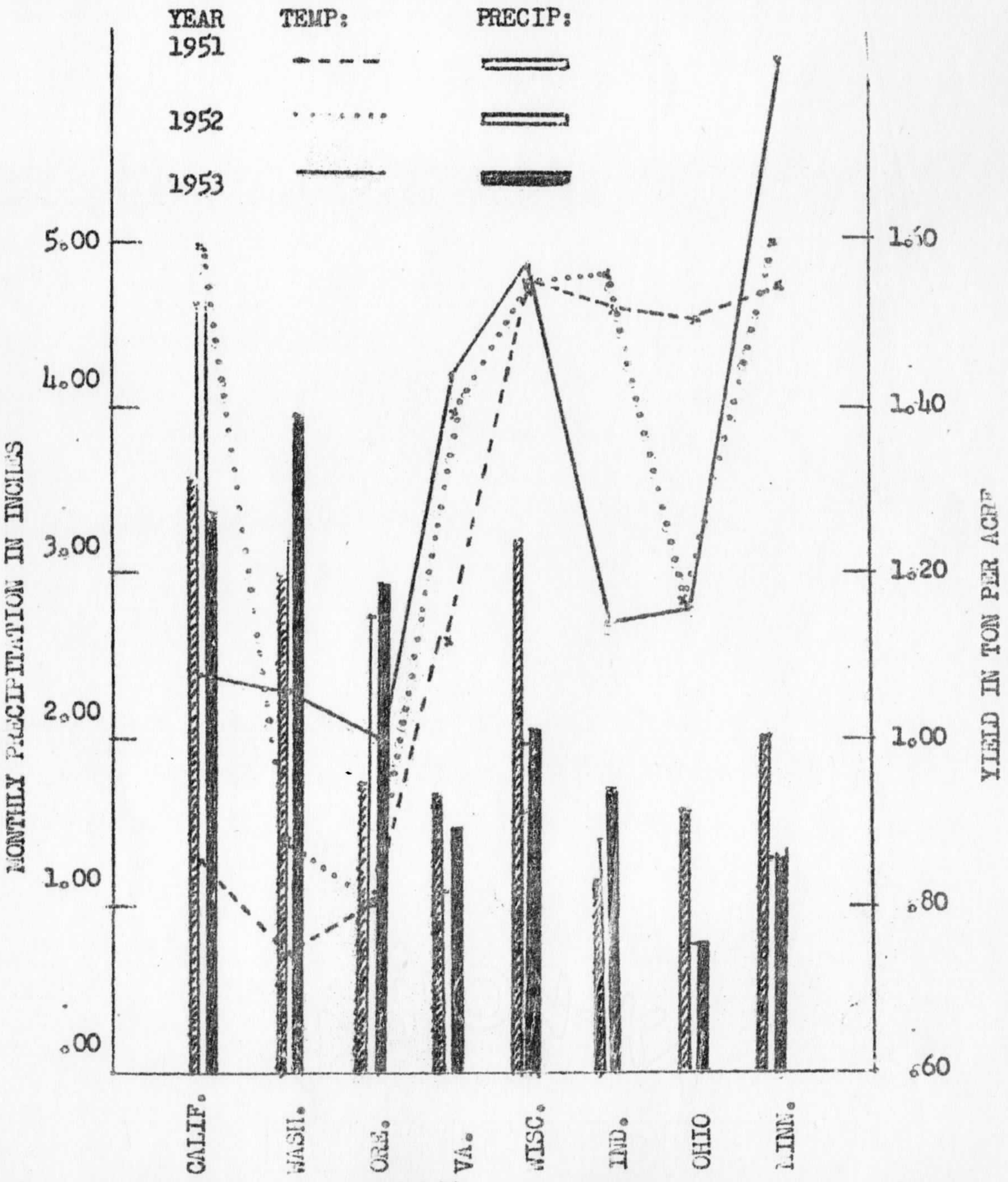
Chart 2

Effective Monthly Daily Mean Temperature
vs.
Yield in Different States of U.S.A. (1951-53)



The reversed temperature scale was used so that the reader can easily relate yield to temperature by a glance. In this connection, it is obvious that it works very well for several states but not all states. Of course, the state-wide average temperature adopted in chart II will not represent exactly the actual air temperature of pea growing regions.

Chart III
Effective Monthly Precipitation
vs. Yield for Different States in U.S.A. (1951-53)

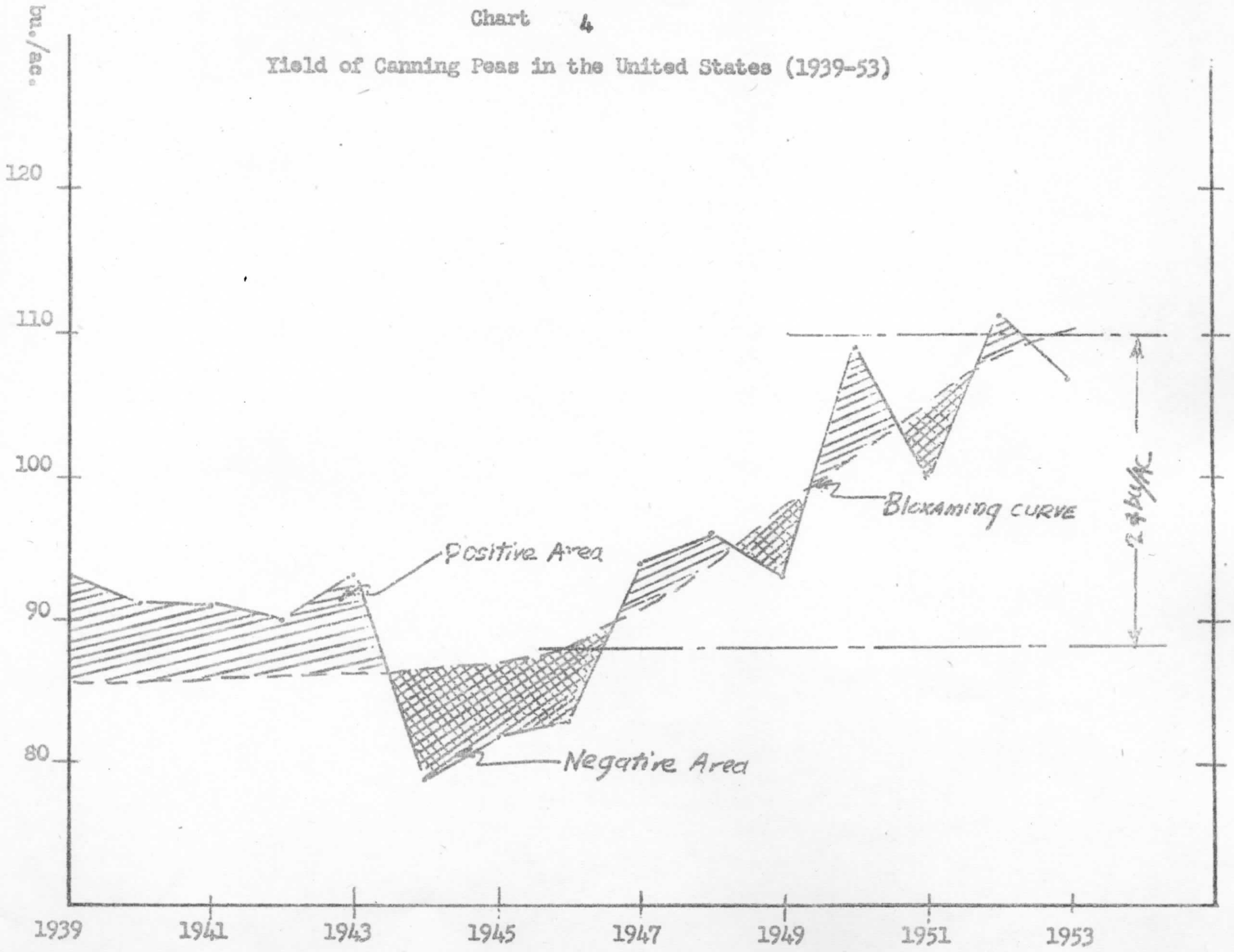


The consistancy of the significant month-precipitation vs. yield is not nearly as good as that of temperature. This might be due to the facts that the space variation of precipitation is large and the monthly precipitation interval is too long to be significant for yield. Again, this is especially true for the western coastal states.

For the United States, as a whole, the yield of peas has shown an average increase of 24 bushels per acre in the 15 years (1939 to 1953), as shown in Chart 4. The main reason for this tremendous change of yield may be due to the choice of better farms, or in other words, a marked difference in microclimate. The improvement of cultural practices may also be responsible for some of the increment. The Bloxaming curve used in Chart 4 is defined so that the summation of area below the curve, or negative areas, is equal to that above, or the positive areas. (Both positive and negative areas have been shaded and the increment of yield in 15 years range marked).

Chart 4

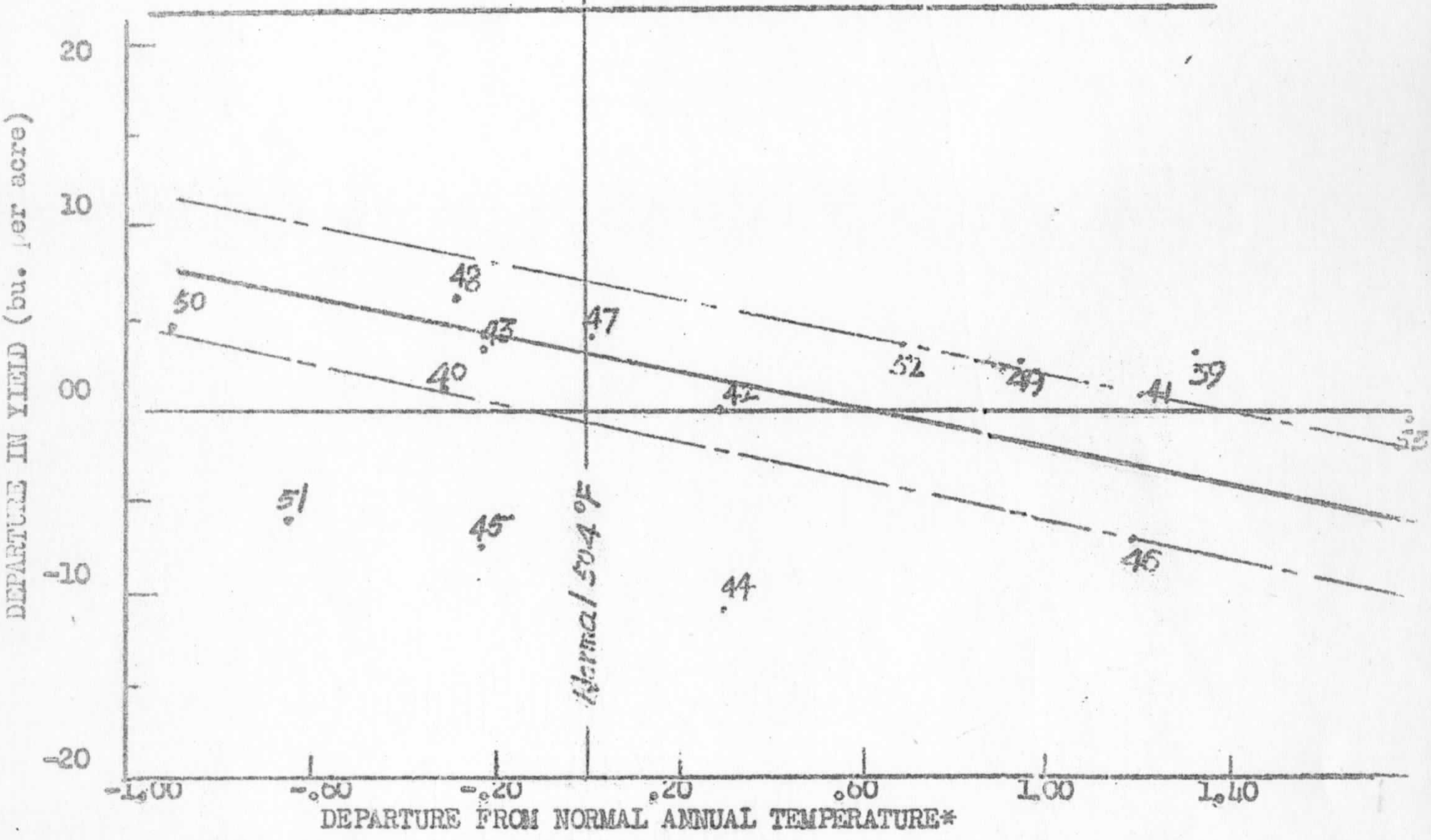
Yield of Canning Peas in the United States (1939-53)



The contribution of temperature and rainfall which go with the departure in yield from normal* on a yearly basis have been shown on Chart 5 and V6. Curves in both charts have been fitted by the method of least squares. In this paper, all lines or curves are fitted by the least square method, unless specifically stated.

Chart 5

Yield of Green Peas vs. Annual
Temperatures in U.S.A. (1939-1953)



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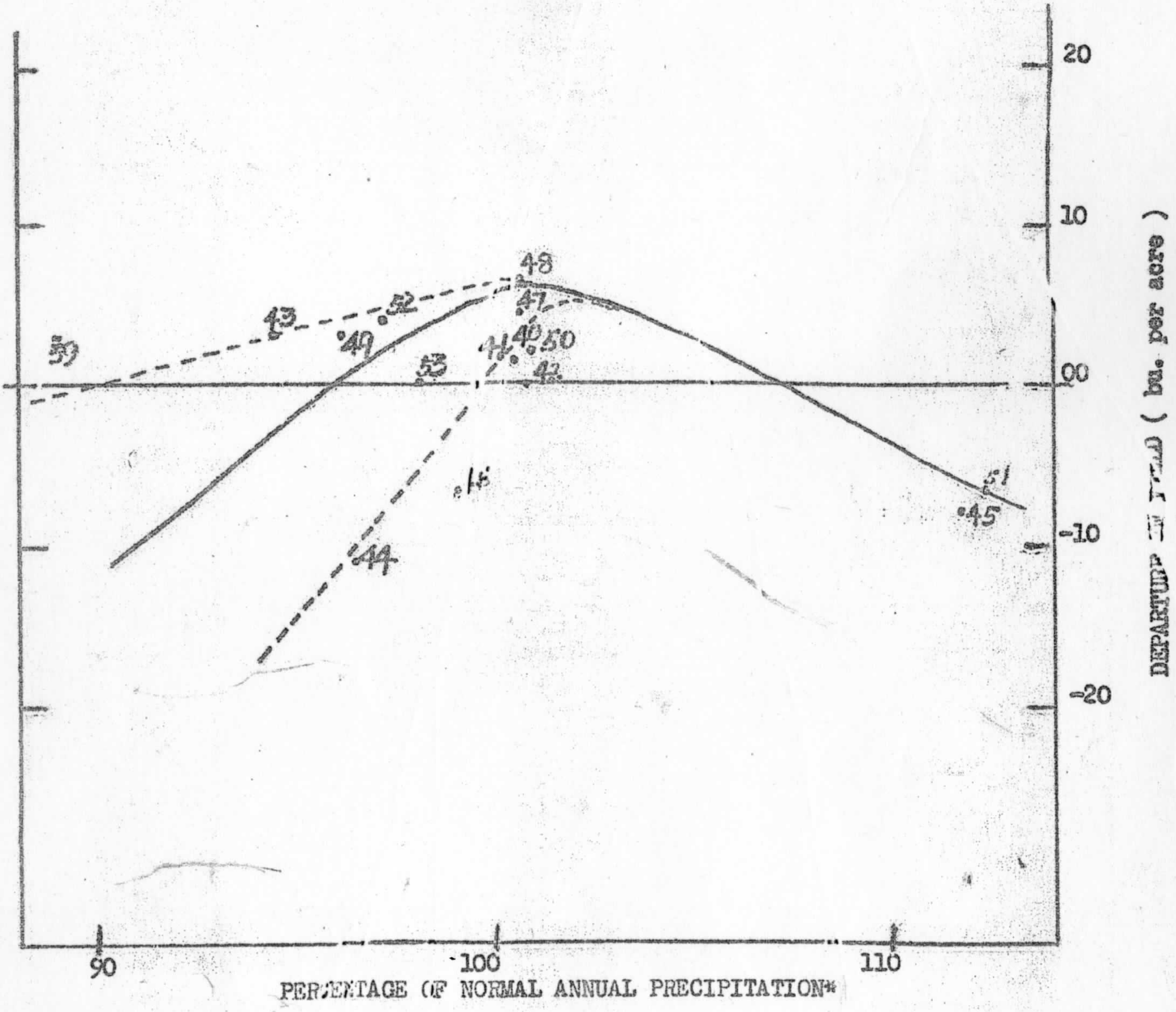
*According to the U.S. Weather Bureaus' definition of "normal" for temperature: For regular full-time Weather Bureau Offices the "Normals" are based on 30 year records from 1921 to 1950. For cooperative stations, in general, they are based on 10 years of records between 1921 and 1952.

Chart 6

Yield of Green Peas vs. Annual Precipitation in U.S.A. (1939-1953)



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*The percentage of normal annual precipitation is the ratio of actual annual value expressed in percentage.

The adoption of annual values rather than monthly or daily values in the above two charts encounters difficulty in the extreme divergence of growing seasons. For instance, the usual date of planting of peas in California is November 1 to February 15, and the usual date of harvesting begins on February 20 and ends June the 30th. Thus the most active harvesting time is between April and May, while in Wisconsin the usual date of planting is April 10 to May 15, which is quite close to this harvesting date for California. Even though the annual mean value used in the above is far from ideal, the general trend of irritabilities* shown is useful throughout this paper. They show: (1) Peas are cool season crops; not only is cool and humid climate needed, but also the requirements of tolerance to chilling and light frost**are necessary; (2) The need of water for the growth of peas have a certain limited value for optimum growth beyond which there is an upper, as well as lower limit. Neither too wet nor too dry will be favorable for normal yield and quality.

REVIEW OF PAST WORKS. It will be convenient to study the weather-pea relationship in the following manner:

(1) In chronological order
(2) According to various requirements of peas which are related to changes of weather, as: a.) water, b.) heat, c.) light, etc.

A. WATER REQUIREMENT: King in 1892 (45) found that the water requirement of peas expressed in transpiration ratio to be 477 in pounds per pound of dry material, which is only slightly lower than clover (564) and oats (515) and much higher than corn (301), barley (375),

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* The ability of plants to respond to stimuli of the environment.

**Peas have an inactive hypocotyl, therefore even a severe frost damage on the leaves and vines above ground will not cause the killing of the plant. By stooling from the axillary buds underground a continuous growth is always possible.

and many others. Briggs and Shantz in 1914 (8) made a more elaborate study and they found that the transpiration ratio would be different for different varieties of peas and also is changeable with time, however the transpiration ratio for the average of all varieties of peas is still higher than the average of all common crops. Shuttleworth in 1899 (45) performed experiments on the water requirements of maturing crops in sub-watered cylinders. His findings were 104 pounds for peas, 65 pounds for oats and only 34 for wheat. Walker (55) tested the yield of peas per acre in Erie County, New York. The yield is closely correlated (0.89±.01) with the rainfall during the month June. These data are based on the average yield per acre on an Erie County farm growing a large acreage of peas from 1914 to 1925. For each 0.10 inch variation in rainfall, there was an average variation in yield of 4.4 bushels. From this time on for decades no publications appear on the water requirements of peas. On the contrary, Curtis and Clark found that sufficient aeration for growing peas in culture solution (hydroponics) will definitely increase dry and fresh weight of peas as well as length of roots and length of top.

The Agricultural Experiment Station of California has estimated the amounts of water needed for different vegetable in a region of very low rainfall, where most of the water supply must come from irrigation. Those estimates, which assume that the root zone of the soil was well supplied with water at the time of planting, for peas and winter lettuce is 6 inches of water and all the other vegetables are higher than peas. Celery can be as high as 30 inches. MacGillivray in 1952 (28) pointed out that root rot is exaggerated by excessive rainfall and it is serious in hot dry spells. In 1952, Fieldhouse, in his Ph.D. thesis (13) determine under controlled experimental conditions that moisture is absolutely need for maturity and yield of canning peas. Veihmeyer and Hendricksen * in 1955 concluded from their own studies extending over many years and from the work of others, that transpiration is independent of soil moisture so long as the moisture content of the soil in contact with the absorbing portion of the roots is at or above the permanent wilting percentage. Brown and Hutchison in their book called "Vegetable Science," (see chapter 19, pages 277 to 284) stated" . . . rains following within a few minutes after the seed is planted often cause a marked reduction in germination. If rain does not follow for 36 hours after the seed is planted, the germination is rarely reduced to any serious extent." This may be the result of low soil temperature due to cold rain, or change in seed depth due to droplet impact.

(B) THERMAL FIELD: Saunders in 1892 (45) found that the germination temperature for the smooth pea is 80° F, wrinkled pea, 68-72° F. The vitality is almost destroyed at 90° F for smooth peas. In the same year Shaw and Zavitz (45) sowed peas at different dates between April 18 to June 6. The bushel per acre decreased with each successive seeding. For those sown on April 18, the average yield was 21 bushels per acre, while those sown on May 23 yielded only 9. Richards (35) in 1923 pointed out that soil temperature was an important factor affecting the pathogenicity of corticium vagum on the peas. Callender in 1924 (9) studied the temperature coefficient of peas which is a measurement of the sensitivity of the peas' response to temperature. He found a high temperature coefficient of 118 for peas. Also he stated that peas will be killed at 95° F within 7½ hours and can be damaged after only a few minutes.

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*Veihmeyer, F.J. and A. H. Hendricksen: Does Transpiration decrease as the soil moisture decreases? Amer. Geophys. Union Trans. 36: 425-28 (1955)

Jones and Tisdale in 1925 (21) investigated the effect of soil temperature upon the development of nodules on the roots of certain legumes. Their findings were that if the daily mean temperature in the soil reaches 59 to 86° F, diseases will develop rapidly, if there are any. Pesola (30) of Finland, in 1935 compared the effect of daylight and temperature related to growth of peas. He concluded that temperature is the decisive factor, while light can be neglected as far as his country is concerned. Boswell and Jones (5) in 1941 stated that 55 to 65° F is the optimal temperature for garden peas. Both quality and yield will be reduced, if temperature is higher than 80° F for even one day. Blossoms and pods will be seriously damaged by frost; however vines are undamaged. They will blossom again and yield a delayed crop for hardy peas. Alaska types of peas have higher resistance to frost, while Perfection is definitely stunted with abnormal growth and low yield. As a whole, peas are less resistant to heat and cold than cabbage. Campbell (10) in 1942 found a very good relationship established between temperature and tenderometer reading. In 1943 Kopetz (24) performed experiments on peas in Halle, Germany. He emphasized that the period preliminary to flowering, the "pure warmth sum" can be regarded as the "varietal constant" particularly for long day plant. From 1948 on, many papers have been published in the United States with respect to the heat unit system. Bomalaski early in 1948 (3) started to use growing degree days unit to measure the maturity of canning peas. He found that the maturity as measured by tenderometer reading is quite uniform at a given heat sum. Peas planted early, when the soil is cool, requires a lower heat summation for maturity than those planted later in the season. Variability in heat summation, due to soil type and fertility, topography and field stands are reduced in the plantings made later in the season. In the same year, Barnard (1) and afterwards Phillips (31), Katz (22), Fletcher (14), Walls (54), Hester (18), Sayre (36, 37, 38, 39), Huffington and seaton (41,42,43,44), Scott (40) and many others made various tests on the heat unit system and the yield as well as the quality of canning peas. Their findings can be summarized as follows:

(i) The daily heat unit accumulation for the growing season or during harvest is a straight line functions; (ii) the daily yield increases are closely related to heat unit values but fall off with advanced maturity; (iii) the tenderometer values show a definite curvilinear relationship with advancing maturity; (iv) the daily rate of change in tenderometer reading values is relatively slow between 85 to 100, but quite rapid beyond 100; (v) the heat accumulation necessary to bring the crop to the same stage of maturity as represented by a given tenderometer reading value was not constant, but varied in such a manner that it was lower when the season was cool, and higher when the season was warm; (vi) Alaska (Alaska, super Alaska, Alah, Yukon, Rocket) needs 1200-1250 degree days for 100 tenderometer readings; late Sweets (Profusion, Prince of Wales, Perfected Wales, Alderman, Bonneville, Miracle, Signal, Wisconsin Merit, and Walah) needs 1625 to 1725 for 100 tenderometer reading; (viii) Temperature is by far the most important factor for predicting harvest maturity of peas. Heat unit values in different areas and between seasons may vary; however, the accumulated heat unit technique proves to be a useful means to predict harvest maturity; (viii) for the computation of heat unit in the germination stage, soil temperature, rather than air temperature, should be used.

The arguments for supporting the heat-unit methods are: (1) No better method exists to take the place of it; (ii) It provides an effective basis for spacing successive plantings of a crop so that the cannery will have an uninterrupted supply of raw material at their optimum maturity once the varietal constant has been established; (iii) It is a definite aid in forecasting and a fairly accurate measure of performance for different varieties, and a definite aid in quality control; (iv) Other factors affecting plant growth may conteract each other, and leave temperature alone to be the determining factor for measuring the maturity; (v) The heat unit system was started as early as 1735 by Réaumur* , who suggested the quantity of heat required to bring a plant to a given stage of maturity was fairly constant. He called this "the thermal constant". Since then, this approach has been adopted and modified for testing various plants and even activities of insects and birds, etc. The findings were fairly satisfactory.

Since 1948, Thornthwaite (50,51) and his collaborators have defined the potential evapotranspiration as the amount of water which will be lost from an extensive water surface or one completely covered with vegetation where there is abundant moisture in the soil at all times. For eight years in their association with the John Hopkins University Laboratory of Climatology, Seabrook, New Jersey, various experimental studies were made on instrumental designs, as well as agro-climatological studies for various parts of the world. Their findings in crop-weather relationships, particularly on the growth of garden peas in "develop-unit" related to the potential evapor-transpiration, are claimed as a new approach to replace the century-old "heat unit" method both for plant development and for the problem of determining irrigation needs. Thus, the prediction of yield as well as the date of blossoming is possible to a high degree of accuracy. "Development unit", is defined as the amount of development, in length of internode that

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*Réaumur, R.A.F.de, 1735: Observations du thermométre, faites á Paris pendant l'année 1735, comparées avec cells qui ont été faites sous la ligne, á l'Isle de France, á Alger et en quelquesunes de nos isles de l'Amerique. Paris Memoirs, Acad. Sci.

will occur in a plant which a unit amount of water is being transpired. A brief summary of Thornwaite's evaluation of the potential evapotranspiration is made below:

Let "e" be the monthly evapotranspiration in centimeter and "t" be mean monthly temperature in ^{o}C, an equation of the form -

$$e = ct^{a} \tag{1}$$

may be written, where the coefficients "c" and "a" vary from one place to another. For the determination of coefficient "a", a monthly index can be assigned as: $i = (t/5)^{1.514}$. Summation of the 12 monthly values gives an appropriate heat index, I. While this index varies from 0 to 160, the coefficient "a" in Eg. (1) varies from 0 to 4.25. The relation between the two is closely approximated by the expression:

$$a = 0.000000675\, I^{3} - 0.0000771\, I^{2} + 0.01792\, I + 0.49239 \tag{2}$$

The coefficient c in Eq. (1) varies inversely with I. From these relations, a general equation for potential evapotranspiration was obtained. It is

$$e = 1.6\,(10t/I)^{a} \tag{3}$$

With the Empirical equation (3) thus established, all constants have to be adjusted according to factors related to latitude and duration of sunlight. In this connection, a number of monograms and tables have been devised and published (1954) by the Johns Hopkins University*.

(C) THE PHOTO-FIELD. Sevey (45) in 1915 published a book on "Peas and Pea Culture" in New York. After collecting various opinions of pea-growers, he came to the conclusion that the garden pea prefers abundant light for its growth and development. Pesola, in 1935 (30) on the other hand, performed experiments on peas grown in Finland, and found they were not affected by light as far as temperature-pea relationship was concerned.

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*Mather, J. R., "The Measurement of Potential Evapotranspiration". Publications in climatology 7 (1): 218-225 (1954). The Johns Hopkins University Laboratory of Climatology.

Fuchs and Kopetz (15,24), in 1943, made experiments on garden peas in both Halle, Germany and Finland. Day-length has been emphasized by them. However, they found that the Finnish type of pea is day-neutral in Finland, where days are longer, but nevertheless under the warm environment at Halle, peas are found to flower earlier. Heath and Wittwer (34) have performed controlled experiments on various varieties of canning peas through 1952. With respect to time of flowering and edible maturity, all varieties behaved as long-day plants when grown at a night temperature of 50°F. Alaska and Surprise, however, were definitely day-neutral, if night temperatures are maintained at 60°F. Idaho Whites, Gradus, Alderman, Early Perfection and Walah (late and midseason peas) behaved as long-day plants at both 50 and 60°F, flowering 10 to 27 days earlier in the 16-hour photoperiod. This was the most complete paper, to our knowledge, dealing with days requisite to flowering, days to maturity, pod characteristics and vine heights. Their findings were that both temperature and photo-period have a marked influence.

Between 1950 and 1953, Lynch and Mitchell (26,27) made an entirely different approach to the prediction of maturity and quality of peas grown in Australia. No weather data was used in their studies, but through mechanical and chemical means, namely maturometer reading, as well as alcholic insoluble product index, they were able to make their predicted values close enough to the observed values.

CHAPTER III

METHODOLOGY

Before proceeding to the methodology of phytometeorology, it is necessary to consider certain related subjects. They are: life cycle of plants; growth and development, and sharpness of phases.

LIFE CYCLE OF PLANTS. — The Lysenko Theory of Phasic Development* and the Theory of "Physiological Predetermination"** by a group of British (Kidd and West 1918 and 1919 and Tinker, 1924, Whyte 1949, etc.) and German workers, Klebs (1918 –), as well as Ashby hypothesis of heterosis on the studies in inheritance of physiological characters*** by a group of American workers (Ashby 1930-37, Lindstrom 1935, East, Sprague 1936, Luckwill 1937, etc.) come to our attention regarding the responses of plants to their environments at different phases (periods or stages) of their life cycles. The findings of the previous work in this respect we may summarize as follows:

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*Lysenko (1935) postulated the theory according to the assumption of:
- (a) Growth and development are not identical phenomena,
- (b) The entire process of the development of an annual seed plant consists of individual stages,
- (c) The stages always proceed in a strict sequence and a subsequent stage cannot set in until the preceding stage has been completed,
- (d) Different stages of development of the same plant or crop require different environmental conditions for their completion.

**The theory of pre-determination emphasizes that events in the seed-stage, such as the effect of fertilization on seeds from the mother plant at the 'Maturation' phase (and also vernalization, winter forcing, chilling processes as well as the germination stage), determine the yield and quality as well as the growth and development of a plant. This is the so-called theory of pre-determination'.

***The causes of heterosis: It is not effected by the relative rate of growth, as determined by inherited and environmental factors but the duration of the period of growth and the initial size of plant, or the size of the floral primordia. The primary cause of the phenomenon lies between fertilization and setting of seeds. The significant stages for the formation of heterosis should be noticed.

The life cycle of a plant can be divided into 4 distinct parts and, subsequently, subdivided into 10 sub-phases:

(A) Seed Stage: In this phase of plant life, 3 sub-phases are described as follows:

(1) Ripening — the presence of mature seeds or fruits over a certain percentage;

(2) After-ripening — Seeds separated from the mother plants, or falling down on the ground, or in storage. There are three significant changes in seeds during this sub-phase: (i) changes in permeability of seed coats, (ii) the formation, or changes in content of certain enzymes, (iii) the transformation or digestion of stored foods.

(3) Dormancy — after the initiation of dormant period, seeds are in rest. However, there are still some minor internal changes going on.

(B) Vegetation Period: After germination there are two important developments in this period:

(1) Pure vegetative development — It starts with leaf primordia and it ends up with vegetative growth both in volume and weight.

(2) Reproductive development — This begins at the initiation of flowering stage.

(C) **Flowering stage: The sub-phase are:**

(1) Ripness-to-flower — Nothing can be observed in this sub-phase yet, except the number of leaves present after sprouting can be counted prior to the floral primordia,

(2) Floral Primordia — with the presence of the microscopically recognizable primordia.

(3) Flowering Inflorescence — with the actual presence of buds and flowers.

(D) Pre-Reproduction Period:

(1) Productive Prematuration — This is the initiation of production.

(2) Parental Maturation — This is the fruiting or fruit setting stage with the starting of fruit form.

For simplicity diagram 1 below shows the interpretations of various authors. There are arguments regarding Synapsis*, Syngany* as well as the irritability** of thermal phases and photo-phases related to various ages of a plant. Since they are out of the scope of the present volume, no further discussion is necessary.

More specifically, a typical 68-day life cycle of Alaska pea is illustrated in Diagram 2. Only the thermal phases are considered. This involves the soil temperature for the seeding and germination stage (prior to the emergence of the arched epicotyl above the surface of the soil), and the air temperature for the rest of the life period.

In fact, most historical data did not have a complete record for all sub-phases of a plant life cycle. Therefore, a rather simple division maybe suggested as follows: (i) seed stage; (ii) seedling stage; (iii) grand vegetative period stage; (iv) flowering or pollination stage; and (v) post pollination stage.

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*Two "crucial stages" of sexual reproduction: (a) Synapsis - chromosome conjugation in meiosis within the immature flower bud during gametoplyte maturation; (b) Syngany - fertilization or gametric union in the embryo-sac.

**The ability of a plant to respond to all types of stimuli.

DIAGRAM 1

Life Cycle of a Plant as Interpreted by Various Authors

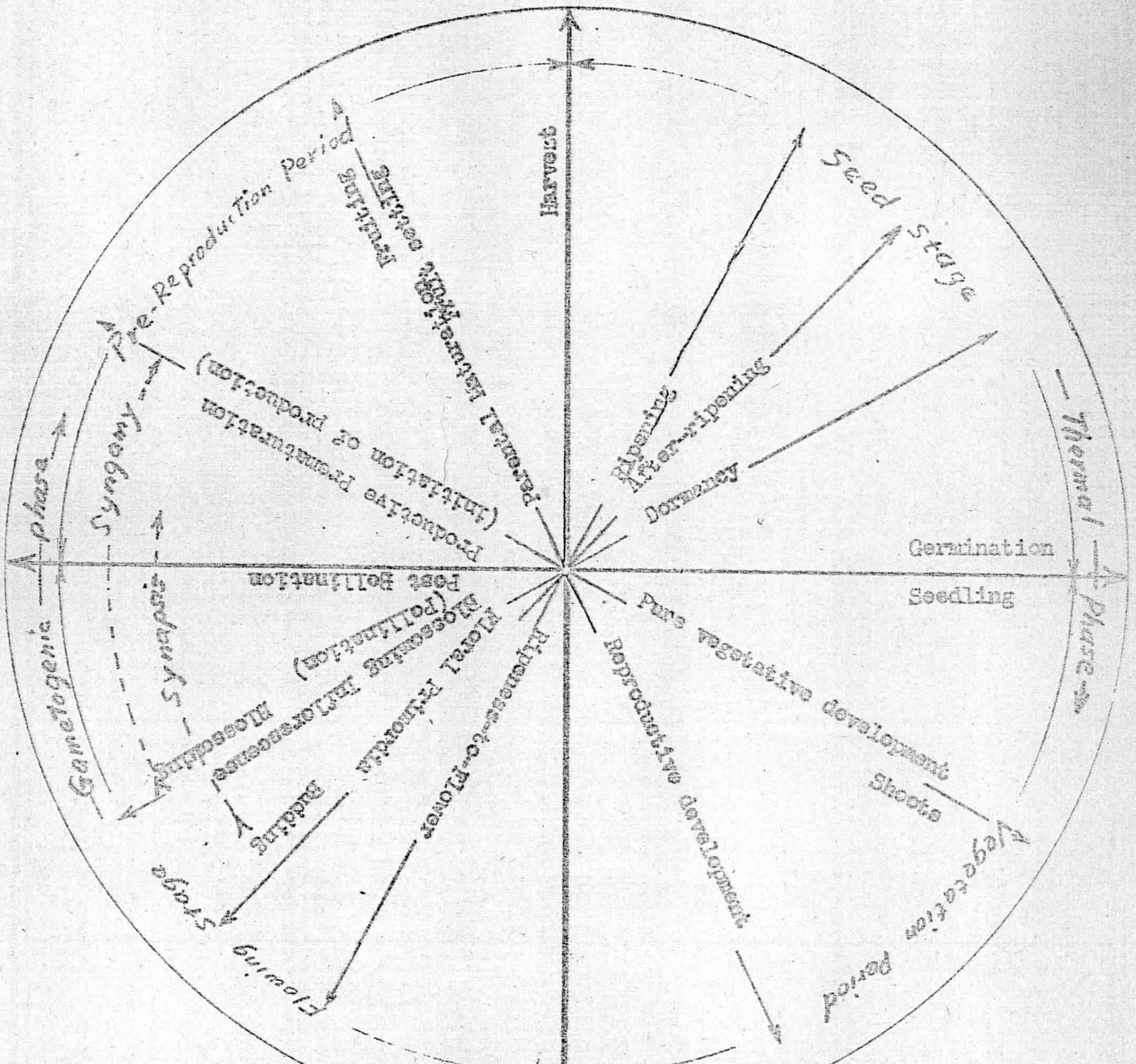
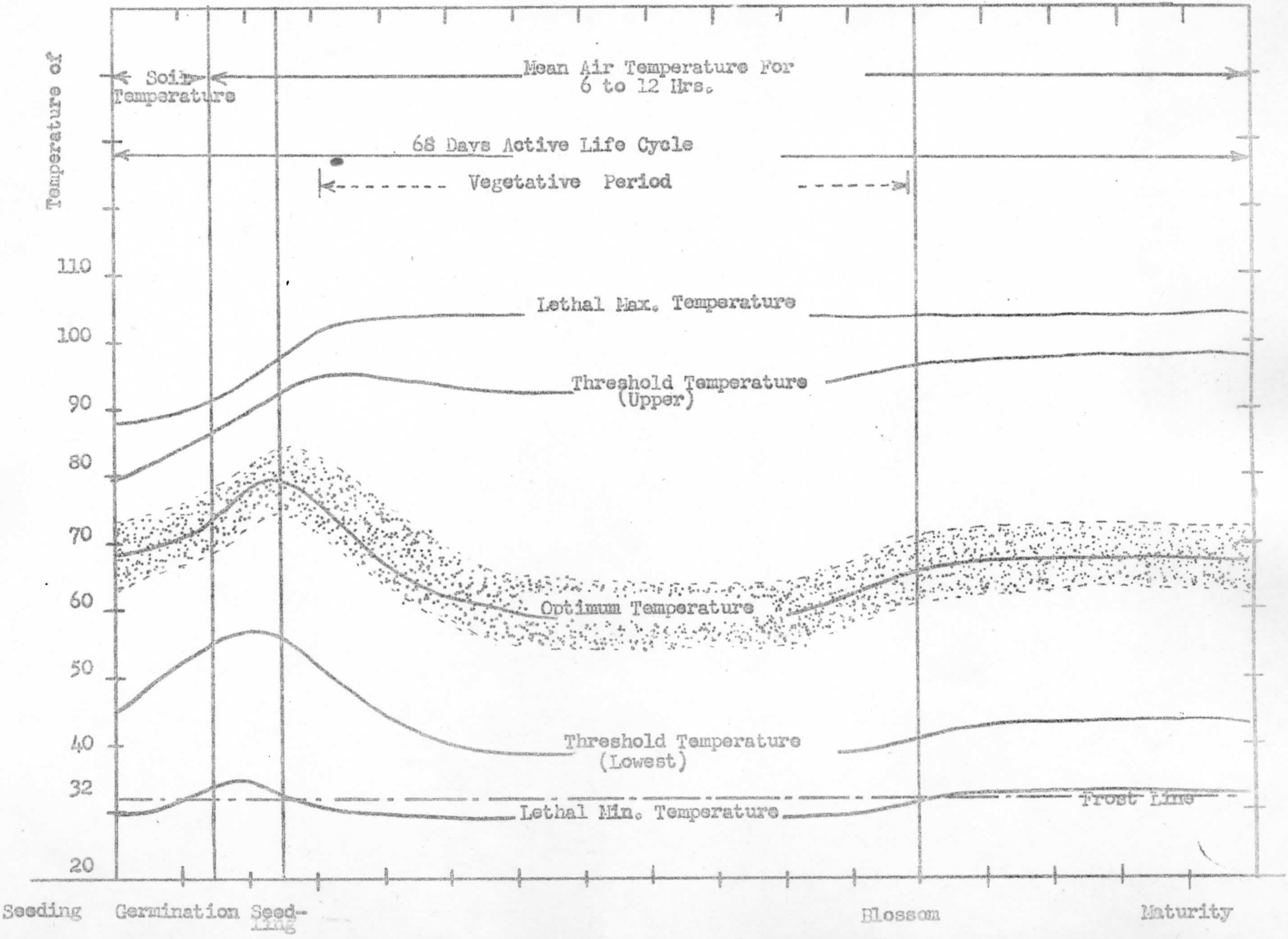


DIAGRAM 2

Irritability of Canning Peas for Thermal Phases



SHARPNESS OF PHASES. — As stated in the preceding section, the refined classification of various phases of the life cycle of a plant has been investigated by many workers since 1900. Nevertheless, not much work has been done on the sharpness of phases. If a phase is said to be "sharp," it must have the following qualifications: (1) It must be determined by objective means, (2) It must be determined accurately, (3) The beginning and ending of a phase for the same variety in a field should occur in a short interval of time, not more than a day or two, 4) The simpler the method for phase determination, the better. In the case of peas, their maturity (or from ripening to after ripening stage) can be measured by either the alcoholic insoluble product (A.I.S.) or the tenderometer reading (T.R.). The latter is rather common practice for canners. For the parental maturation stage, it can be determined by (i) number of peas per pod, (ii) length of pods; which determines the edible maturity (experiment by Reath and Whittwor (34) and others.) The emergence of peas from the surface of soil, the completion of plumules, the stipular leaves, as well as the appearance of the first tendrils. The length of internodes, etc. can be counted and measured in the different stages of the vegetative growth period. As for the flowering stage, Ripeness-to-flower can be recognized by the number of leaves present. Floral primordia can be detected by the aid of a microscope while the blossoming inflorescence can be seen by the naked eye. The growth of a pea plant for its entire growing period can be counted from the third node up (for the first two nodes are underground under normal conditions). The length of internode varies with varietal and environmental differences. With a single growing point and rapidity in growth, the measurement of the number of nodes and the length of internode can be used as criteria to determine the stage of development. In fact, Higgins (19) in 1952 described a 10 stage development of the vegetative stage to the completion of a node (based on nodes of a single pea plant) for farmers in Seabrook, New Jersey to follow. The order of node is named with a number, (e.g. 4 stands for the fourth node, etc.) while the tenth of a node is given by decimal figures. 5.8, thus, means the plant is at a stage of the 5th node and eight tenths toward the 6th node. A further discussion of Higgins' method, as well as other devices for phenological observation, will be given in the section on "Presentation of data and observational guide" in this chapter.

In general, peas have a habit of growth and development which may be ulitized more readily to recognize the phases than other crops. Nevertheless, we are confronted, in practice, with a handicap, — the irregularity in time of appearance of a plant phase from one part to another at the same field. It has been recorded that the time from the date of planting to the date of emergence may vary from 5 to 15 days from year to year, due to the differences in climatic factors. It can vary 5 to 8 days in the same field, due to the difference in microclimatic factors, as well as the edaphic conditions. Neither the date of flowering, of maturity, or of elongation of internode, etc. would be uniform in the same field. This discrepancy can be eliminated by recording when the majority (say 50%, 60% or any arbitrary percentage above 50%) of the plants in the field appear in a certain observed phase. Furthermore, average values of the same phase in several fields of one area will always reduce the differences due to environmental factors.

Since sharpness of various phases varies, the sharpest phase of ~~development~~ should be chosen as a boundary for correlations with plant growth and development, as well as the physiologically significant phases.

GROWTH AND DEVELOPMENT - It is beyond doubt that environmental factors play an important role in growth and development in all phases of the life cycle of peas, in addition to genetic and other factors. Went* has performed experiments in the Earhart Plant Research Laboratory in California recently with a very homogeneous environment, showing that all plants will grow to identical size and shape, if they have the same varietal and genetic characteristics. He concluded that the same variety of plant seeds, if they are treated exactly the same in regard to environment, will behave uniformly throughout the growing season. This puts the emphasis on the environment.

It is extremely important to differentiate the words, "growth" and, "development," for they are basically different. Growth is an increase of weight without any profound qualitative changes in the growing part. Development is the progress of a series of internal qualitative changes (with or without external changes) governed by the factors of the environment which leads through all different stages until death.

In consideration of the growing season of peas as a whole, the "growth" can be considered as a continuous function, while the "development" is a discontinuous one. Dealing with the problems of "yield" in peas, throughout the entire growing season, is a problem of "growth" whereas limiting investigation to a certain phase, such as, blossoming is a subject of "development."

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*Information obtained from F.W. Went's lecture in University of Wisconsin - March 1956.

PRESENTATION OF DATA AND OBSERVATIONAL GUIDE — At this point let us consider some of the environmental factors, for a plant may be regarded as expressing the environment.

The ecosystem has been considered as the largest functional unit, and includes both the organisms (biotic community) and the abiotic environment - each influencing the properties of the other. A pea field may be considered an example of an ecosystem. The biotic communities (biosphere in the broader sense) include the pea crop, weeds, companion crops, microorganisms, insects, etc. Effects between plants (competition for light, moisture, nutrient, carbon dioxide, etc.) and the effects of the temperature and water conductivity of the plant are biotic factors. The seeding rate, weed control, and method of cultivation are also biotic in being controlled by man.

The abiotic environment, in the main, consists of the atmosphere and the upper layer of the lithosphere. The former involves all atmospheric phenomena, integral or partial, which concern the plant; namely, the thermal field, the photofield, the water availability, and their interrelationships. The latter involves the soil moisture, soil temperature, water table, soil structure, as well as surface and subsurface run-off, percolation, etc. These are relations of a plant to its substratum, or edaphic factors.

It is possible to assume that the biotic factors are <u>constant</u>, as used in this phytometeorological study, and let the development and growth be a function of edaphic and climatic factors. A constancy of biotic factors could be obtained by either known cultural practices or through statistical manipulation, thus leaving edaphic and climatic factors alone for our present investigation. A brief statement of these two factors follows:

(A) Climatic Factors: (a) Photo-field.— Solar radiation is the main control of the photo-field. Individual factors are (i) the intensity of light; (ii) the duration of light — or the length of civil twilight time* plus the daylight time; (iii) the quality of light — the variation of wave length due to altitude, turbidity of atmosphere, etc. It is common knowledge that the incoming radiant energy of the sun brings about fundamental chemical and physical changes of a plant for the manufacture of carbohydrates, protein, fats and other complex materials, beside influencing the air temperature, the soil temperature, moisture content (both in air and soil), and transpiration. The use of solar energy for the photosynthesis process is about 30% of the total energy, while in the end the plant production is only 2%. This reduction in the use of solar energy for plant production is mainly controlled by the environmental factors which in turn cause the physiological functions, such as the translocation of hormones, auxins, etc. (b) thermal-field —involves, the air temperature, the soil temperature and the temperature of the leaf. Strictly speaking, air temperature is the space-average temperature of the gaseous medium of the plant. It is not the air temperature of the weather shelter as reported "officially" by the local Weather Bureau. The soil temperature is related to the edaphic factors, while the leaf temperature is related to the biotic factors. Leaf-temperature changes externally with the intensity of solar radiation, air temperature, wind, etc. and internally with the biotic functioning

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* Reference cited on page 6.

of the leaves. Thus, as a cloud covers the sky for a few minutes at a time, or a gale blows across a leaflet, the leaf-temperature will change accordingly. The moisture content of the leaf, the degree of the opening of stomata, as well as the structure of leaves will affect the temperature even if the external factors are the same. In the diurnal change of air temperature, the night temperature is much more important to the growth and development of plants. Others, such as the fluctuation of temperature from day to night, or inter-diurnal temperature, the summation of temperature within certain upper and lower limited threshold temperature, etc. will be discussed in detail later. (c) the water availability. - In a field as a whole, it is convenient to make a water budget; that is, incoming versus outgoing:

(1) Incoming water to plants: The main source of water is from precipitation, provided no irrigation is added. Forms include:

(i) Rainfall - its amount, intensity and frequency in the growing season:

(ii) Snowfall - consists of both snowfall and rainfall of the previous winter, as well as water leftover from the previous growing season.

(iii) Soil moisture and underground water system. Some may be contributed through capillary action of soil, but mainly it is determined by the moisture holding capacity of soil;

(iv) Water vapor in the air -- can be expressed in relative humidity*, absolute humidity, specific humidity, and mixing

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E.C. Stone, F.W. Went, and C.L. Young: Water absorption from the atmosphere by plants growing in dry soil, Science, Volume 111, pp 546-548, 1950 ratio — and its condensation products,—dew, fog and mist, etc. This can be expressed in terms of water deficit and evaporating power.

Went has computed theoretically from the amount of dew deposit per year relative humidity and radiation with the assumption that the sky is cloudless, calm, clear throughout the year. It turns out to be 15 inches. Harrold and Dreibelbis** performed a series of lysimeter measurements at Coshocton, Ohio, It was found that an average equivalent of 9.1 inches of rain was deposited throughout the year in the form of dew —approximately 20% of the total water supply.

(2) Outgoing water from plants: The dissipation of water can be accomplished by the following processes:

(i) Transpiration — stomatal, cuticular and lenticular;
(ii) Evaporation — from surface of soil or wet leaf surface;
(iii) Run-off — surface and sub-surface run-off;
(iv) Percolation — filtration of water to below the root zone;
(v) Interception — by leaves, etc.

(B) Edaphic factors — Any factors other than climatic and biotic as described in the foregoing section are edaphic. They are soil temperature and its gradient, soil moisture, soil structure, aeration, drainage, nutrients, and P^H of soil.

Two main types of raw material are needed for the study of environmental effects on the growth and development of crops. They are: Environmental data and phenological data. The presentation of data is the key to a successful study of the environmental weather-plant relationship. The phytometeorologist can present a

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*F.W. Went: Fog, mist, dew and other sources of water, Water Yearbook of Agriculture, pp 103-109, 1955

**L.L.Harrold and F.R. Dreibelbis: Agricultural Hydrology as Evaluated by Monolith Lysimeters, U.S.D.A. Technical Bulletin 1950, 1951.

long lists of observational desiderata for applied purposes. For many of these the proper observational techniques are inadequate or even nonexistent. This is particularly true for the phenological record. The existing phenological data are far too meager to match the environmental data. There is an immediate need to increase phenological observations for the study of garden peas. This is a paramount step for improved analyses. An observational guide is described at the end of this section.

Points which should be noticed on the presentation of data are:

1. Data expressed either as a single element or a combination of elements must be presented in terms of short intervals of time, such as week-interval, 5-day interval, daily basis or even hourly basis. As a rule, the shorter the interval, the better.

2. Average values should be avoided, if possible. Mean values, such as annual temperature, monthly daily mean temperature, seasonal mean temperature, etc. are in a sense fictitious while the hourly temperature, daily maximum and minimum temperature are real.

3. Environmental data should represent the actual environment at a spot or an area or over a region. Thus, the microclimatic data, or data observed in the field should be used, particularly for elements which are subject to rapid space variation.

4. Phenological data should be taken according to the sharpness of the phases. Biotic factors should be eliminated by means of graphical and mathematical methods (for details see next section)

5. Desirable form should be chosen for the presentation of data or the combination of phenological and environmental data, such as, graphs, maps, tables, alignment diagrams, formula, etc., as well as models in three or four dimensions.

6. For inadequate observational material, or even missing data which are needed in the analyses, through theoretical means (or a suitable technique) a substitute may sometimes be secured.

7. Length of record presented should be, at least, 5 years in a group so that scatter diagrams will be at least vaguely representative. Of course, the large the record, the better the result.

Phenological observations of peas should be made at:

(a) planting data (time of day, beginning and ending) and sequence of planting. Note the intensity and amount of precipitation within 36 hours after seeding.

(b) emergence date: Record the percentage of emergence.

(c) daily development of plant.*

(d) blossoming date: Record the different percentages of flowering.

(e) date of fruit maturity; record tendermometer readings, average number of peas per pod (perhaps the alcoholic unsoluble products) and amount of yield.

(f) date of natural growth stop: - Note the particular appearance at the terminal growing point when growth has stopped naturally.

A complete record of the micro-environment, cultural practices, fertilization, etc., should be taken for each field.

YIELD AND QUALITY ANALYSES. — A correction should be made for increase in yield or improvement of quality due to improved cultural practice, so that the corrected variability of yield might be representative of the changing environment. This is possible through the experimental record of the increase in yield resulting from an improvement of cultural practice only. "Cultural Practice" is a general term which involves a certain control of the environ-

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* For details see Appendix I.

mental complex.* It may be more influential, on farm production, than the changing environment.

In practice, there are two methods for this correction of yield, if only known figures of increase in yield due to cultural practice are given. These corrected figures can be called "artificial yield." They are: (1) Graphical method; (2) Mathematical method.

(a) Graphical method: Plot time (by year) against yield (in pounds per acre) on ordinary graph paper.

Lacking any other evidence a linear regression line may be computed the slope of which gives the rate of improvement of yield (Chart 2). If the date of introduction of new practices is known separate lines should be drawn for the data earlier and later than that date. If occasional irregular, and gradual improvements are made a freehand curve of best fit must be drawn. The "artificial yield" is then taken as the departure of the actual value from this line. If a single known date of improvement is accompanied by experimental evidence of the amount of improvement, say 10%, then yields prior to that date may be increased by ten percent to make them comparable to those obtained after the cultural improvement.

Chart 2 shows the correction of 5% (and 10%) increase in yield during the period of 9 years at Rosendale, Wisconsin.

If this so-called artificial yield or yield corrected for the 10% increase as indicated in Chart 2, is divided by number of growing days for each planting sequence thus as "apparent or potention yield" would be obtained with a unit of pounds per acre per day. Chart 3 is made by plotting this against number of growing days for the mean of the first and the last sequence. The arithmetic mean of the number of growing days (i.e. 60.5) is indicated by an arrow in the scatter diagram while

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*This is a complicated combination of all environment factors, biotic and abiotic. Therefore, we will define cultural practice as the control (by the human being) of the environment to fit the crop; while breeding is the control of the crop to fit the environment.

Chart 2

Yield Analysis for Alaska Peas
Rosendale, Wisconsin

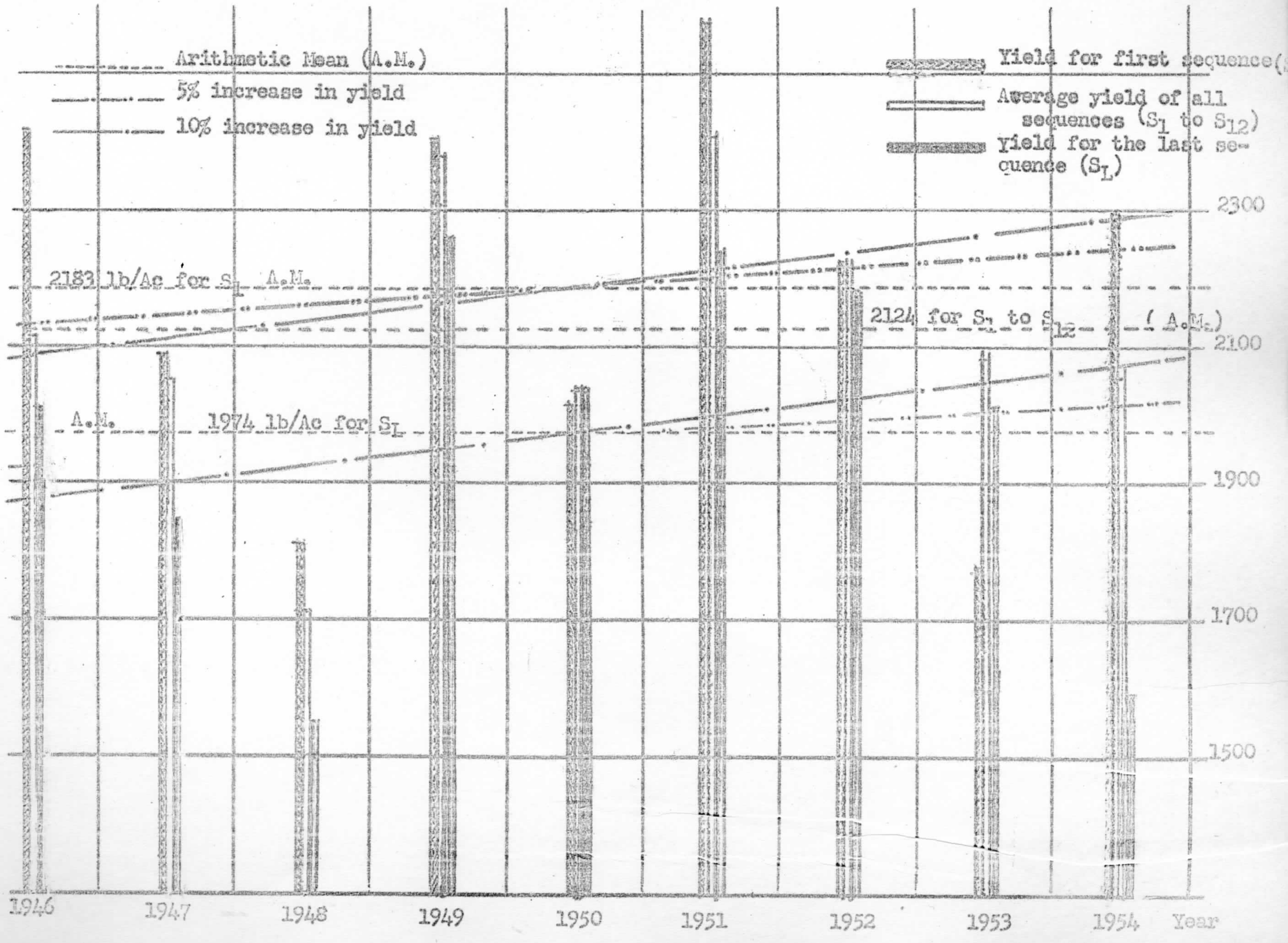
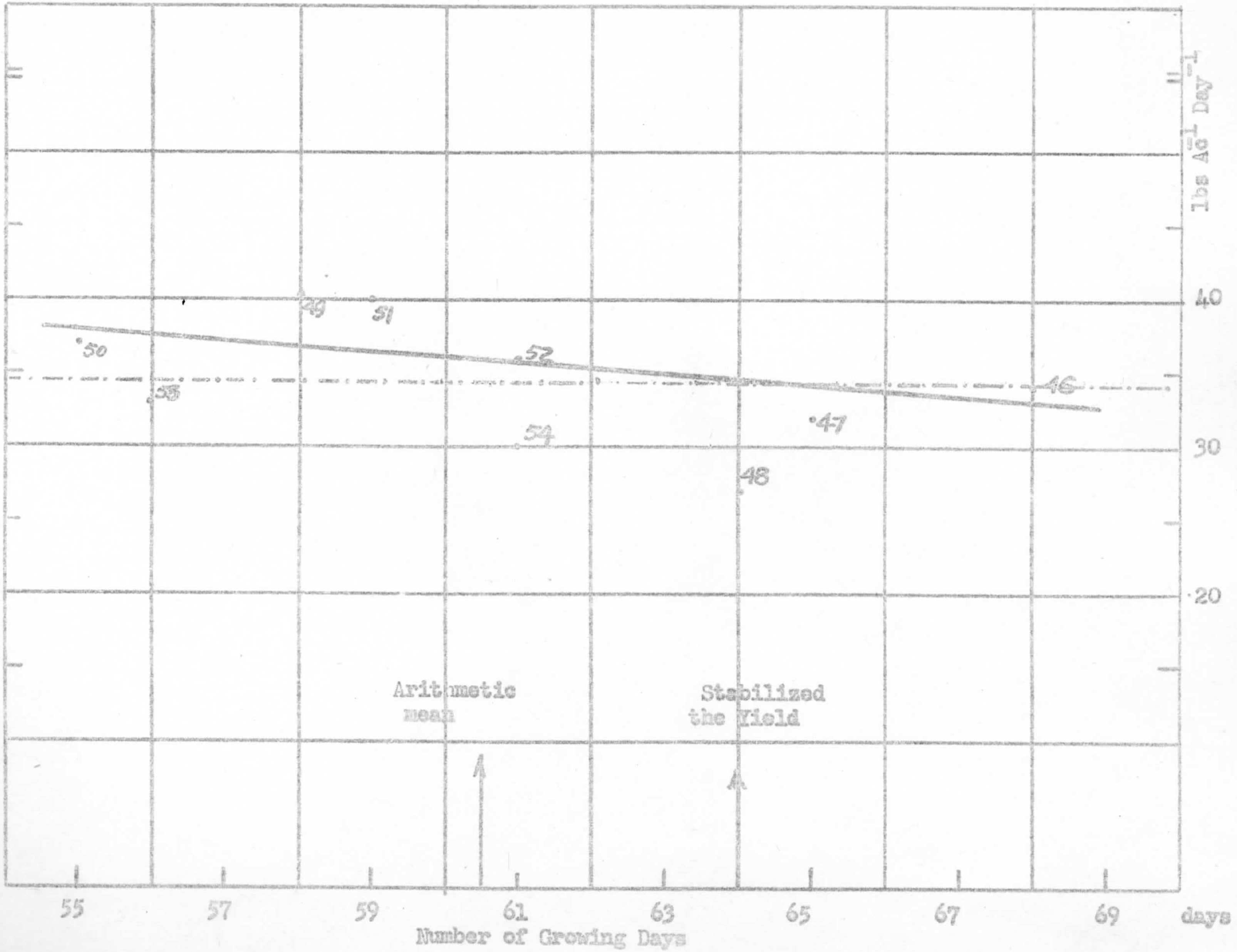


Chart 3

Number of Growing days versus Apparent yield
for the mean of the first and the lasting planting sequence



the arithmetic mean of the apparent yield (i.e. 34.4 lb/ac/day) is shown in dashed line. It is obvious that the best fit line (or the solid line) of the scatter diagram is very close to the dashed line. In other words, this shows that a constancy of apparent yield existed and the longer the growing season the higher the yield. This is particularly true for the same year and thus the first planting sequence for each year has longer period of growth, which is usually accompanied by a higher yield.

(b) Arithmetic Method: A linear correction can be established through mathematical formulation for any assumed or determined percentage increase in yield due to the improvement of cultural practices. The corrected yield thus obtained is essentially the same as that obtained by the graphical method stated above. Therefore, it is also called the artificial yield. Let i be the order of year; c the corrected value; d the departure of yield from the arithmetic mean; N the total number of years; M the arithmetic mean yield; Y_i the yield of the ith year, then we have

$$d_i = M - Y_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$d_{ic} = d_i + (N/2 - i + 1)/100 \times M \quad \ldots\ldots\ldots (5)$$

This is more accurate than the graphical method, but it is hard to reconcile to different rates of increase in yield. In other words, only the linear correction can be made through mathematical means, in practice.

An example of applying equation (5) above to Alaska pea data in Gillet and Bonduel, Wisconsin for the years 1946 through 1955 is shown in Table 3.

PREPARATION OF METEOROLOGICAL CHARTS.— We are concerned primarily with the meteorological environment. The preparation of meteorological charts herein illustrated can be applied to the edaphic environments as well. It is necessary to enter day by day weather records for the field (or for the nearest station) on a chart, such that day to day changes of weather

Table 3

ALASKA PEAS
Seeding - Gillet & Bonduel, Wisconsin
Yield Analysis According to Tenderometer Range in lb/ac.

T.R.	Number of cases			Mean Yield lb/ac.			Mean Seeding & Harvest Dates (Growing Season Days)						Yield Analysis According to T.R. Range in lb/ac.								
	1	2	3	1	2	3	1	d	2	d	3	d	1			2			3		
Year													di	c	dic	di	c	dic	di	c	dic
1946	1	9	4	1107	1620	2223	4/9-6/28	81	4/10-6/29	81	4/13-6/30	79	-98	60	-38	226	70	296	622	80	702
1947	4	5	5	1413	1688	2109	5/9-7/10	63	4/28-7/10	74	5/6- 7/10	66	208	48	256	294	56	350	508	64	572
1948	12	11	4	1077	1213	813	4/24-6/24	62	4/24-6/27	65	4/28- 6/29	63	-128	36	-92	-181	42	-139	-788	48	-740
1949	6	3	2	617	873	1114	5/8-6/27	51	5/7-6/27	52	5/4- 6/26	54	-588	24	-564	-521	28	-493	-487	32	-455
1950	16	13	6	1235	1488	1664	5/7-7/2	57	5/4- 7/7	65	5/14-7/8	56	30	12	42	94	14	108	63	16	79
1951	13	9	6	1704	1962	2042	5/4-7/3	61	5/7- 7/6	61	5/7- 7/7	62	499	-12	487	568	-14	554	441	-16	425
1952	8	20	5	1410	1797	1650	4/30-6/30	62	4/27-6/29	64	5/9- 7/5	58	205	-24	181	403	-28	375	49	-32	17
1953	19	12	6	1474	1033	1315	5/9- 7/1	54	5/19-7/5	48	5/4- 6/30	58	269	-36	233	-361	-42	-403	-286	-48	-334
1954	6	24	15	1021	1120	1523	5/18-7/8	52	5/17-7/9	54	5/7- 7/9	64	-184	-48	-232	-274	-56	-330	-78	-64	-142
1955	1	21	20	995	1149	1555	5/25-7/9	46	5/4- 6/29	57	5/6- 7/1	57	-210	-60	-270	-245	-70	-315	-46	-80	-126
Total	86	127	73																		
Mean				1205	1394	1601															
Mean Standard Deviation				80.6	105.5	105.7															
Mean Variance				66.9	75.7	66.0															

Remarks: T.R. Means Tenderometer Readings.
1 equal T.R. 90-99; 2 equals T.R. 100-109; 3 equals 110-119.
di: Departure from arithematic means.
c: Correction made for 10% increase in yield.
dic: Corrected departure in yield.
d: Days

can be studied. The entering of meteorological parameters ought to be as complete as possible and average values should be avoided. The important meteorological parameters for peas, as mentioned in the foregoing section, will be illustrated further in details as follows:

(1) Water requirements (or water availability) is the determining factor responsible for yield and quality of a pea plant. Because:

(a) It is a mesophyte;
(b) It has a medium to high transpiration ratio of 451 to 650;
(c) It needs tremendous moisture both in air and soil, as experimentally determined by Fieldhouse (13), even though peas cannot stand wet roots. Moreover, wilting and rotting of peas will be caused by high soil moisture levels but will be prevented by flooding*
(d) It is a nitropositive plant, such that the nitrogen compounds in rain or snowfall are of importance.

Thus, the amount and the frequency of precipitation in the growing season and of the previous winter should be plotted in a meteorological chart. Relative humidity at noon hour, as well as its daily mean, should also be entered for reference. If possible, the soil moisture data should be counted as one of the important entries.

(2) The percentage of possible sunshine, the cloudiness, the solar intensity, as well as the length of day, should be plotted. Because:

(a) Peas are long-day plants, except in the case that the night temperature is maintained at 60°F, then Alaska and surprise are classified as a day-neutral, (34).

(b) It seems that peas need a full bright sun for the optimal development since there is no report that shade is needed. In this connection, Halkias and Veihmeyer** have found a high correlation between solar intensity and the water used by plants. This further proves the importance of solar intensity for the growth of plants.

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*Water - Agriculture Yearbook, 1955, P 31. Scleratia is a soilborne fungus which can be favorably developed by high soil moisture and can be survived for 11 years in dry soil, however, it can be destroyed in 6 to 12 weeks by flooding.

**N.A. Halkias, F.J. Veihmeyer, and A.H. Hendrickson: Determining Water Needs For Crops From Climatic Data; Hilgardia, 24 (9): 207-233 (1955)

(3) The maximum and minimum temperature (if possible, the daily mean night temperature, as well as the daily mean temperature) should be entered. Because:

(a) H. C. Thompson, of Cornell University, grouped vegetables into three classes with respect to cold resistance, namely hardy, half-hardy and tender. He defined "hardy" as those which will stand hard frost, "half-hardy" as those which will withstand light frost, and "tender" as those which will not withstand any frost. He puts peas as hardy plants. This signifies in part that low temperature might benefit the growth and development of peas.

(b) The night temperature might be of more influence than the day temperature for the vegetative phase as well as after blossoming. The former seems to contribute a positive correlation to the yield, while the latter a negative one.

(c) The fluctuation of night and day temperature appears to be an important factor controlling the development of the plant, therefore, a summation of fluctuation is necessary for a certain stage of plant life.

(d) Temperature is just as important as precipitation for peas, however, neither the monthly nor seasonal temperature can actually represent the thermal field of the plant environment.

The temperature-precipitation correlation in one region will differ from that in another. Therefore, it should be established whether the diversity in quality of peas as related to precipitation can be seen directly in terms of temperature. Usually, the higher the temperature, the higher the tenderometer reading.

All the above factors thus far described are inter-related and interact with each other. Moreover, the response of a plant to these factors, either singly or combined, would be different in different stages of growth. For instance, the vegetative phase will be favored by increase of roots, uptake of nutrient salts, particularly nitrogen, but all this will hinder in the ripe-to-flower stage, because in the flowering stage, light, particularly daylength in combination with temperature, will play the important part. In this connection, all different stages of the life cycle of peas should enter into the meteorological chart as completely as possible.

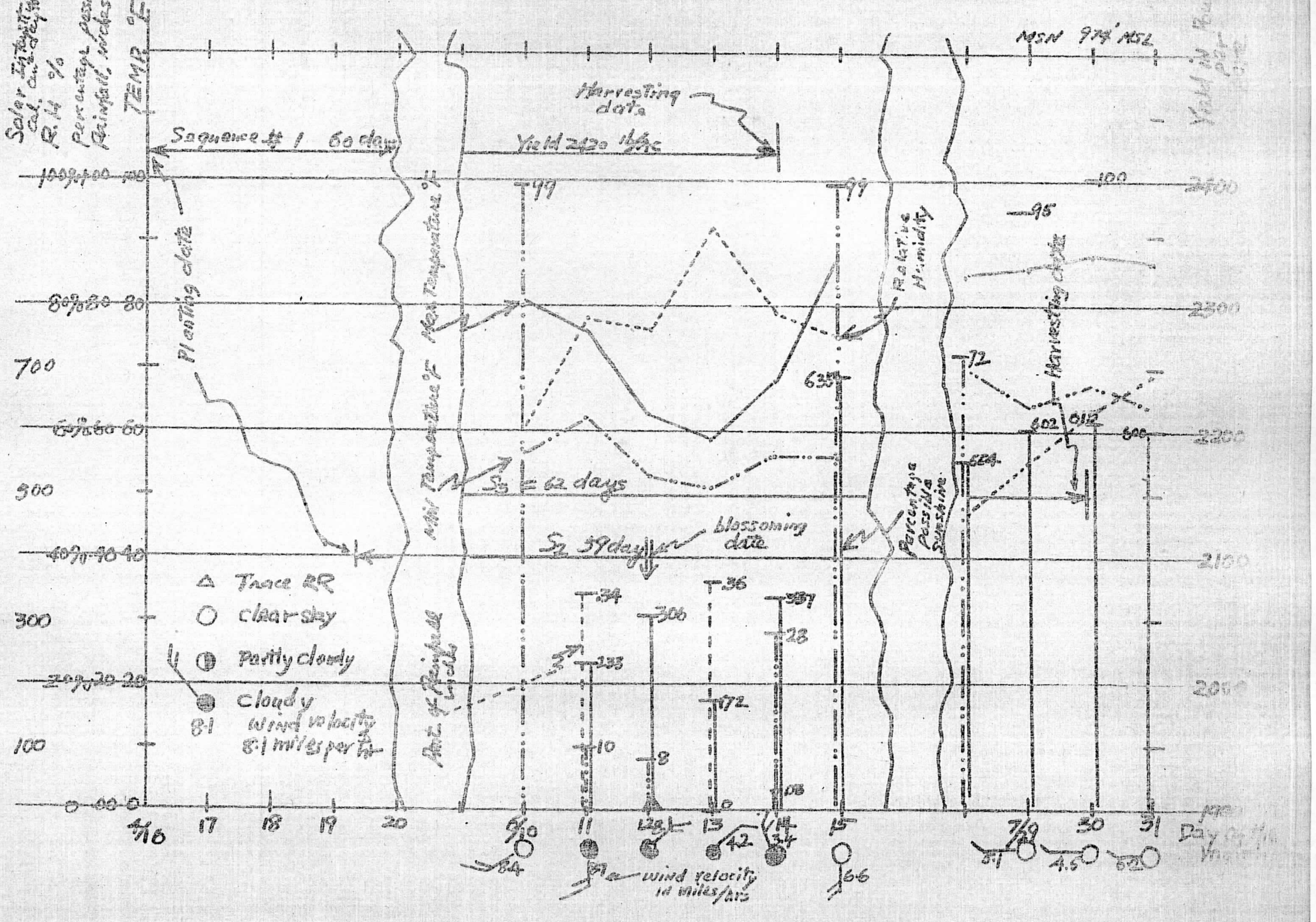
An example of the meteorological chart is shown in Chart 8.

RELATIVE-MINIMUM-DROUGHT IN WEEK-INTERVAL. - As far as drought is concerned, the amount of and frequency of precipitation, such as inches of rainfall and number of rainy days, are the major factor.

Dew can be considered as a major factor in some regions, but is difficult to measure. This will described later in this chapter. There are a number of ways to dissipate the total amount of actual rainfall. They are: interception, surface run-off, sub-surface run-off, percolation, as well as evaporation and transpiration by plants. Thus, neither does all rainfall go to the plants, nor is it reserved in the soil for the use of plants during a later period. During rainy periods, the correction for surface and sub-surface run-off seems to be larger and more variable with time than correction for interception and transpiration processes, etc. The correction of actual precipitation for run-off has been studied for Fayette silt loamy soil. Kind of crop, as well as the intensity of precipitation has been considered. Regressions lines were computed from 16 years of record for the evaluation of run-off. For details see Appendix II. For the number of rainy days, the official definition that one hundredth of an inch or more per day constitutes a rainy day is not applicable.

Chart 8

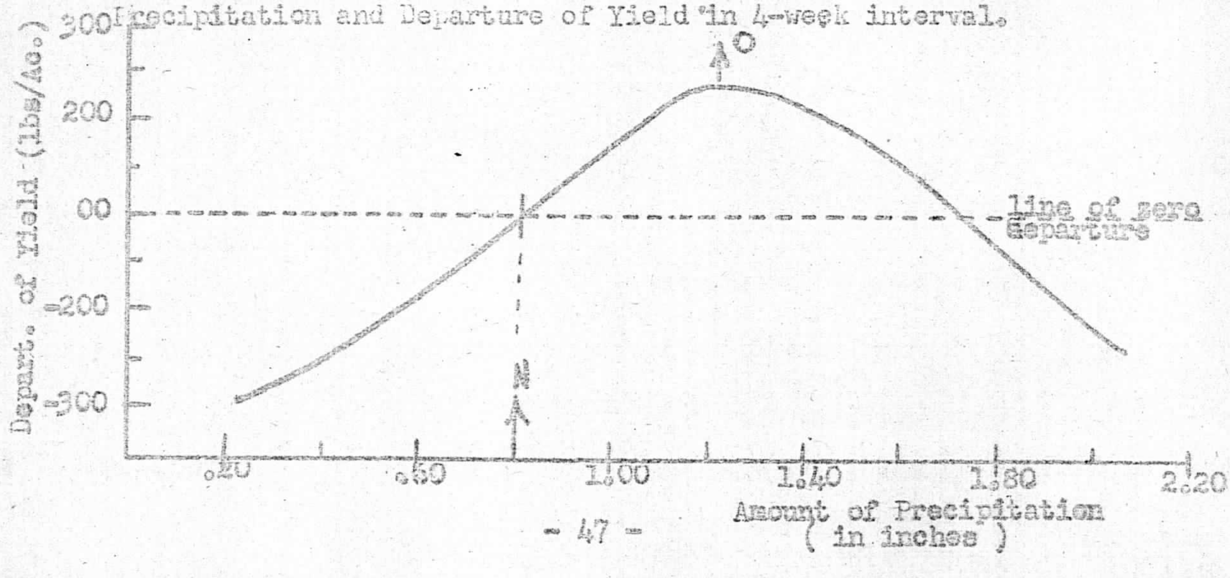
A Meteorological Chart For Growing Season Of Peas In Madison, Wisconsin 1929



Thus, criteria for the definition of "a crop rainy day" should be set up. This will vary tremendously for different species of plant. Nevertheless, this has been done for peas. Appendix III gives the details.

With the correction for run-off, the relative minimum of the total amount of precipitation in a small whole-number of week-interval (i.e. 1, 2, 3, ... continuous weeks) can be computed from the meteorological chart of each growing season separately. The term "relative minimum" refers to the amount of rainfall in the dryest whole week (or 2, 3, 4 weeks, etc.) of the growing season. After evaluating the relative minimum amount of precipitation in weekly intervals, a scatter diagram is prepared on ordinary graph paper for each interval with abscissa for amount of precipitation in inches and ordinate for departure of "artificial yield" in pounds per acre. Each point on the curve represents a year. This so-called "relative minimum precipitation in weekly interval," was initiated by Barger and Thom (48,49) of Iowa State College, Ames, Iowa. They applied this to the study of drought intensity vs. the yield of corn in Iowa. What we have done here is an adaptation of their idea. A model of the curve for this type of scatter diagram for the analysis of drought effect in the growing season is shown in Diagram 3.

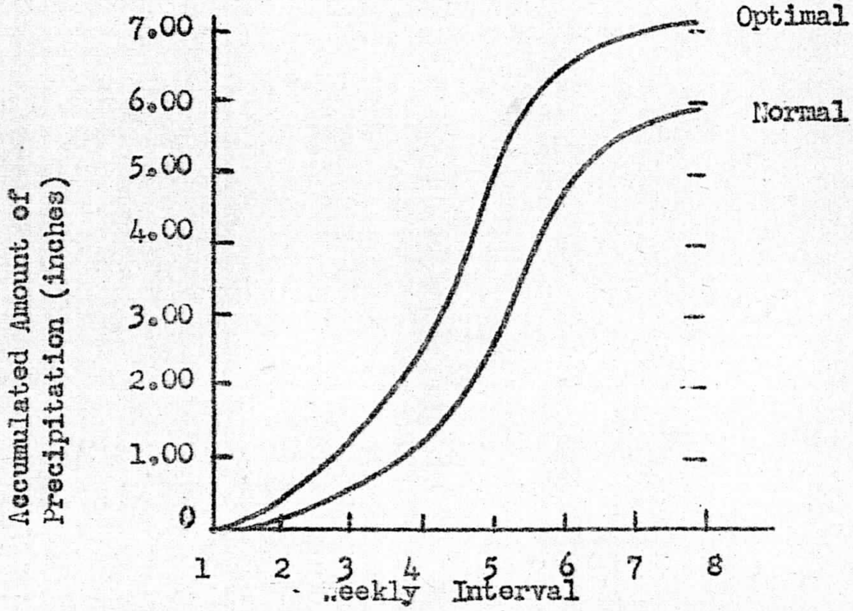
Diagram 3
A model of Scatter Diagram for the Analysis of Relative Minimum Precipitation and Departure of Yield in 4-week interval.



The intersection between the curve and the zero-yield-departure-line establishes the minimum amount of rainfall needed for that particular weekly interval, to still get normal yield. It is marked with an arrow and labelled with, "N" on the above diagram. The amount of rainfall associated with the peak of the curve indicates the highest yield or the optimal rainfall in this particular weekly interval. This is marked with an arrow and labelled with "O". Figures indicate the year of each point. Taking all these scatter diagrams together, the critical relative minimum values for each week interval may be combined into a composite chart. A model of this is shown in Diagram 4:

Diagram 4

A model of the normal and the optimal yield of crops is related to the amount of rainfall.



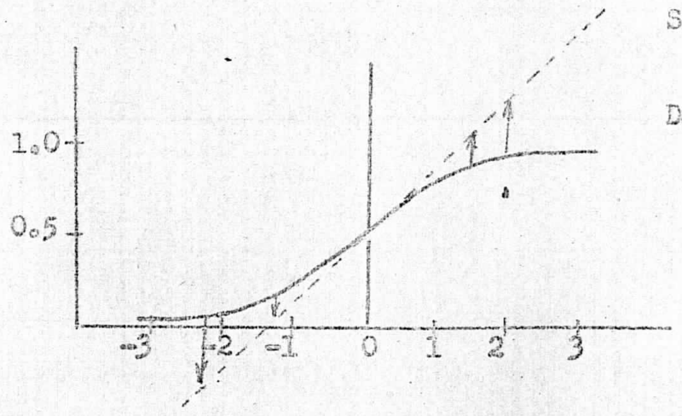
It is obvious that a smooth curve can be drawn through all the points for normal yield, as well as another curve for the optimal. This gives a further justification of these values obtained from the scatter diagrams. The same procedure can apply on the evaluation of number of crop rainy days, application of which for Rosendale Data is shown in Chapter IV.

The benefit of this diagramatic method, as it will be used extensively in this paper, are that "errors of any sort" and "correlations," etc., can be visualized at once, besides the ease of construction. In this connection, many trials can be made without costing too much effort and time.

The closeness of the curves of Diagram 5 to a normal distribution can be tested with Arithmetic Probability paper. This is done by plotting the cumulative distribution of the sample upon the probability paper and then noting how closely this curve approximates a straight line. If the curve is approximately a straight line, the distribution is approximately normal. If it deviates considerable from a straight line, then the distribution is not normal. The fact that the sample distribution gives a curve which is not a straight line is an indication that the population from which it comes is not normal. Diagram 5 below shows how a curve can be straightened out by a probability paper while Diagram 6 is an application of this on the yield of cigar-binder-leaf versus weekly interval precipitation in the East hill farms of the University of Wisconsin, Madison, Wisconsin.

Diagram 5

An illustration of the effect of normal-probability paper to the cumulative Distribution of a sample.

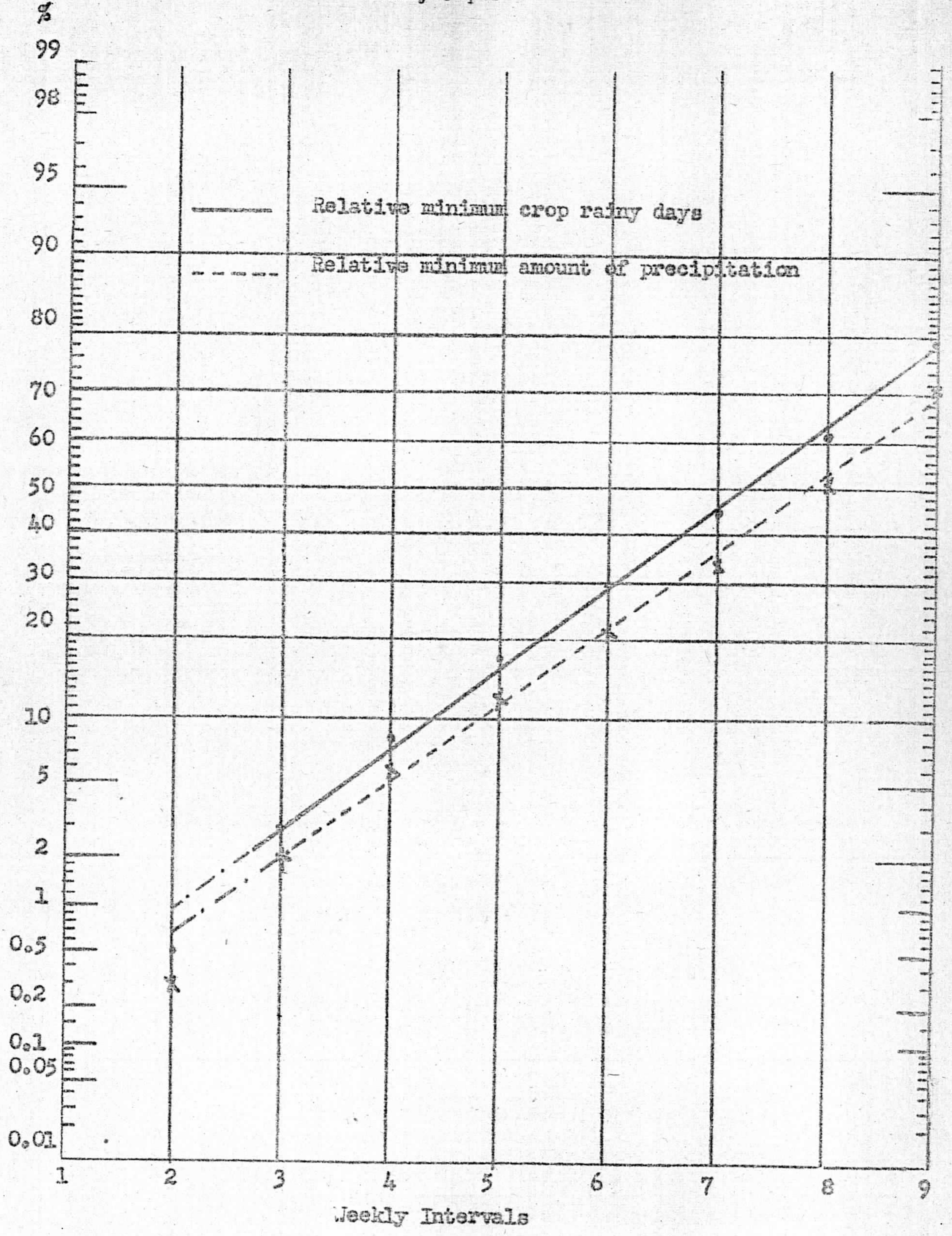


Solid: cumulative-normal distribution curve;

Dash: A straight line. (stmetching from a probability paper)

Diagram 6

An Example on Yield-rainfall Curve Of Cigar-binder-leaf in Arithmetic Probability Paper



The solid line of the above diagram is a curve to be tested while the dashed line is a straight line to verify the closeness of the curve to a normal distribution.

SPELL OF DROUGHT EVALUATION.— There is another approach of which the pea-weather relationship may be evaluated based on water availability. This is to find the number of days of drought in a growing season which keeps the plant from growing. Drought, herewith, can be defined as the time when plants lack available water to about the near wilt-point. Thus, yield, as well as quality of a crop, will be reduced as the days of drought increases. The evaluation of drought, or number of such dry days in a growing season, is explained in the following paragraph.

First, measure the moisture content of the field to a depth of the root zone to start with. Then estimate the diminution or increase of this moisture in the field according to

(i) Transpiration, or water uptaken by plants. This is the main dissipation of moisture stored in the soil.

(ii) Precipitation. This is main source of addition of soil moisture. In the latitude of Wisconsin the form of precipitation in the growing season is either rainfall or dew. For the former, the loss of water through runoff, both surface and sub-surface can be estimated from the runoff regression chart (See Appendix II). The loss of water by percolation and evaporation is comparatively smaller than the runoff during time of rainfall. Therefore, they can be neglected without much error.

The evaluation of transpiration can be done indirectly through the use of solar radiation and species of plant. Veihmeyer etc. found that transpiration of plants with considerable root systems does not decrease as soil moisture decreases.* A correlation of the difference in evaporation between black and white atmometers and water used by crops holds throughout the season when the crop has obtained its maximum spread and provided the field capacity is above permanent wilting point. This relationship is given by the simple equation:

$$U = SD \qquad (6)$$

where U is the monthly use of water by crops in inches, S is the coefficient, or the slope of the regression line (which will be different for different plants and, of course, should be determined by empirical means**), and D is the difference (in cubic centimeters) in monthly evaporation between black and white atmometers. Each D unit is equal to 0.028 gm-cal/cm^2 mean monthly radiation. Therefore, equation (6) can be rewritten as:

$$U = RS/0.028 \qquad (7)$$

where R is the mean monthly radiation in gram calories per square centimeter. R can be obtained from stations with observations of solar radiation. Also, R is more representative of a larger region than either temperature of precipitation.

It is obvious that for a given plant, with a known S, then

$$U = KR, \text{ where } K = S/0.028 \qquad (8)$$

Thus, the rate of diminution of water from the soil through transpiration can be determined from solar radiation data. The evaporation of moisture from the soil surface, as found by a number of investigators, is insignificant in comparison with transpiration. This is especially true when the ground is covered by the crowns of the plants.

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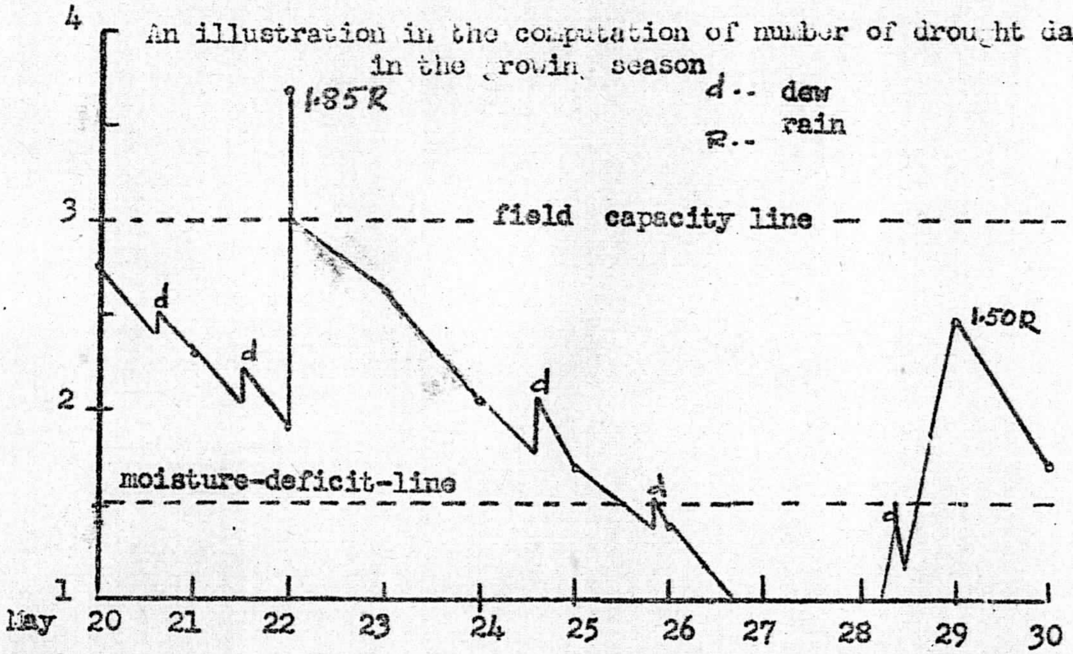
*Reference cited on p. 43: The results, on which this conclusion is based were obtained by Veihmeyer's group from areas of widely different climatic conditions, such as Davis, in the Sacramento Valley; Santa Cruz, on the coast under relatively low evaporation conditions: Shafter, on the upper end of the interior valley; and Coachella Valley, a very hot, dry area in the south.

**The value of S assigned for crops is independent of the total leaf area and also of the height of the plant. The coefficient S, for alfalfa and walnut, are about the same. The former is 0.0134 and the latter is 0.0135. Nevertheless, S can be obtained with better results from a Livingstone black and white bulb atmometer with a flat surface rather than a spherical one.

Having the evaluation of U described above, together with the precipitation data, it is possible to compute the number of drought days in the growing season. The results will be better if the above equations hold for each individual day. An illustration of the computation of the number of dry spell days is shown in Diagram 7.

Diagram 7

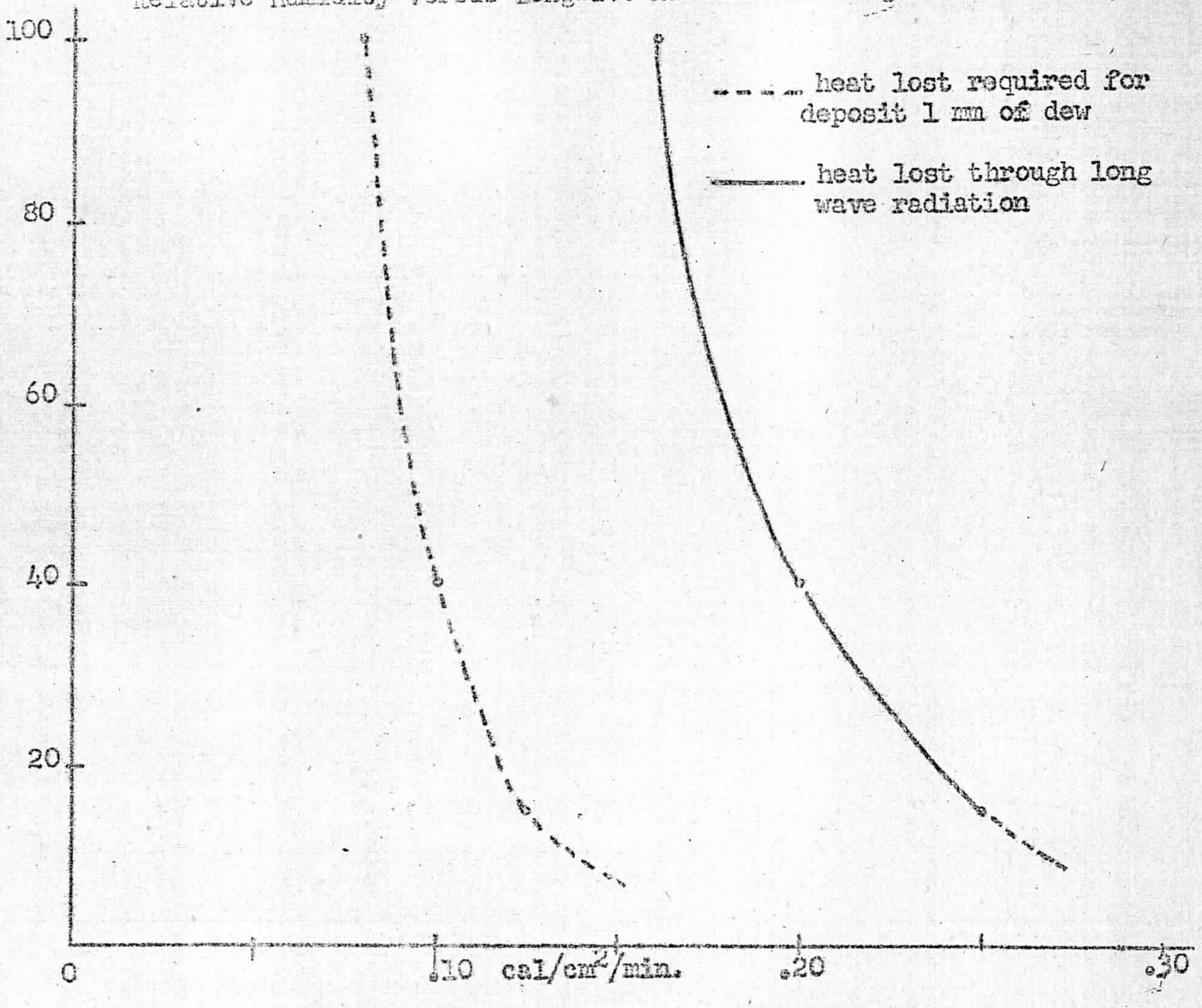

An illustration in the computation of number of drought days in the growing season

The occurrence of drought days can be easily seen in the above diagram.

DEW (?). — The contribution of dew to the total incoming available water for the growth and development of a plant is considerable, even though difficulties still exist in the accurate determination of the amount of dew. Went made an estimate of the amount of dew deposited during calm, clear nights. His approach was based on a computation of the balance of total loss of heat from the precipitable water held by the lower column of the atmosphere with the latent heat evolved by condensation in the process of dew formation. He pointed out that theoretically for a whole calm and clear night, a deposit of one millimeter of dew is possible. It is estimated that for a relative humidity of 40 percent, about 500 calories must be removed to cool a sufficient air volume to the dewpoint to deposit a gram of water, which also required loss of about 570 calories of heat of condensation. Since on clear nights the long wave radiation amount to 0.20 cal/cm^2/min. at a relative humidity of 40%, half of the radiation or 0.1 cal/cm^2/min. is available for dew deposition. The relative humidity versus the long wave radiation is shown in Chart 10.

Chart 10

Relative Humidity Versus Longwave Radiation during Clear Nights



At it was pointed out on page 35 above, Harold and Dreibelbis found that an annual average of dew deposit in Coshocton, Ohio was 9.1 inches. On the contrary, Duvdevani found that the total amount of dew precipitation in Israel amounted to approximately one inch a year.

In dry regions the absolute humidity is low. Thus, the outward radiation is greater. Since the relative humidity is lower, the air must be cooled more to reach the dewpoint. These two opposite effects largely counterbalance each other. In this case, dew is independent of relative humidity, but solely dependent on absolute humidity.

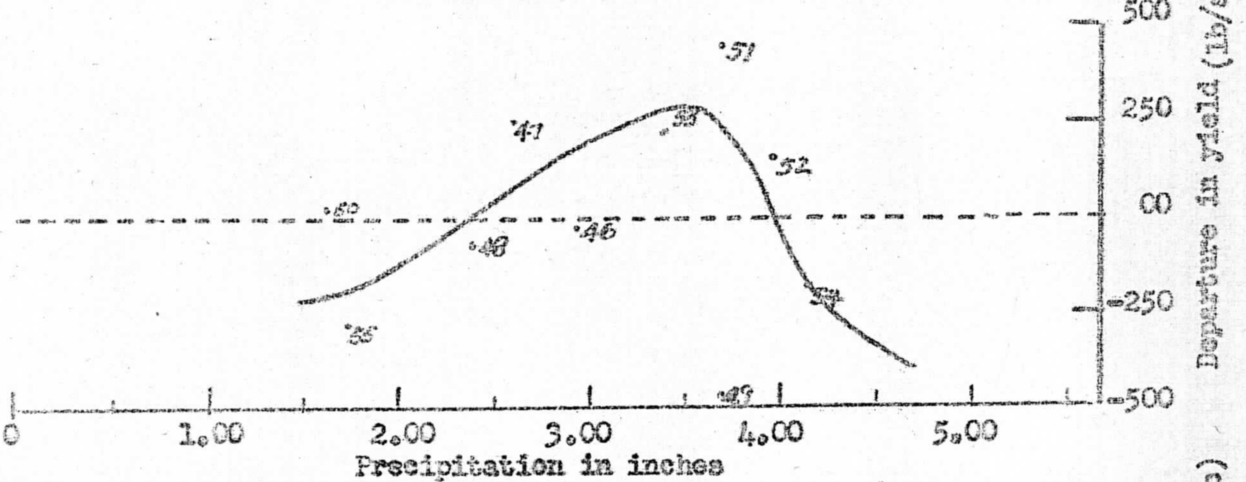
By and large, it is fair to make an estimate that the deposit of dew for a calm clear night in the latitude of Wisconsin is about 0.8 millimeter, or .03 inches. This amount of dew is more effective for the growth of plants than the same amount of precipitation, because it forms gradually in the dark, calm clear night, and the intake of dew is by young succulent leaves instead of roots. Therefore, losses by interception, evaporation by sunlight, wind, etc., in the case of rainfall can be avoided. Furthermore, saturated air in the vicinity of plants is essential for their growth. In particular, a water supply even in such minute amounts as dew, would be effective for the growth of plants at night, since most plant growth occurs during the night. The dew water that runs off the leaves collects in the soil on which it drips. The amount of dew, however, is too small to wet more than a few millimeters of soil. Hence, the intake of water by plants through the root zone from dew is not as important as absorption directly through the leaves.

TOTAL PRECIPITATION IN THE REPRODUCTIVE STAGE.— The accumulation of rainfall in the reproductive stage, that is in the period between blossoming and maturity is important, as far as the quality of peas is concerned. The higher the precipitation, the better the quality as measured by tenderometer reading. This idea has been checked with Alaska peas grown in Gillet and Bonduel, Wisconsin. An example is shown on Chart 11.

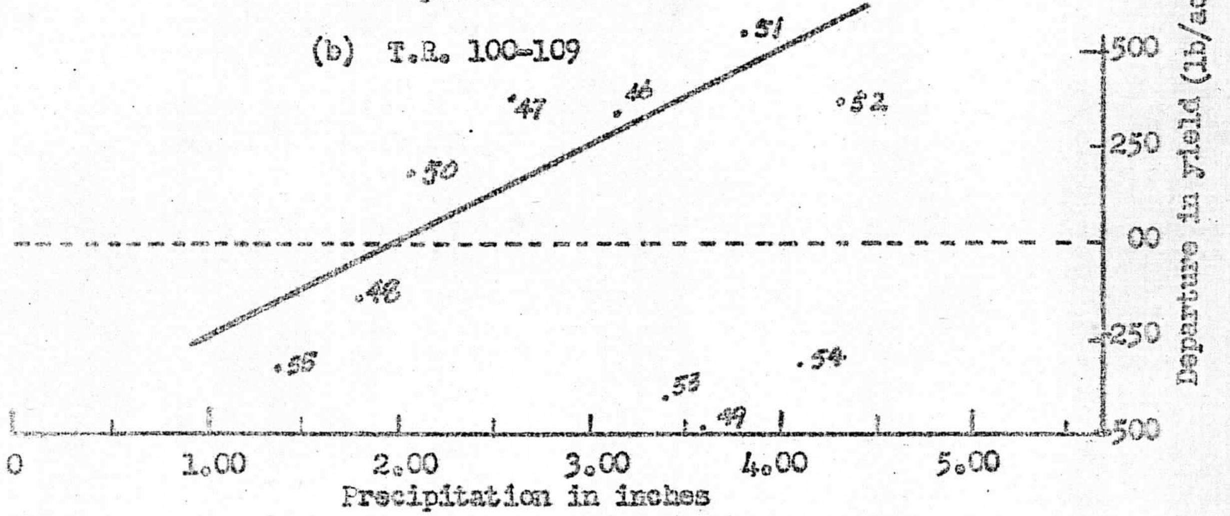
Chart 11

Total Precipitation in the reproduction stage versus quality of Alaska Peas in Gillet and Bonduel, Wisconsin. (1946-1955)

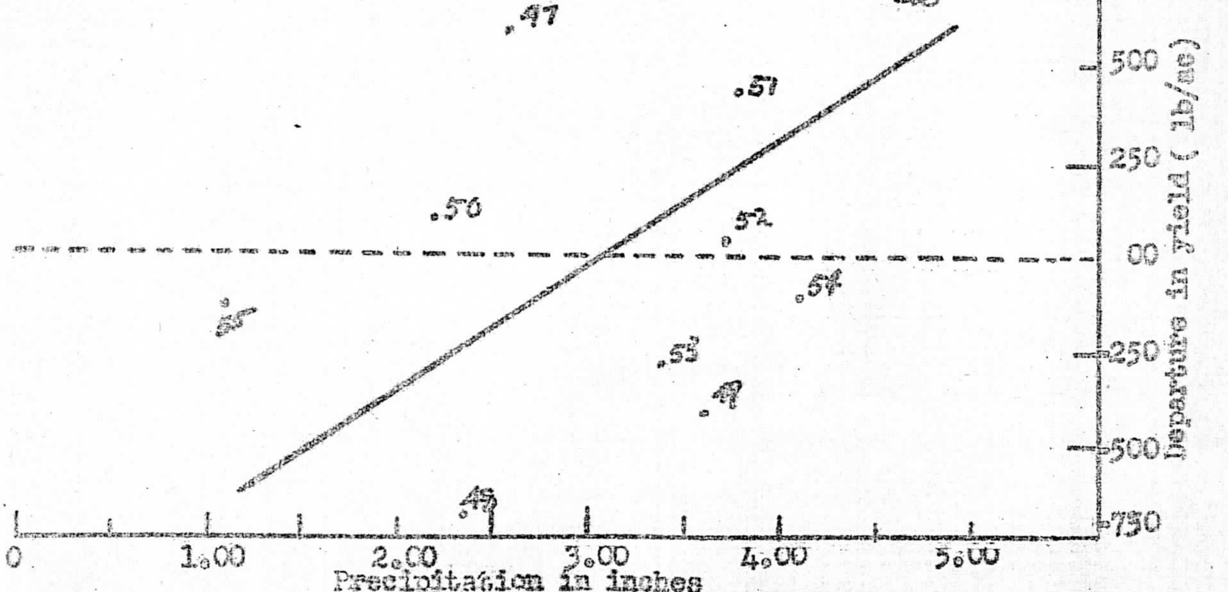
(a) T.R. 90-99



(b) T.R. 100-109



(c) T.R. 110-119



CUMULATIVE SNOWFALL & RAINFALL PRIOR TO PLANTING DATE.—The normal cumulative percentage frequency of minimum temperature in the first week of November at El Dorado is 69% at or below 32° F, and 52% at or below 28°F; while in Shawano, it is 74% at or below 32°Fand 55% at or below 28°F.* That is to say, in these districts, the source of most of our data November days are close to freezing. Since the vapor pressure at these temperatures is low, especially over ice, there is justification for using this time as the beginning of accumulation of precipitation for use the following spring. In other words, both snowfall and rainfall on a field will tend to be reserved in the soil rather than to be dissipated by means of transpiration and evaporation, run-off and percolation. This reserved moisture will not only be of use to the crops, particularly the early cool season crops, but will also affect soil temperature and the activities of microorganisms in ammonification and nitrification**. Furthermore, the nitrogen level will be increased on account of its presence in both snow and rainfall. Thus, the correlation between such total accumulated precipitation prior to planting and the yield, as well as quality of crops is worth investigations. Since the pea is a nitropositive plant***this factor is particularly effective. The effect on the yield of Alaska Pea in Gillet and Bonduel, Wisconsin has been tested using precipitation accumulated starting October first of the previous winter and the first of every successive month to the date of planting. The day of planting is excluded. Examples are given in Chart 12 and Chart 13.

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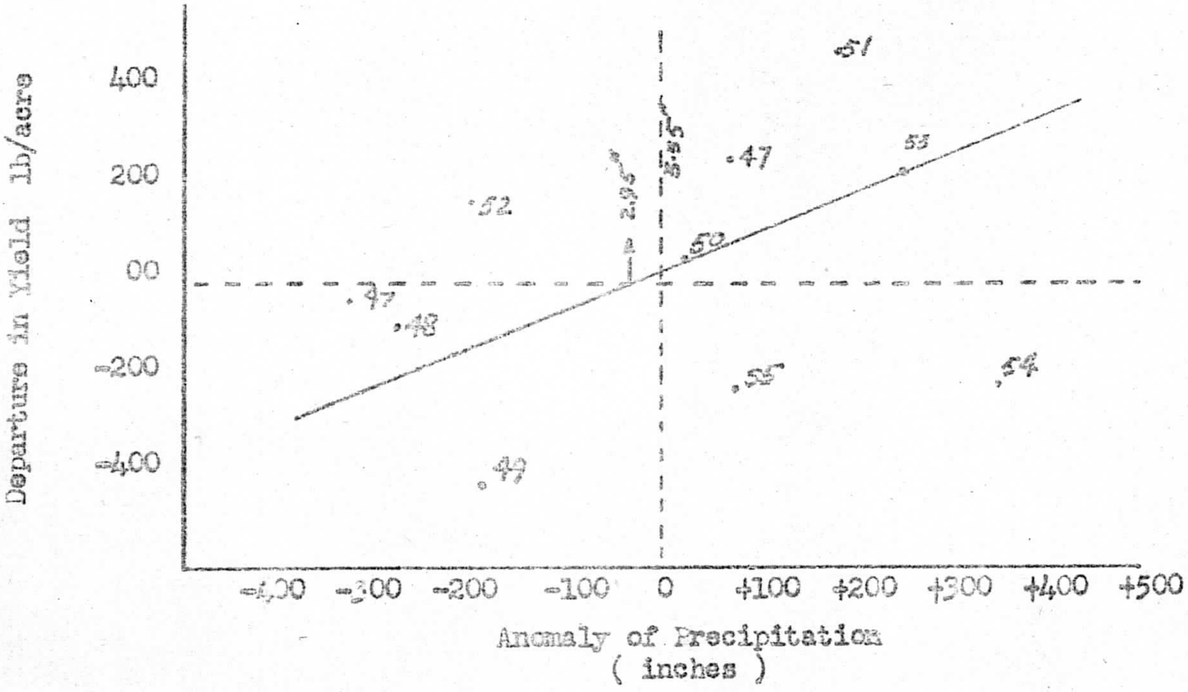
*Data from Wang, J.Y. and Suomi, V.E. Phytoclimate of Wisconsin, Part 2, Temperature. Agr. Exp. Sta. Bul. Univ. of Wisconsin to be published in 1956.

**The optimal soil temperature for nitrification as well as ammonification in field condition is 27.5°C or about 81.6°F. According to Waksman, S.A., Soil Microbiology, John Wiley & Sons Inc. N.Y. (1952).

***Explanation see Chapter 3 - page 43.

Chart 12

Anomaly* of the Accumulation of Total precipitation from April first to the date of Planting versus Departure of Yield for Alaska Peas grown in Gillet and Bonduel, Wisconsin. (1946 - 1955)



This chart shows that 2.95 inches of total accumulated precipitation prior to planting is required in order to give a normal yield. The establishment of the accumulation of total precipitation from the beginning of different months for normal yield is shown in Chart 13, which is a combination of sewwral charts of the type of Chart 12.

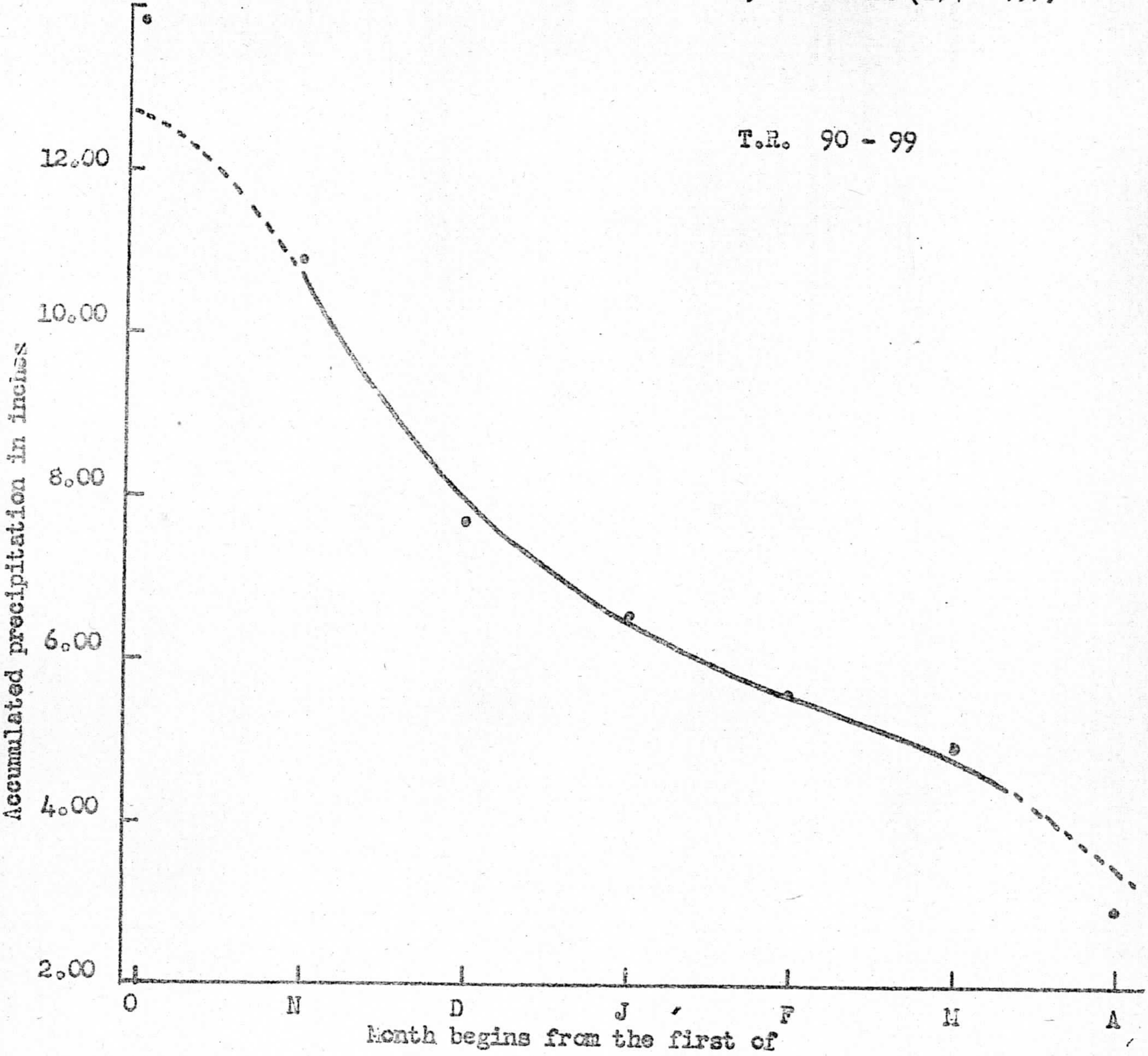
---

*The departure of a certain period mean value of a meteorological element from the mean value for the same period at the same locality.

Chart 13

Accumulation of Total Precipitation prior to Planting Date for

Normal Yield of Alaska Pea in Gillet and Bonduel, Wisconsin (1946-1955)



The ogive* of the above chart shows that the accumulation of the total precipitation from October first of the previous winter, as well as that from May first, has no correlation at all for the yield of peas. The rest of the months indicate a fairly good correlation. Whether or not this contribution to yield is important will be discussed at the end of the present chapter. Table 4 shows the results of Chart 13 in tabular form.

---

*Accumulative curve, term used in statistics.

Table 4

Accumulation of total precipitation prior to planting date for normal yield of Alaska pea in Gillet and Bonduel, Wisconsin (1946-1955).

Month begins from the first of:

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	
Accumulated Precipitation	12.60	10.65	8.00	6.45	5.55	4.80	3.50	1.50	(inches)

MINIMUM RELATIVE HUMIDITY IN WEEKLY INTERVALS.—The general methods follow essentially the same approach as described in the section on RELATIVE-MINIMUM-DROUGHT IN WEEKLY INTERVALS. The differences are in the choice of unit as well as the choice of the representative hour for the observation of the relative humidity. In the usual sense, relative humidity is expressed in percentage, therefore, the unit is not suitable for an accumulation of several weekly intervals. Thus, a new unit is chosen. It is suggested in the present paper that the overall mean value for a one-week interval be defined as one unit. Of course, this is rather arbitrary for any other suitable unit can be chosen at the convenience of the worker. In the example given in Chart 14 below, an average relative humidity of 44% on one day or 308% accumulated per week is adapted as one unit. Hence, all the weekly accumulated values have to be divided by 308. As for time of observation, in U.S. Weather Bureau practice three observations are made for the local time: 7:00 A.M., 7:00 P.M. and the noon hour. The first two observations represent the night humidity pretty closely while the noon hour observation represents the day-time. In our test of the yield of tobacco leaf for cigar-binder in Madison, Wisconsin, we found good correlation for the noon hour data. A set of rather unique scatter diagrams can be obtained by using the minimum weekly intervals of relative humidity recorded at the noon hour.

By definition relative humidity is the ratio of the actual water vapor pressure present to the saturation water vapor pressure at the ambient air temperature, in percent. The water vapor pressure used is referred to the vapor pressure over a free water surface. Of course, vapor pressure of water over ice as well as over green leaves, etc. will be quite different from that over a free water surface. In equation form, we have

$$R.H. = e/e_s \times 100 \text{ - - - - - - - - - - - - - - - - - } (9)$$

where R.H. is the relative humidity

e is the actual ambient vapor pressure

T is the ambient temperature

e_s is the saturated vapor pressure at the same temperature T.

The relative humidity is not an expression of the water availability alone, for it is a function of the air temperature (T), the air pressure (P), and the wet bulb temperature (Tw). For an ordinary psychrometer, this wet bulb temperature depends upon the nature of the wet bulb surface, as well as the ventilation. As far as plant growth is concerned, the relative humidity is an important parameter to be considered. In fact, many investigators found relative humidity more closely related to plant growth than many other meteorological parameters.

Chart 14 gives the relative minimum R.H. required in weekly intervals for the normal and optimal yield of cigar-binder-tobacco in Madison (1930 - 1938), while the summary for various weekly intervals is shown in Chart 15.

Chart 14

Relative Minimum 9 week-interval Relative Humidity for Normal Yield of cigar-binder leaf in Madison, Wisconsin (1930-1938)

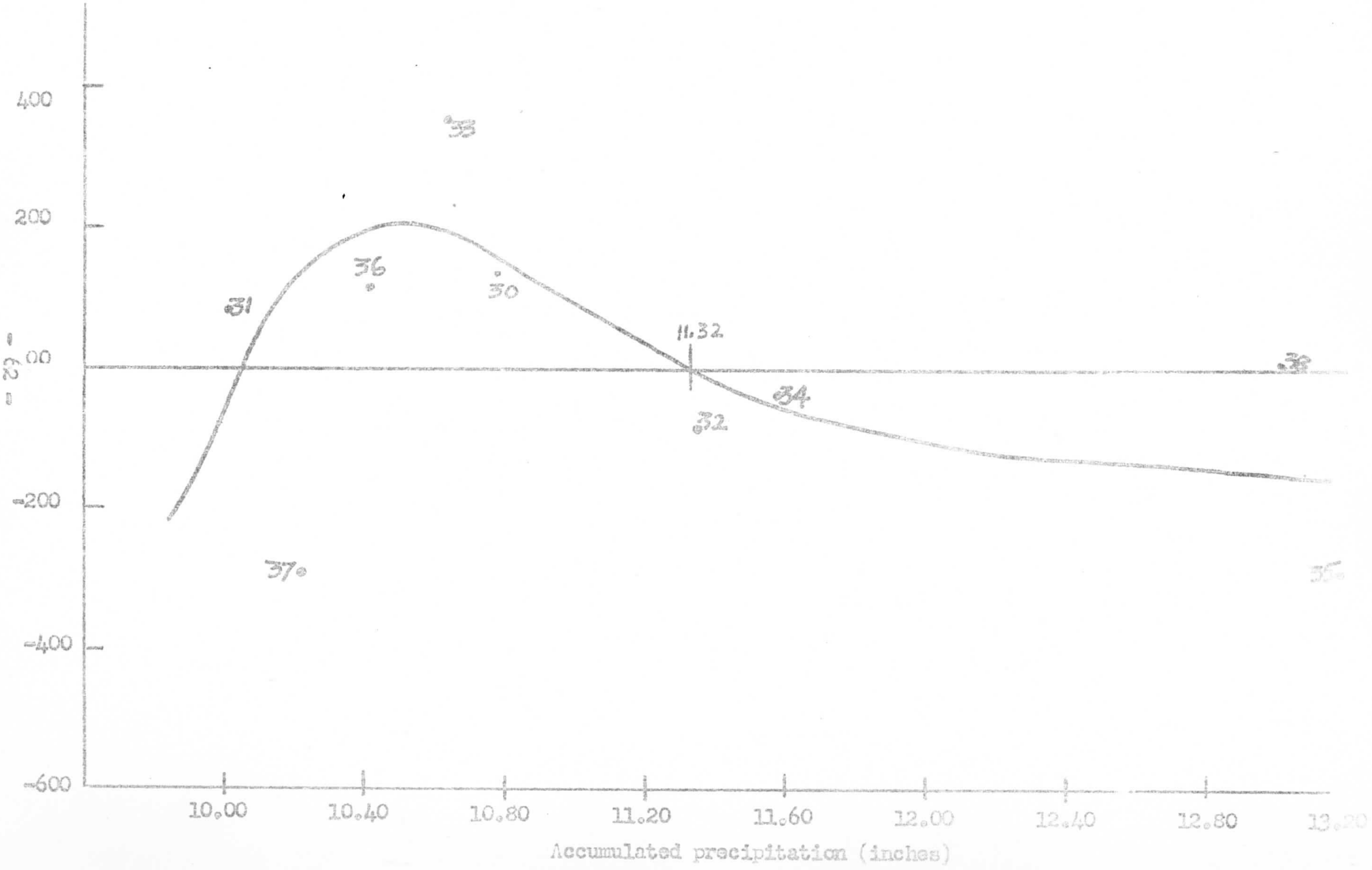
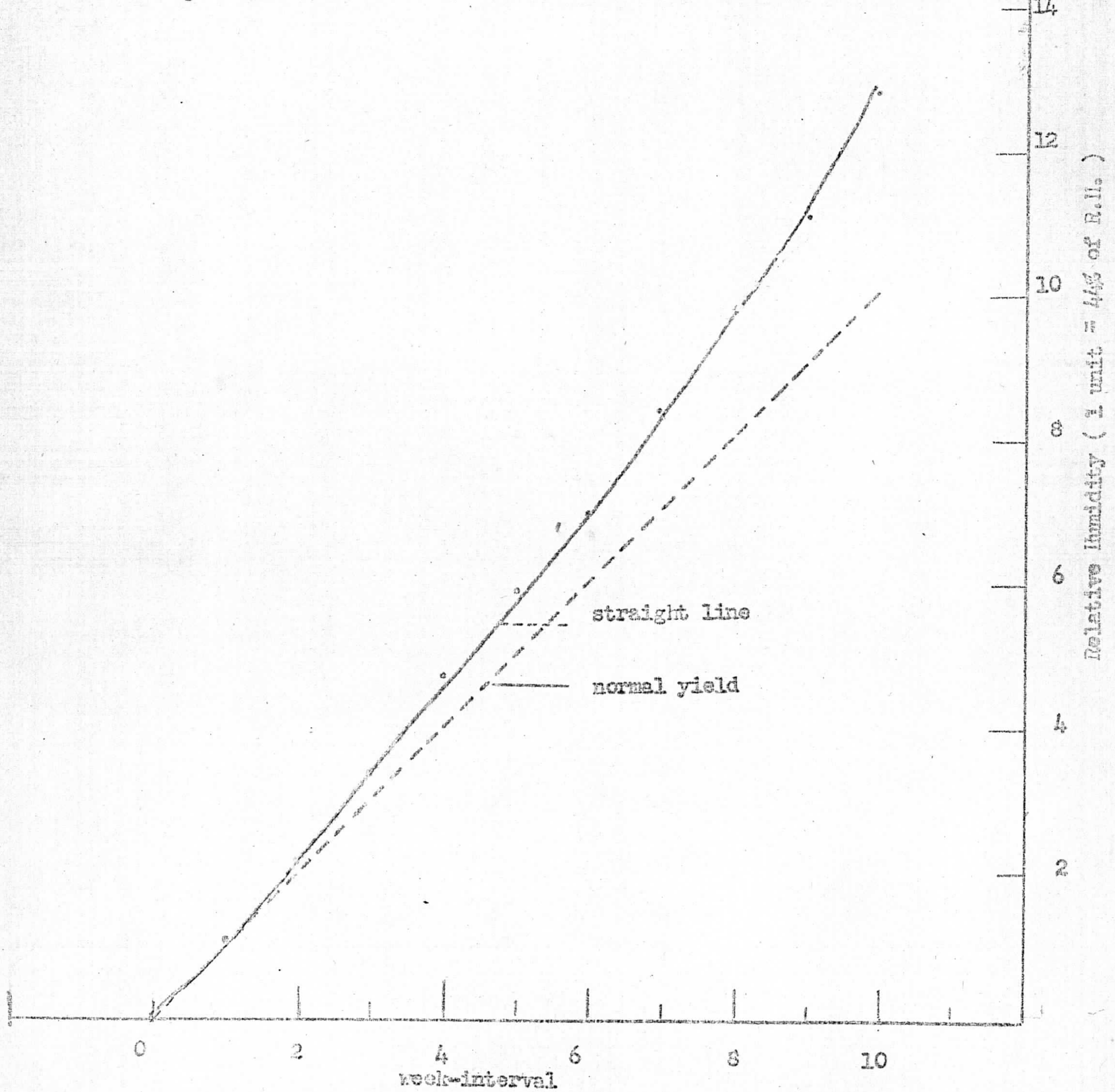


Chart 15

Relative Minimum Relative Humidity for the Normal yield of

Cigar-binders in Madison, Wisconsin (1930 - 1938)

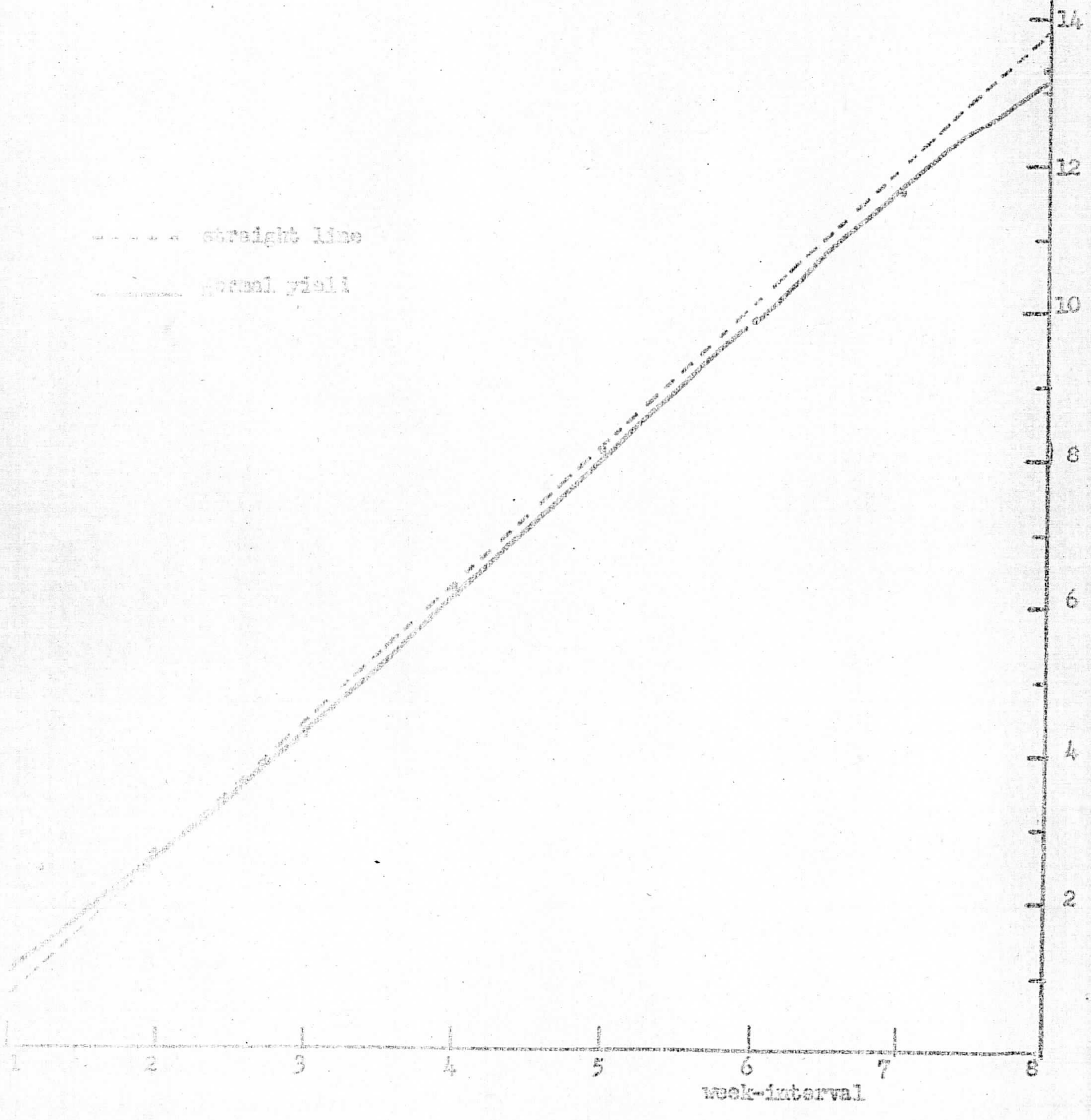


A straight line is drawn in the above chart to show the deviation of the humidity vs yield curve from a linear relationship.

For Alaska peas, the relation is shown in Chart 16.

Chart 16

Minimum Relative Humidity Requirement in Weekly Interval for Normal Yield of Alaska Peas Grown in Gillet and Bonduel, Wisconsin (1946-55)



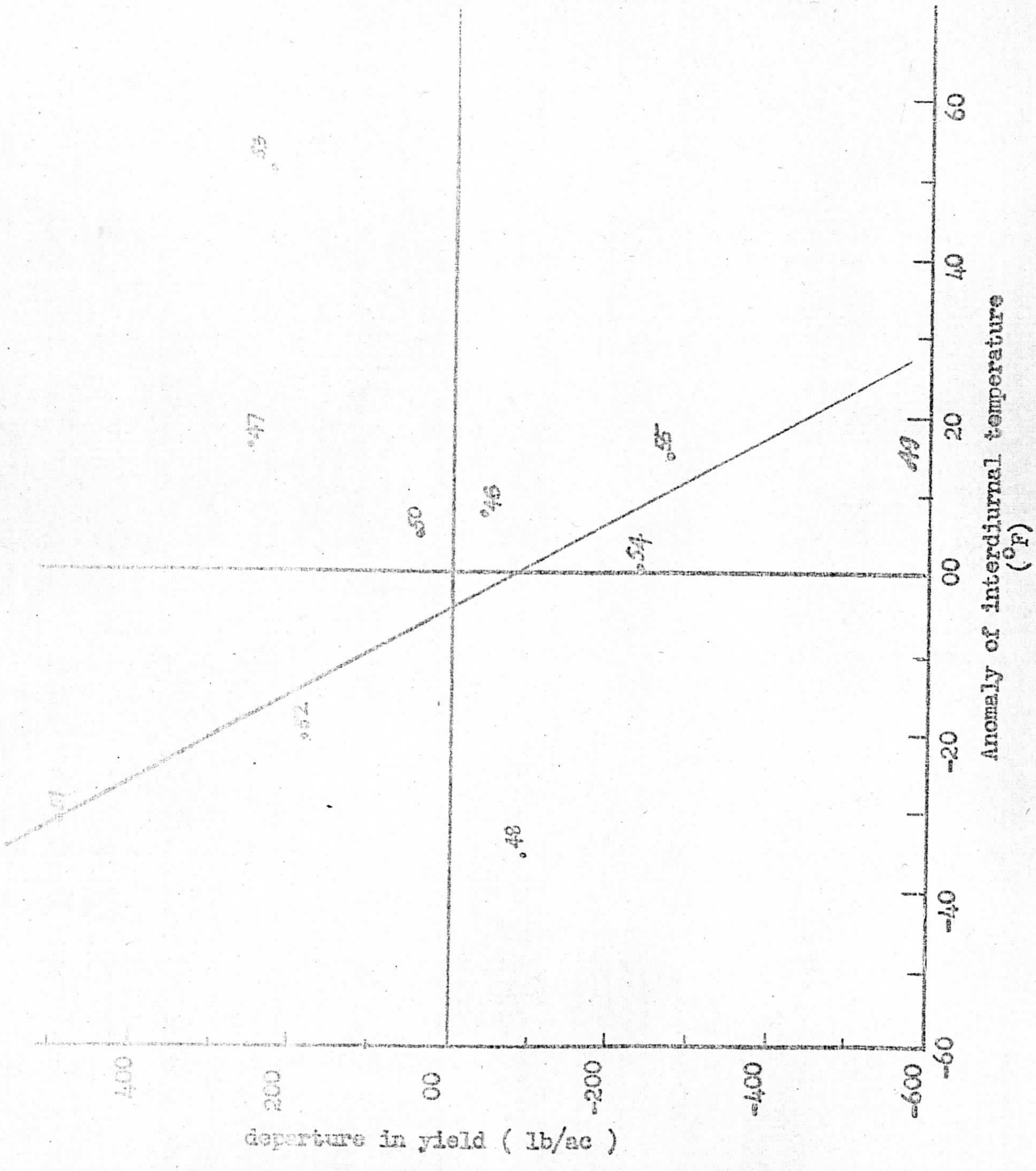
RELATIVE MAXIMUM - NOCTURNAL TEMPERATURE.—For regions where the hourly temperature has been observed, it is convenient to compute the arithmetic mean of night time temperature for the interval between the beginning of civil twilight and ending of the civil twilight the next morning. For regions without hourly temperature records, the mean night time temperature has to be computed from the daily maximum and the minimum temperature record. A theoretical method has been established and is shown on Appendix IV.

The relative maximum mean night temperature in weekly intervals is obtained by following exactly the same method as stated in the section concerning RELATIVE MINIMUM - DROUGHT IN WEEK-INTERVAL, except that the maximum values are most interesting here. The reason for using the maximum night temperature instead of the minimum temperature is that peas are more sensitive to high night temperature: presumably the higher the night temperature, the lower the yield and quality.

No tests will be described in the present volume using this parameter.

INTER-DIURNAL TEMPERATURE DIFFERENCE .— The rate of change of air temperature usually follows the sun angle. In the latitude of Wisconsin, the warming process, on the average somewhat follows a sinusoidal curve, while cooling follows an exponential one. After the air temperature attains its daily maximum value, some 11 to 16 hours are required to come to the daily minimum the next morning; and the time required depends upon the season. For the pea-growing season in Wisconsin, it is about 13 - 14 hours. The difference between the daily maximum and the minimum of the following day can be called the inter-diurnal temperature difference of maximum and minimum. In brief, it may be named "the inter-diurnal temperature difference." It is the *fluctuation of temperature* from day to night. Most canning peas seem to be very sensitive to this change, except those green pea varieties such as Little Marvel, an old home garden pea and Wando, the USDA hot weather peas. Tests on canning peas for their irritability to temperature fluctuation have been accomplished as below:

(a) Summation of Fluctuation.— The summation of all the differences between maximum and minimum temperature inter-diurnally, as stated above, for the period between flowering and maturity of Alaska Peas is given in Chart 17 - 19.

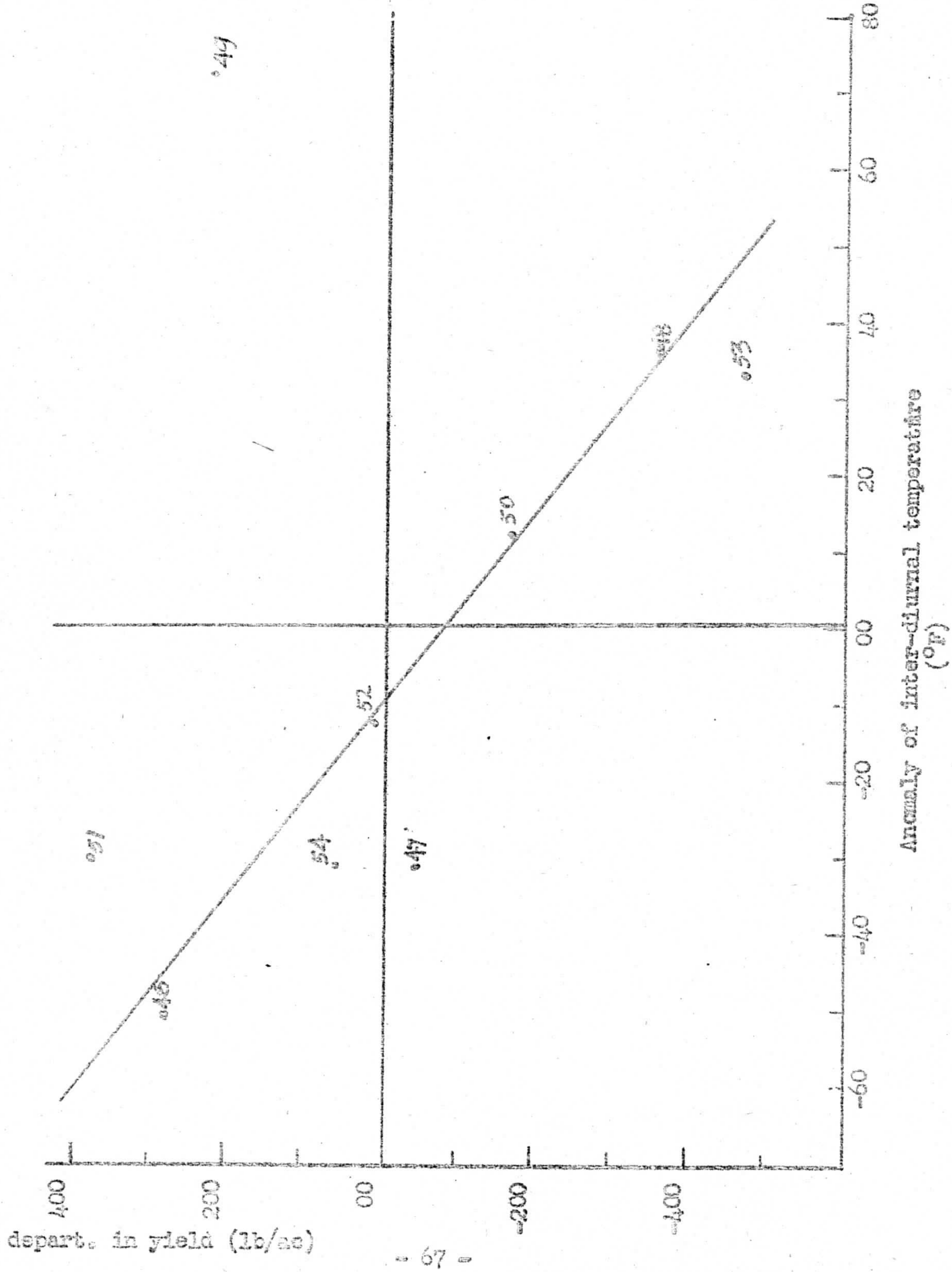


Summation of Inter-diurnal Temperature Difference between Blossoming and Maturity versus Departure of Yield for [illegible] 20 - 99 in Gillett and Bonduel, Wisconsin (1946 - 55)

The negative correlation between yield and summation of temperature fluctuation is high and appears the same for all ranges of tenderometer readings (i.e.T.R. 90 -99; 100-109 and 110 - 119). The average slope of the curve in the above chart is 1.81.

Chart 18

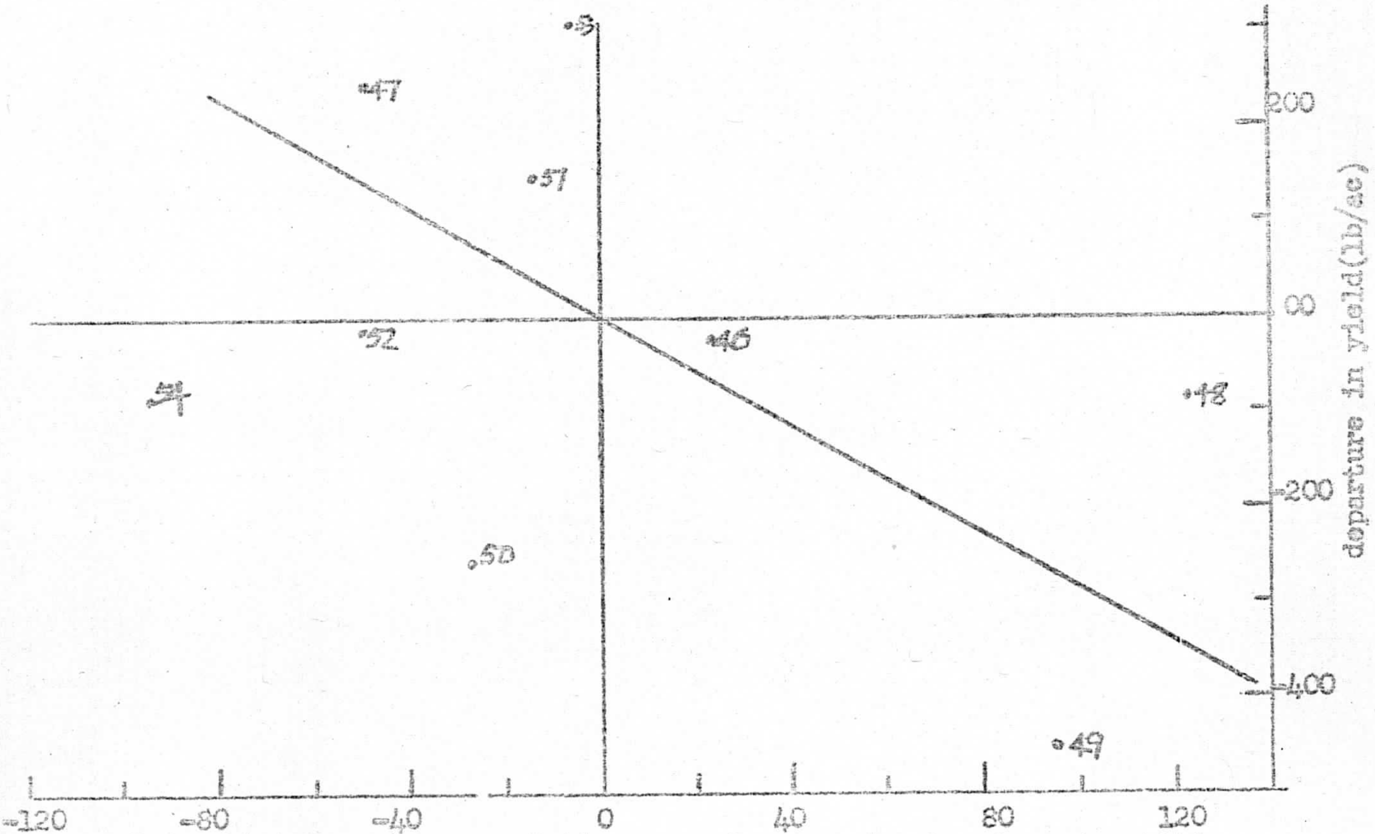
Summation of Inter-diurnal Temperature Difference Between Blossoming and Maturity versus Departure of Yield in Rosendale, Wisconsin (1946 - 1954)



A high negative correlation also exists in Rosendale, but the slope of the curve indicated in the above chart is less steep than that of Chart 17, for the slope is 0.77.

Chart 19

Summation of Inter-diurnal Temperature Difference Between Blossoming and Maturity versus Departure of Yield in Belvidere, Illinois (19 46-54)

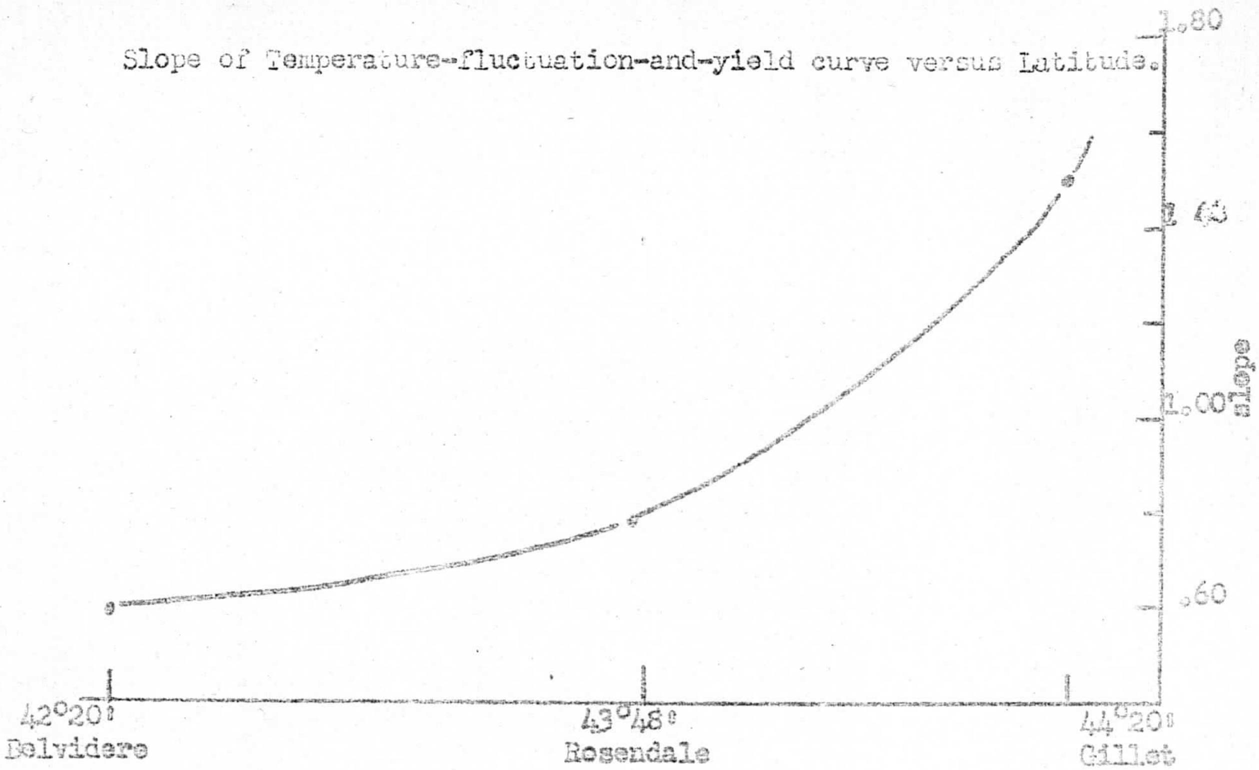


Same high negative correlation as before, again the slope is still less steep than the above two charts.

(b) Latitudinal Distribution.— It is most interesting to notice the change of slope from north to south, for it indicates less sensitivity to inter-diurnal fluctuation at Belvidere. This slope of temperature fluctuation and yield curve versus latitude is given in Chart 20.

Chart 20

Slope of Temperature-fluctuation-and-yield curve versus Latitude.



The value for Gillet and Bonduel used in the above chart was a mean of all tenderometer readings.

Findings for the summation of temperature fluctution against yield are tabulated in Table 5.

Table 5

Summation of Temperature Fluctuation at the Stage Between Flowering and Maturity as related to the Yield of Alaska peas in different areas of Wisconsin and Illinois.

REGION	POOR YIELD	NORMAL YIELD	OPTIMAL YIELD
Belvidere	greater than 527	527	less than 527
Rosendale	greater than 472	472	less than 472
Gillett	greater than 505	505	less than 505

The mathematical express for this "summation of inter-diurnal temperature difference" used in this section can be formulated simply as below:

where, $T_1 \equiv \frac{\sum (T_{Mi} - T_{mi+1})}{x-1}$ ------------------------ (10)

T_I is the inter-diurnal temperature in °F;

i is the date of the calendar day;

Tm is the daily maximum temperature in °F;

Tm is the daily minimum temperature in °F;

X is number of days in a certain stage of plant growth.

In the present example X is approximately equal to 21 days for the period between the blossoming and maturity for Alaska peas in this latitude.

NIGHT TEMPERATURE.—A test somewhat similar to that made for inter-diurnal temperature difference in the above section was also made for night temperature. The summation of all the daily mean night temperatures (T_E) throughout the growing season can be expressed mathematically as below:

$$T_E = \sum_{i=D_p}^{D_M} (T_e - T_{c,L})_{T_{c,u}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (11)$$

where T_E = the effective night temperature or the daily night time temperature below the upper critical temperature $T_{c,u}$ and above the lower critical temperature $T_{c,L}$;

T_e = the daily mean night temperature in °F;

i = the date of calendar day;

D_p = date of planting (or seeding);

D_M = date of harvesting (or maturity);

T_c = critical temperature; subscript U designated upper limit, L, lower limit.

In regions with hourly temperature records, the values of T_e can be obtained readily, however, for regions without hourly temperature records the daily minimum temperature can be used as a substitute. In this case, the values assigned for the critical temperature (both upper and lower limit) should be so adjusted empirically for the best correlation.

The use of upper and lower limit of the critical temperature is such that to have all daily mean night temperatures (Te) substract the lower limit critical temperature (Tc.L), first. Then, if any daily mean night temperature is higher than the upper critical temperature the record (or value) of that particular day is discarded.

An example of this is shown on chart 21, (a) (b). The upper and the lower limit of critical temperature used for chart 21 (a) were 45°F and 39°F, respectively, while in Chart 21 (b), 50°F and 39° were used respectively. These values were obtained through a series of tests. Chart 21 (a) is for the last planting sequences, while Chart 21 (b) is for the first planting sequence of Alaska Peas in Rosendale, Wisconsin.

Chart 21 (a)

Summation of Night Temperature versus Departure of Yield for Alaska Peas in the Second Planting Sequence at Rosendale, Wis. (1946-1954).

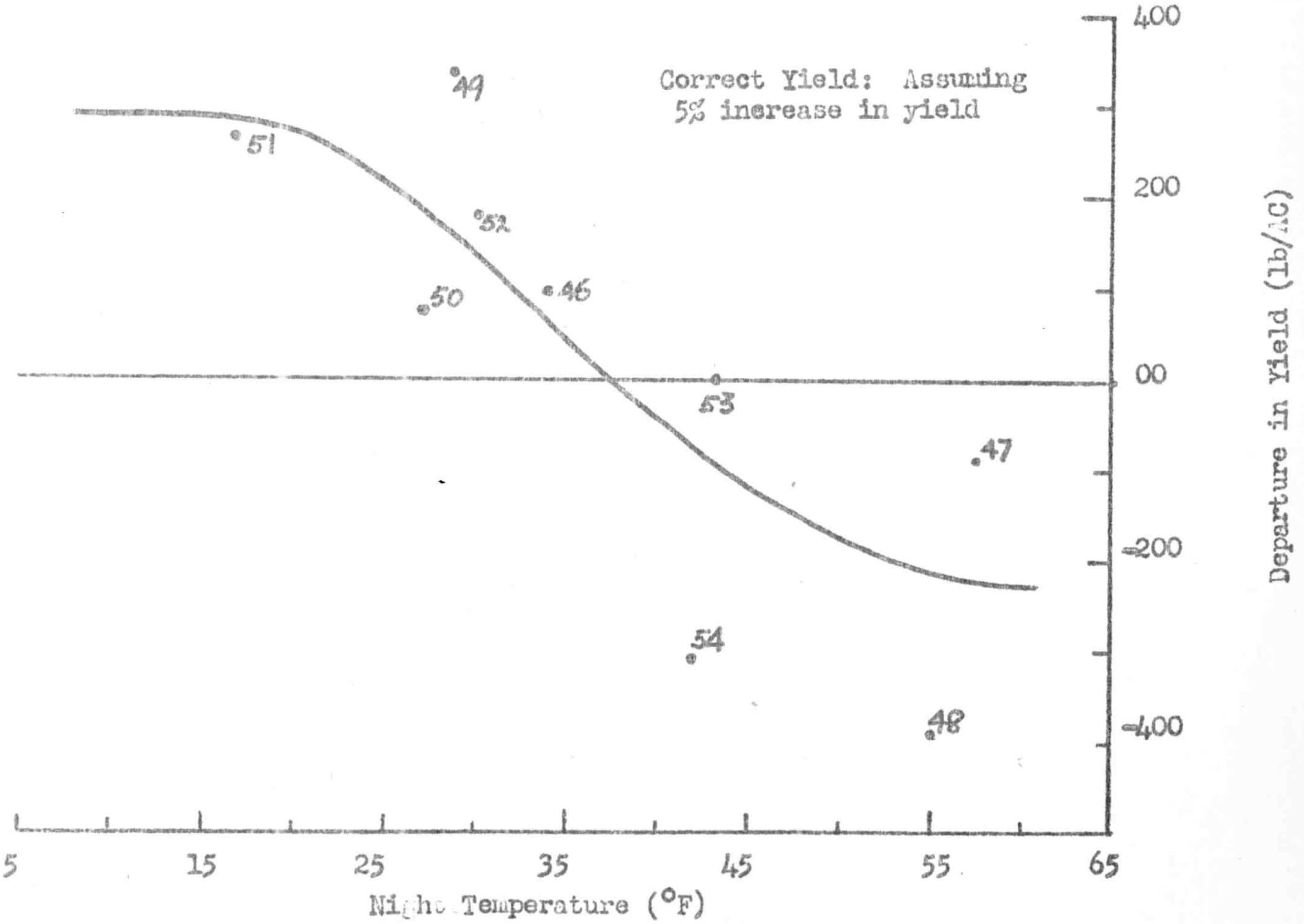
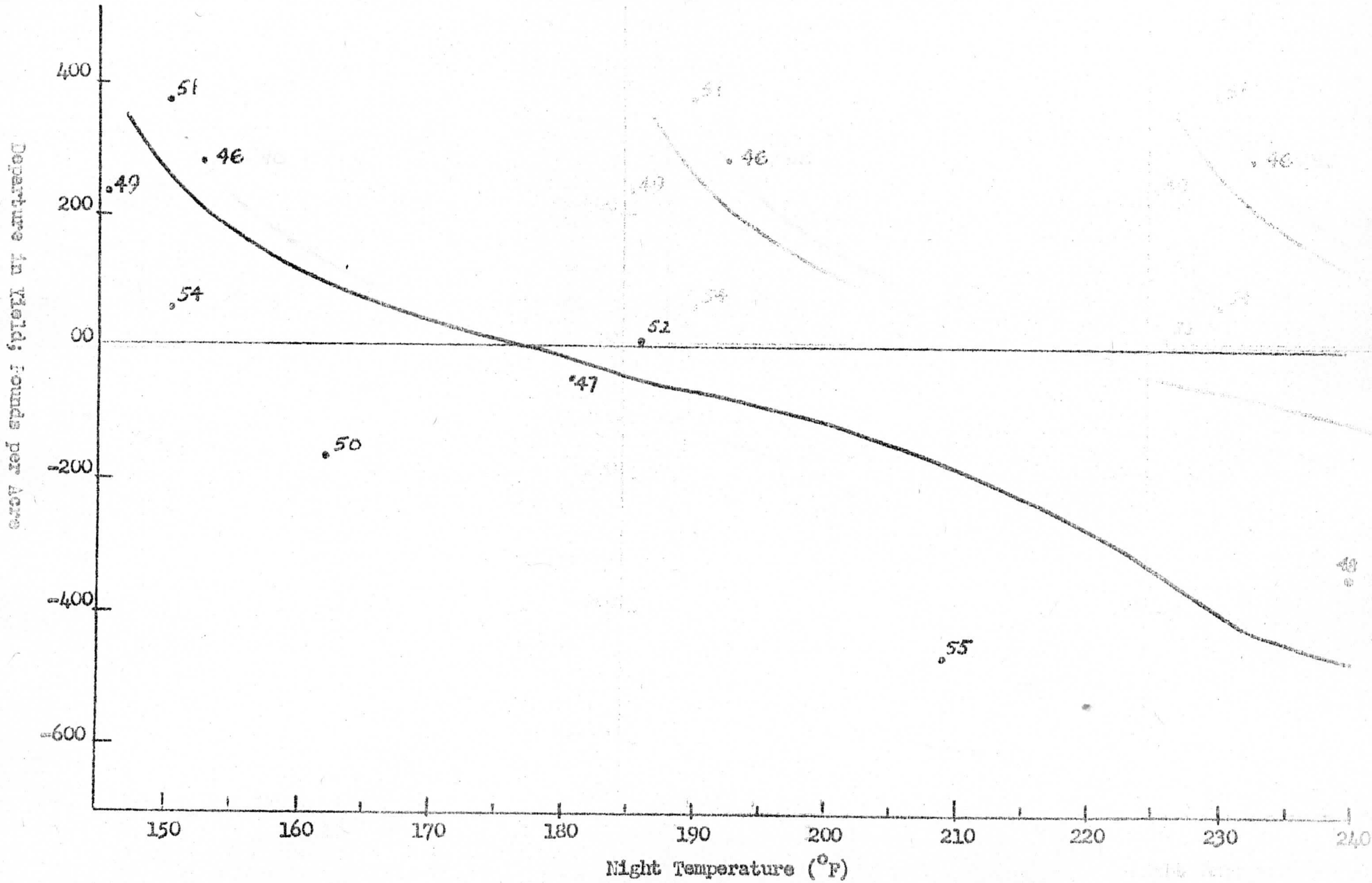


Chart 21 (b)

Summation of Night Temperature versus Departure of Yield for Alaska Peas in the First Planting Sequence at Rosendale, Wisconsin (1946-1954)



The night temperatures used in the above two charts were the daily minimum temperatures observed in El Dorado, Wisconsin. Correlations in the scatter diagram of Chart 21 (a) seem just as good as in Chart 21 (b). Indeed, the emphasis by various authors in recent years on night temperature, as an important factor in the growth of plants, has been hereby substantiated.

PHOTO-THERMAL UNIT.— This refers to a combined effect of light and temperature on the growth of plants. The light designated here is the day-length while the temperature is the effective temperature. In our latitude, the length of day can be expressed as hours between sunrise and sunset, for the addition of twilight hours to the daytime has no significant effect on the absolute value ultimately secured. This is simply because the monthly change of twilight time is very small. The effective temperature is computed from a upper and lower critical temperature, as was done in the foregoing section. The photo-thermal units, or simply P.T.U. can be expressed as follows:

$$PTU = \sum_{i=D_p}^{D_M} (T_M - T_{c,L})_{T_{c,U}} \cdot t_s \quad \cdots\cdots\cdots\cdots\cdots\cdots (12)$$

where,

i = date of the calendar day;

D_p = date of planting;

D_m = date of maturity;

T_m = daily minimum temperature, °F;

T_c = critical temperature, (subscript U designated upper limit; L, lower limit) in °F;

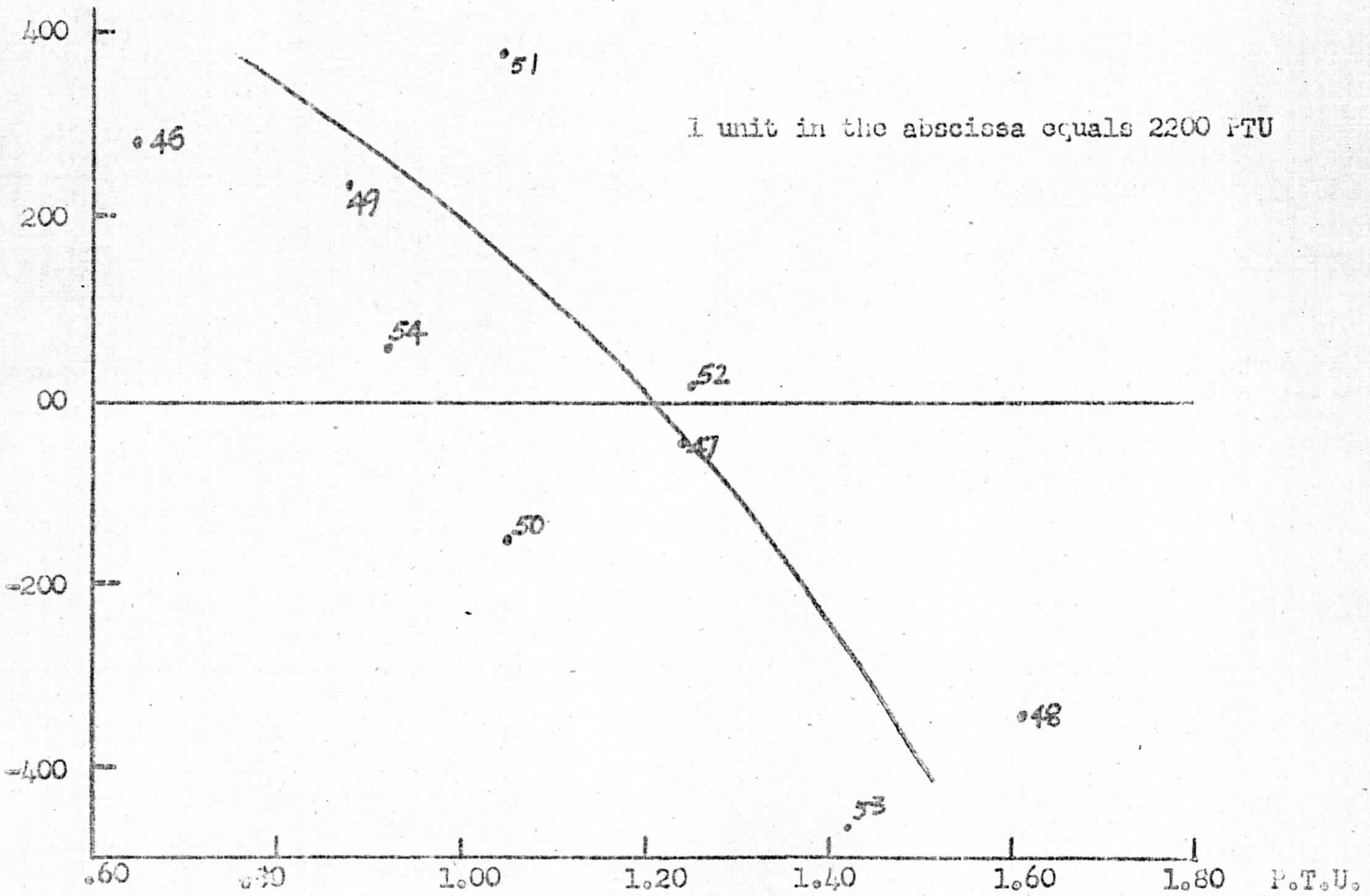
T_s = possible sunshine hours.

The induction of reproduction by a combination of photo-period and temperature has been used by Chroboczek (1934) and the term "photo-thermal induction" has been suggested by Olson and Stout in 1940. The photo-thermal system has been adopted and tested by a number of workers: In 1948

Murneek* made an historical review of research in photoperiodism; Allard emphasized the importance of length of day to plant life, and Nuttonson studies wheat phenology correlated with photo-thermal units. Others, such as Madariaga and Knott (1951), Reath and Wittwer (34) in 1952, McCall and Voight (1953), have made similar studies on lettuce, peas and wheat respectively. Nevertheless, no study of historical data for Alaska pea yield by means of photo-thermal units, (including the use of upper and lower temperature limits as designated in this paper) has been made. Charts 22 (a) and (b) illustrate this relation.

Chart 22 (a)

Photo-thermal Units versus Yield of Alaska Peas in Rosendale, Wisconsin (1946 - 1954) — the first planting sequence.



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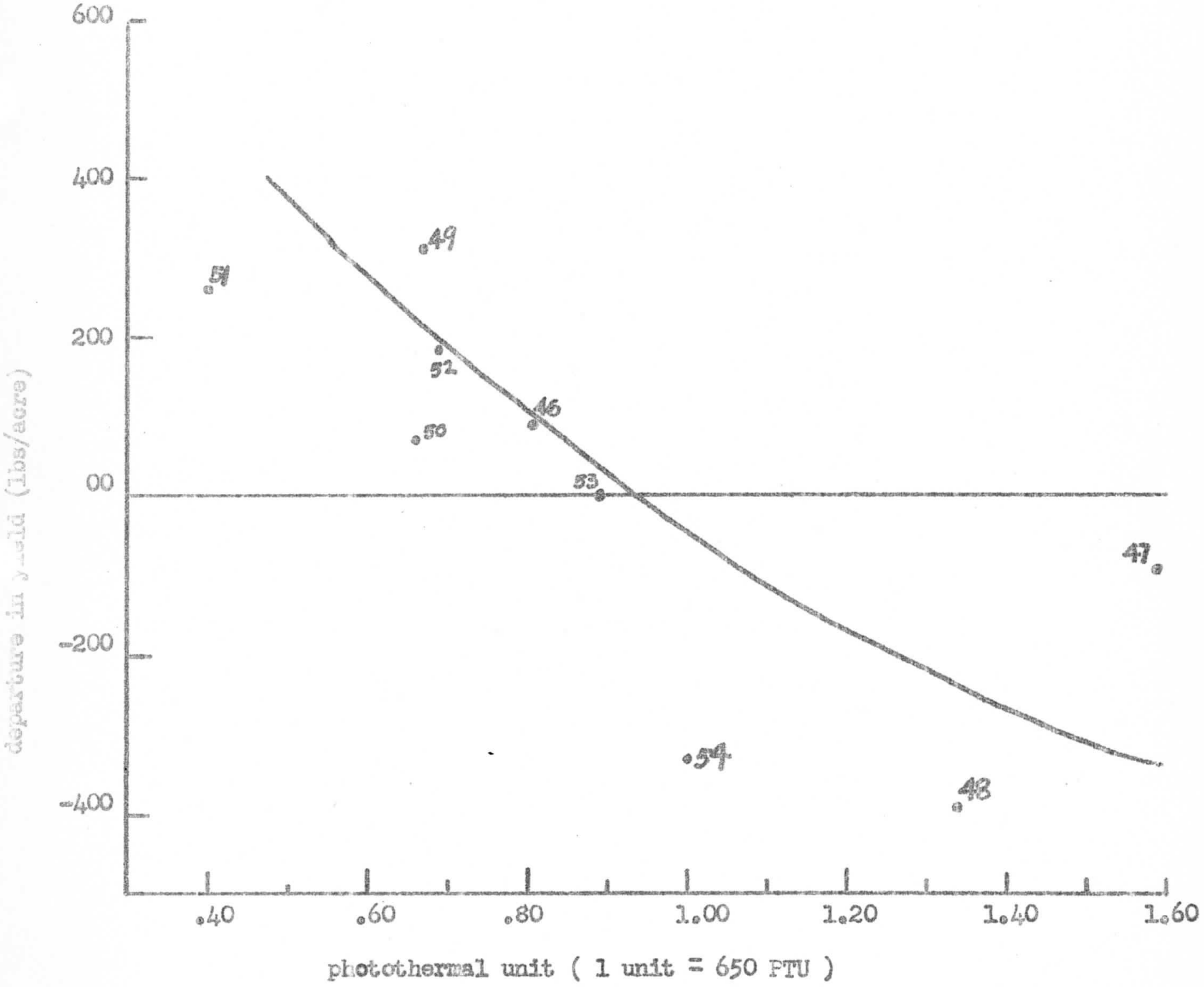
*Murneek, A. E. and Whyte, R. O., Vernalization and Photoperiodism — A Symposium. Waltham, Mass. (1948)

The upper critical temperature used in the above chart is 50°F while the lower limit is 39°F. The unit used in the abscissa is 2200 P.T.U.

Chart 22 (b)

Photo-thermal Units versus Yield of Alaska Peas in Rosendale, Wisconsin (1946-1954) — for the second planting sequence.



The upper limit of the critical temperature used in the above chart is 45°F, while the lower limit is the same as Chart 22 (a). The unit in the abscissa used is 650 P.T.U.

ENERGY DEGREE UNITS.— Following the concept of the photo-thermal-unit, it is possible to establish a so-called "Energy degree unit" which is defined as:

$$EDU \equiv \sum_{i=D_p}^{D_m} (T_a - T_{c,L})_{T_{c,U}} \cdot E \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

where ,
i = date of calendar day;
D_p = date of planting;
D_m = date of maturity;
T_a = daily mean temperature; in °F;
T_c = critical temperature (subscript U designates upper limit; L, lower limit) in °F;
E = solar radiation (Langley per day).

Garner and Allard in 1920 - 23 published a series of papers* and Post in 1942 published a similar paper indicating the importance of the length of day rather than the intensity of solar radiation. Their findings are that a minimum light intensity of 3-5f.c.** seems to be sufficient for most plants, while full solar radiation on a clear day at sea level is about 10500 f.c. Some marine algae seem to be able to carry on sufficient photo-synthesis to maintain themselves at a depth where the intensity is about the same as that of moonlight (bright moonlight is about 0.05 f.c.) Nevertheless, so far as the transpiration-to-photosynthesis-respiration relationship is concerned, the energy-degree unit rather than the photo-thermal unit is important. Further study of plant growth using this new

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* Garner, W.W. and Allard, H.A., Effects of the relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agr. Res. 18:553-606, (1920)

__________, Further studies in photoperiodism. The response of the plant to the relative length of day and night. Jour. Agr. Res. 23:871-920.

__________, Effect of abnormally long and short alternations of light and darkness on growth and development of plants. Jour. Agr. Res. 42:629-651.

** 1 calorie per square centimeter per minute equals 6000 foot-candles.

unit should be thoroughly tested. On account of solarization (or light inactivation) the $T_{c,L}$ and $T_{c,U}$ value should be carefully chosen.

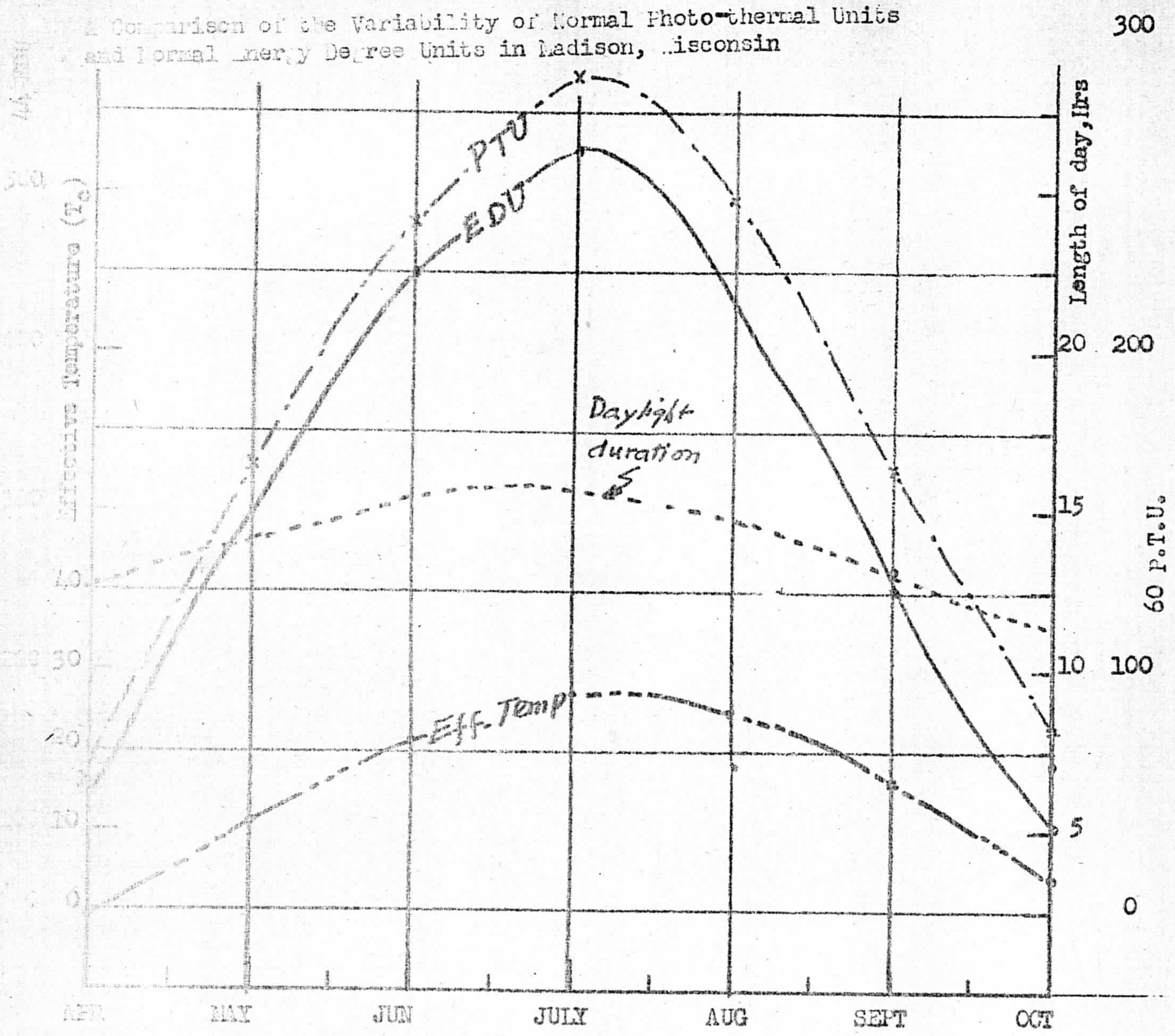
A comparison of photo-thermal units and energy-degree-units with consideration of the effective temperature and length of day, has been made for Madison, Wisconsin for the months of March through October for over 50 years of record. The normal energy degree unit computed is based upon:

$$EDU = (T_a - T_{c/t})M. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where it is the number of days in the month, while the other symbols are the same as given above. The effective temperature is Ta-Tc where 36°F is chosen for T_c. Chart 23 shows the result of this comparison.

Chart 23

A Comparison of the Variability of Normal Photo-thermal Units and Normal Energy Degree Units in Madison, Wisconsin



The above chart indicates that the inter-monthly change of energy degree units is somewhat similar to that of photo-thermal units. This shows that the effective temperature plays an important role in the evaluation of both of these units. The regional variation of temperature is sharp, while the spatial variation of solar intensity and length of day is gradual. Thus, scores of workers in the past obtained fairly good correlations between effective temperature and the growth or yield of crops. The above chart shows also that both effective temperature and

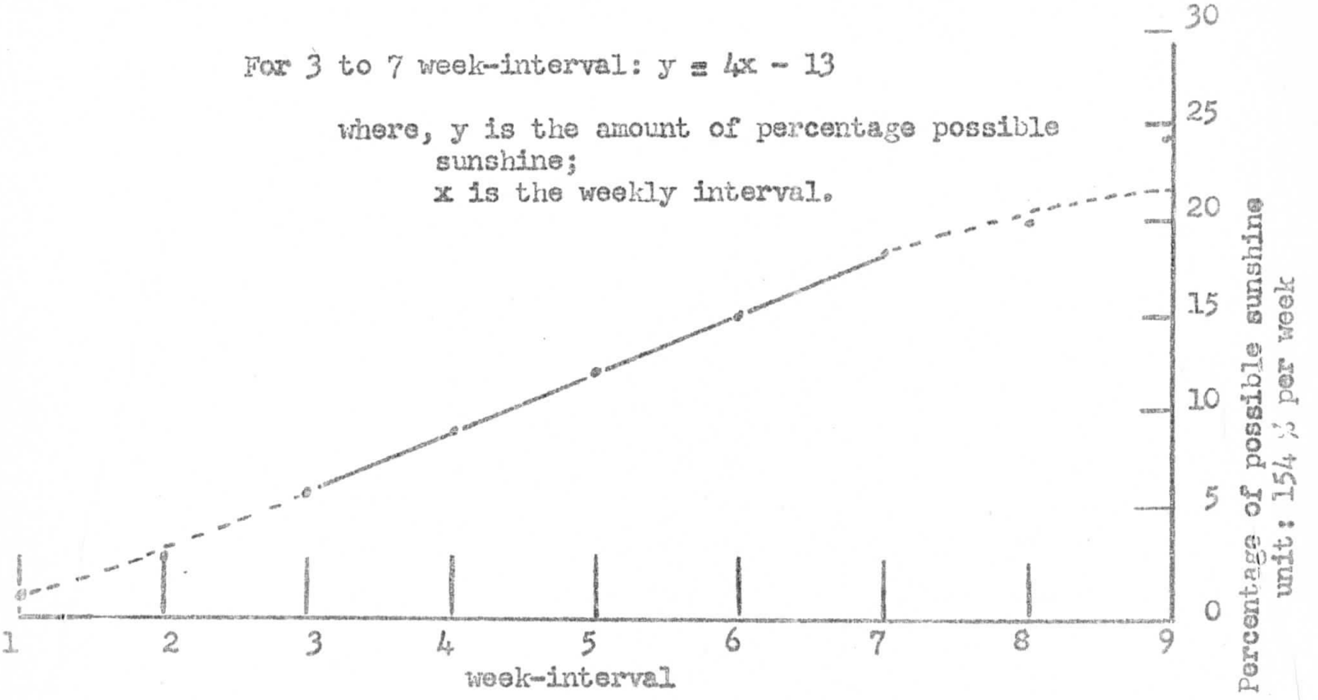
~~the growth or yield of crops. The above chart shows also that both effective temperature and~~ energy degree curves skew up somewhat from spring to autumn months, while the photo-thermal curve shows rather a normal distribution.

RELATIVE MINIMUM PERCENTAGE OF POSSIBLE SUNSHINE IN WEEKLY INTERVALS.--

Percentage of possible sunshine is defined as the actual sunshine in hours divided by the possible sunshine hours in the day, expressed in percentage. Data can be obtained from the first class Weather Bureau stations in this country. The relative minimum of these values in weekly intervals, as well as the choice of units, may be investigated by the same procedure as that used in the computation of the accumulated relative humidity. The effect of this percentage of possible sunshine on plant growth and development results from a combination of day-length, or photo period, and solar intensity. An illustration of this is given in Chart 24.

Chart 24

Relative Minimum Percentage of Possible Sunshine in Weekly Interval versus Yield of Alaska Peas in Rosendale, Wisconsin (1946-54)



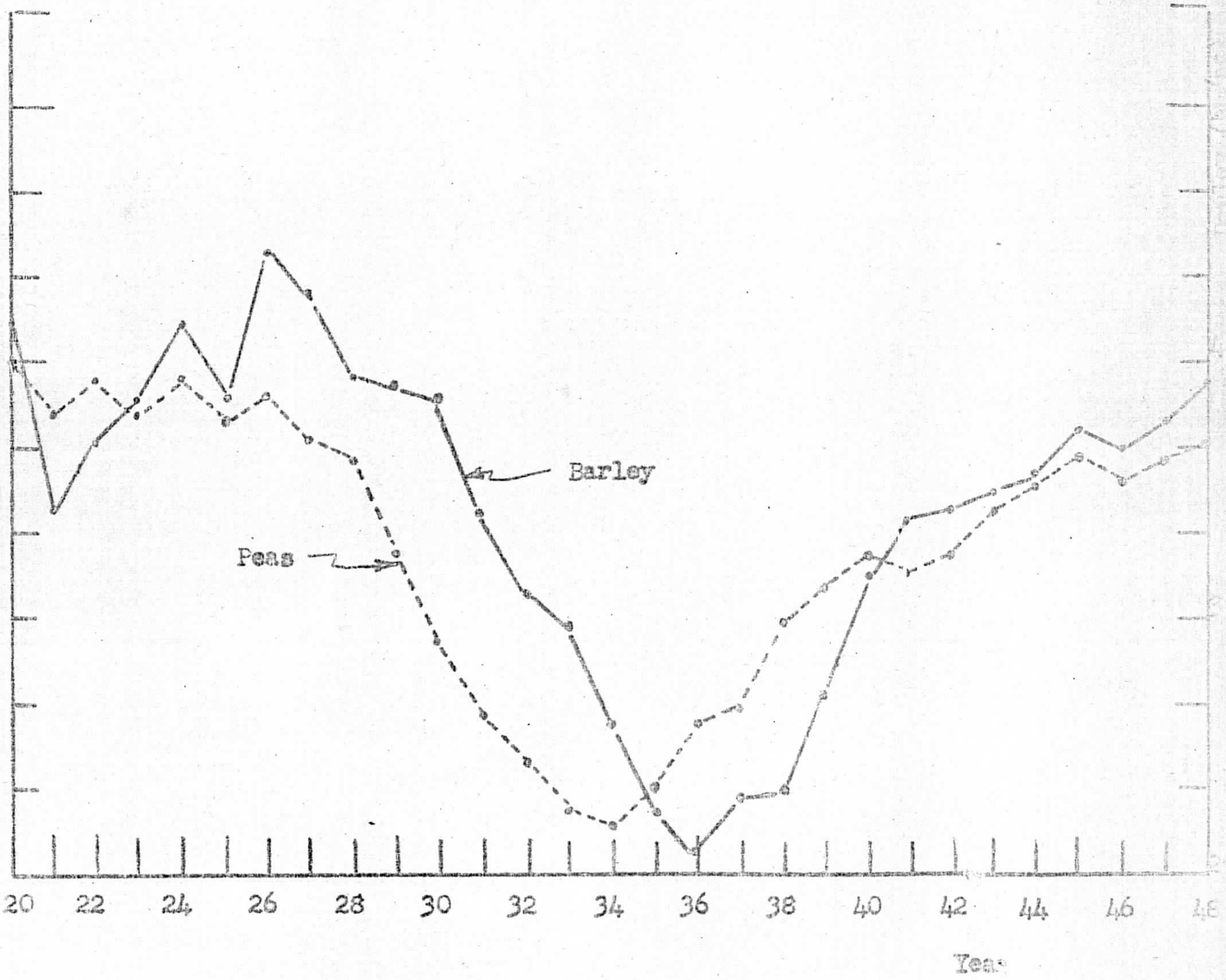
PHYTOMETER.— Since a definition of the plant is, "An expression of environment," as previously stated, it is safe to say that the plants reveal the totality of environmental factors. In the use of the phenological phenomena of one plant as related to these of another plant, the former is the "phytometer" or the guide plant of the latter. The term, "phytometer," as it has been used by many phenologists of the world, implies the use of the appearance of one or a group of plants as the measuring stick for another plant or plants. This approach may serve as a biological forecasting tool e.g. for the prediction of the date of blossoming, of maturity, as well as the yield and quality, etc. This idea can also be applied for phase to phase relationship between the "guide plant" and the other plant. In this case, a plant with a high degree of sharpness should be used as the guide plant. It is interesting to note that the American Indians had a saying that corn should be planted when the leaf of a white oak was the size of a mouse's ear. This uses the white oak as a "guide plant" for corn. Many biological sciences use phenological events as measuring sticks from time to time.

Much has been said about the importance of the idea of the phytometer, but little work has been done quantitatively, i.e. expressing the correlation in figures. A comparison of the yield of barley and winter wheat in Madison, Wisconsin for a number of years is shown in chart 25. The correlation, in general, with the progress of the year is very good.

Chart 25

Yield of Barley and Canning Peas through the course of the Year in Madison, Wisconsin

Explanation: the analyses based upon the bloxaming of the annual values in fives(i.e. the value for 1920 =(1918 +'19 + '20 +'21 + '22) ÷ 5,and so for each year).



SIGNIFICANT ADVERSE WEATHER CHECK .— It is obvious that some severe weather is enough to cause considerable damage to plants. Furthermore, some rather severe weather may not be harmful at a certain phase of plant development, but may be significantly harmful at another phase.

As mentioned on page [illegible], rainfall within 36 hours after planting will cause a marked reduction in the germination of peas and, in turn, a poor yield. This is an example of significant adverse weather causing serious damages to a plant at a particular period. The same amount of rainfall in any other phase or period of the plant life cycle may be beneficial instead of harmful. Thus, a check of all significant adverse weather occuring during the growing season is necessary. The possible adverse weather events which may cause damage are: very strong wind of Beaufort Scale 9* or above, (including sandstorms, hurricanes, or tornados); Very heavy precipitation (very heavy thunderstorm shower, a very long continuous rainfall, a hail storm); A severe cold spell (a killing frost, a snowfall); An extra-ordinary warm spell (maybe a continuous period of over 100°F of day time temperature for a week). As for the adverse weather prior to the time of seeding, the soil might be too wet or too cold, etc. The degree of damage in terms of reduction in yield and quality of peas might be figured out by comparing the yield or quality with a normal year or with a year of similar weather conditions, if sufficient data are available. All these odd checks of adverse weather should be recorded in the meteorological chart as stated in the earlier part of this chapter. An example of this type of odd check will be given in the next chapter. Of course, damage due to insects and disease might be more serious than that due to adverse weather.

This latter is one of the biotic factors and should be eliminated from the original data. In other words, from our yield data, for instance, there should be excluded any field data markedly affected by damage from insects and disease.

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*B.S. 9 equivalent to a wind of 47 to 54 miles per hour.

COMBINATION OF ENVIRONMENT FACTORS.-- Volumes of papers have been published in the past on the application of single environmental factors to the growth and development of a plant, more specifically to the amount and quality of yield in a crop; however, little has been done on the effect of combinations of environmental factors. It is beyond doubt that all factors should be treated in unison and not separated. The difficulties arise from the lack of methods of combination.

In this section, three approaches to the combination of environmental factors are suggested. They are (a) mathematical approach, (b) diagrammatic approach and (c) statistical approach.

(a) Mathematical approach: Quantitative functional analysis is only possible if the environmental and conditioning factors investigated can be expressed in numerical terms. So far as the mathematical approach is concerned, no single numerical value can be assigned to a given complicated climate. It becomes necessary to work with individual climatic components, combination of all components being made by means of partial differential equations. Some other exponential expressions related more or less to the statistical approach will be described at the end of this chapter.

Let potential yield (Y_p) be a function of biotic (b), edaphic (e), climatic (c) and time (t) factors. Mathematically, this may be expressed as:

$$Y_p = Y_p' (b, e, c, t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Thus, we define the word "potential yield" or Y_p as the inherited characteristics possessed by the seed or the reproductive organ of a crop such that it contributes potentially to a known yield at the time of maturity.

If all environmental factors were held constant, the yield would vary but slightly; and if all environmental factors were joined optimally maximum yield would be expected. It follows that a normal yield occurs only with certain combinations of environmental conditions, such as all normal. It is the departures from those normal yield, with which we are concerned, for they are the departures responsible for the difference of yield in each planting sequence.

Y_p in Eq. (15) may represent <u>quality</u>, as well as <u>quantity</u>, e.g. T.R. for the unit measure of quality, or pounds per acre for quantity. By isolating the the variable, we have

$$dY_p = (\partial Y_p/\partial b)_{e,c,t}\, db + (\partial Y_p/\partial e)_{b,c,t}\, de + (\partial Y_p/\partial c)_{b,e,t} dc + (\partial Y_p/\partial t)_{b,c,e}\, dt. \qquad \ldots\ldots\ldots\ldots (16)$$

where subscrips denote the factors held constant. The total time-variation of potential yield (dY_p/dt) will be

$$dY_p/dt = (\partial Y_p/\partial b)_{e,c,t}\, db/dt + (\partial Y_p/\partial e)_{b,c,t}\, de/dt + (\partial Y_p/\partial c)_{b,e,t} dc/dt + (\partial Y_p/\partial t)_{bce} \qquad \ldots\ldots\ldots\ldots (17)$$

The interpretation of the above expression in Eq. (17) is as follows:

dY_p/dt.... The change of the potential yield (Y_p) with time and $\int_{Dp}^{D_M} (dY_p/dt)\, dt$ is the actual yield at harvest where

D_p is the date of planting and D_M is the date of maturity; presumed to be the date of harvest;

$(\partial Y_p/\partial b)_{e,c,t}$.. The partial change of the potential yield with respect to biotic factors with edaphic factors, climate and time being constant;

db/dt ... The total rate of change of biotic factors with time;

$(\partial Y_p/\partial e)_{b,e,t}$.. The partial change of the potential yield with respect to edaphic factors, biotic factors, climate and time being constant;

de/dt .... The total rate of change of edaphic factors with time;

$(\partial Y_p/\partial c)_{b,e,t}$ .. The partial change of the potential yield with respect to climatic factors with biotic, edaphic factors and time constant;

dc/dt .... The total rate of change of climatic factors with time;

$(\partial Y_p/\partial t)_{b,c,e}$ .. The partial change of the potential yield with respect to time, independent of biotic, climatic and edaphic factors.

With either constant cultural practices or for yield values corrected by mathematical manipulation, (see Eq. 4 and 5, page 41), the partial derivative in the first term $(\partial Y_p/\partial b)_{e,c,t}$ will probably almost equal zero, even though the db/dt may be rather large. This simply means that the response of the plant to its biotic environment remains constant. e.g. we assume no variation in the competition for moisture, light, etc. between plants in one planting sequence and the other. Of course, these biotic factors still vary with time. Thus, the first term to the right of Eq. (17) is approximately zero.

$$\text{i.e.}\quad (\partial Y_p/\partial b)_{e,c,t}\, db/dt \simeq 0$$

The last term of Eq. (17), $(\partial Y_p/\partial t)_{b,c,e}$ is the partial change of the potential yield with respect to time, if all the other factors are held constant. According to the definition of "potential yield" this is approximately zero.

$$\text{i.e.}\quad (\partial Y_p/\partial t)_{b,c,e} \simeq 0$$

with the above considerations, Eq. (17) can be rewritten as

$$dY_p/dt = (\partial Y_p/\partial e)_{c,t}\, de/dt - (\partial Y_p/\partial c)_{e,t}\, dc/dt \quad \ldots\ldots\ldots\ldots (18)$$

The integration of the above expression becomes

$$Y_a \cong \int_{p}^{D_M} dY_p/dt \; dt \cong \int_{D_p}^{D_M} \left\{ (\partial Y_p/\partial e)_{c,t} \; de/dt + (\partial Y_p/\partial c)_{e,t} \; dc/dt \right\} dt \quad \ldots(19)$$

Then, as a first approximation the departure of yield from normal will be

$$\Delta Y_p \cong Y_a - \bar{Y} \cong \sum_{i=p}^{M} \left\{ (\partial Y_{p_i}/\partial e_i)_{c,t} \Delta e_i + \partial Y_{p_i}/\partial c_i \Delta c_i \right\} \quad \ldots\ldots\ldots\ldots(20)$$

where the range of time is between the date of planting to the date of harvest. That is a specified growing season and $\bar{Y}$ is the mean yield.

The above differential form of expression is nothing but common sense reduced to symbols. Each term of the right hand side of Eq(20) is, of course, a symbol which expresses the relationship of one group of elements with the others. The further break down of each group according to individual elements is rather complicated, but useful. The complexity is too large to be handled by hand computation; therefore electronic computation is needed. For the sake of convenience, a climatic factor is used to illustrate how a break down of Eq (20) is possible. Let this climatic factor be C, then the consecutive and successive weekly intervals can be assigned as C_1, C_2, C_3---- etc., representing first-week interval, second-week interval and third-week interval, respectively -

Thus, for a certain year Eq. (20) becomes

$$(\Delta Y_p)_y \cong \left\{ \Delta Y_p/\Delta C_1 \, dC_1 + \Delta Y_p/\Delta C_2 + \Delta Y_p/\Delta C_3 \, dC_3 + \ldots\ldots\ldots\ldots \right\}_y \quad \ldots\ldots(21)$$

where subscrips "y" refer to a specified year, and

$\Delta Y_p/\Delta C_1$, $\Delta Y_p/\Delta C_2$, $\Delta Y_p/\Delta C_3$, etc.,

are the coefficients and are quasi-constant for a given week-interval. They can be assigned the symbols K_1, K_2, K_3 respectively. The terms dc_1, dc_2,

dc_3, etc. are the change of the particular climatic factors in the different consecutive week-intervals. For a number of years, a group of linear equations may be established as below:

$$(\Delta Y_p)_1 = (K_1dC_1 + K_2dC_2 + K_3dC_3 + \cdots\cdots)_1$$

$$(\Delta Y_p)_2 = (K_1dC_1 + K_2dC_2 + K_3dC_3 + \cdots\cdots)_2 \quad \cdots\cdots \quad (22)$$

$$(\Delta Y_p)_3 = (K_1dC_1 + K_2dC_2 + K_3dC_3 + \cdots\cdots)_3$$

$$(\Delta Y_p)_4 = (K_1dC_1 + K_2dC_2 + K_3dC_3 + \cdots\cdots)_4$$

- - - - - - - - - - - - - - - - - -and the like.

We may solve for the K's of the above group of equations with given Y_p's and dC'_s simultaneously, in the case of, for example, an 8-year record for 8 unknown K values. In general, a least squares solution is required. Of course, either one of these methods is too tedious, in general, for hand computation. The aid of the electronic computor is usually necessary. This ends up with a single-parameter equation to represent one climatic element.

For any one particular year a temporary predicted yield can be computed from the single-parameter equation for any one element. Let us indicate $(\Delta Y_e)_{P_c}$ and $(\Delta Y_e)_{P_s}$ as the departure of predicted yield due to the element P_c the corrected precipitation in the growing season, and P_s for the percentage possible sunshine in the growing season, respectively. Thus, a combination of different elements is possible for this one particular year as:

$$\Delta Y = a + b(\Delta Y_e)_{Ca} + c(Y_e)_{Cb} + d(Y_e)_{Cc} + \cdots\cdots \quad (23)$$

Where Ca, Cb, Cc, etc. are factors concerned. The nature of these weighting factors will be further considered as below:

The constants of equation (23) are then determined by the usual multiple correlation method. After solving the constants, a, b, c, etc. we obtain a final predicting equation.

Both edaphic and climatic factors can be classified into positive factors and negative factors:

(a) Positive factors: The positively correlated elements are either edaphic or climatic factors which give an increase of yield of peas within certain limits of amount or intensity. For instance, increased precipitation usually increases yield. However, too much precipitation will reduce the yield as well. In a scatter diagram, such as illustrated on page 47, Diagram 3, 1.50 inches in 4 weeks time give the optimal yield, so that the amount of precipitation has a positive influence up to 1.50 inches. For more than 1.50 inches the yield will be significantly reduced. So far the positive climatic factors investigated in this paper are:

(i) Pa- The accumulated precipitation prior to the sowing date of a crop (see page 57 - 60) in inches;

(ii) Pc- The corrected precipitation in successive weekly intervals (or in relative minimum weekly-interval - see pages 45-51) during the growing season, in inches;

(iii) R.H. - Thr relative humidity of the air, in percentage (see page 60 - 64);

(iv) Ps - The percentage possible sunshine in weekly interval, with percentage as unit (see page 79 - 81)

(b) The negative factors. The negatively correlated elements are either edaphic or climatic which give rise of a decrease in yield with the increase of the intensity of the negative elements. It is usually found in scatter diagrams that there are linear relationships throughout between these negative elements and the departure of yield. In other words the only limitation of the intensity of these in correlating with yield is complete failure of the crop. They are:

(i) T_I - Summation of the inter-diurnal temperature of maximum and minimun in degree Fahrenheit (see page 66 - 70);

(ii) T_E - The maximum night time temperature accumulated in degrees Fahrenheit (see page 70 - 73)

(iii) PTU - The summation of photo-thermal unit, in degree-hour (see page 73 - 76)

All the positive factors, when applied to Eq (22), should be added, while the negative factor subtracted.

All the above equations are essentially linear, however, environment-pea relationships are generally not linear. These non-linear phenomena may be visualized in most of the scatter diagrams in the next chaper. Therefore, for a more satisfactory solution, non-linear approaches should be introduced, such as, the contingency table approach* and the polynomial approach.**

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*For a good example of the use of contingency tables, see Eberhard W. Wash, et al, "The Construction and Application of Contingency tables in Weather Forecasting." Air Force surveys in Geophysics No. 19 (1952). Air Force Cambridge Research Center.

**For example, of the application of polynomials to crops, see Yang, S.J., "The effects of certain climatic factors on the yield and quality of Barley. Ph.D. Thesis, University of Wisconsin (1951).

(b) Diagrammatical Approach

We will consider two diagrammatical approaches to the combination of environmental factors: (i) the isoline analysis, (ii) the multidimensional setup.

(i) Isoline analysis: The basic chart for the analysis is illustrated in Chart 26. It is a plot of the relative minimum precipitation for each week interval, as ordinate against the sequence of years as abscissa. Isoline of relative minimum precipitation are drawn for small whole numbers. (The ordinate, of course, may be some other element as well.)

Glancing at these isohyetals as compared to yield, it is obvious that there there is a general tendency for the ridges to coincide with high yield years and the troughs with the low yield. Sometime one isohyetal will not indicate this trend, in a particular year, however, the other isolines will do it. For instance, the 1.00" and 2.00" isolines show a definite trough toward 1934 line which has a yield slightly below normal, while there is a significant ridge in 6.00" isohyetal to compensate it. Note, also, the prounced ridge situated in the 1947 line which was the lowest yield year, of course. This whole analysis fails for 1935 and it is suspected that some other factors dominate. A base line can be set up on chart 26. Measure the distance between the base line to the intersection between one of the isolines and the axis of one of the years. Yield seems to vary directly (for most of the cases) with this measured distance.

We may perform a similar analysis for the accumulated precipitation prior to the transplanting of tobacco grown in the same region, in monthly interval against the sequence of years. Chart 27 is obtained.

Chart 26

Relative Minimum Precipitation in various week-intervals for Tobacco grown in Madison, Wisconsin (1930-38)

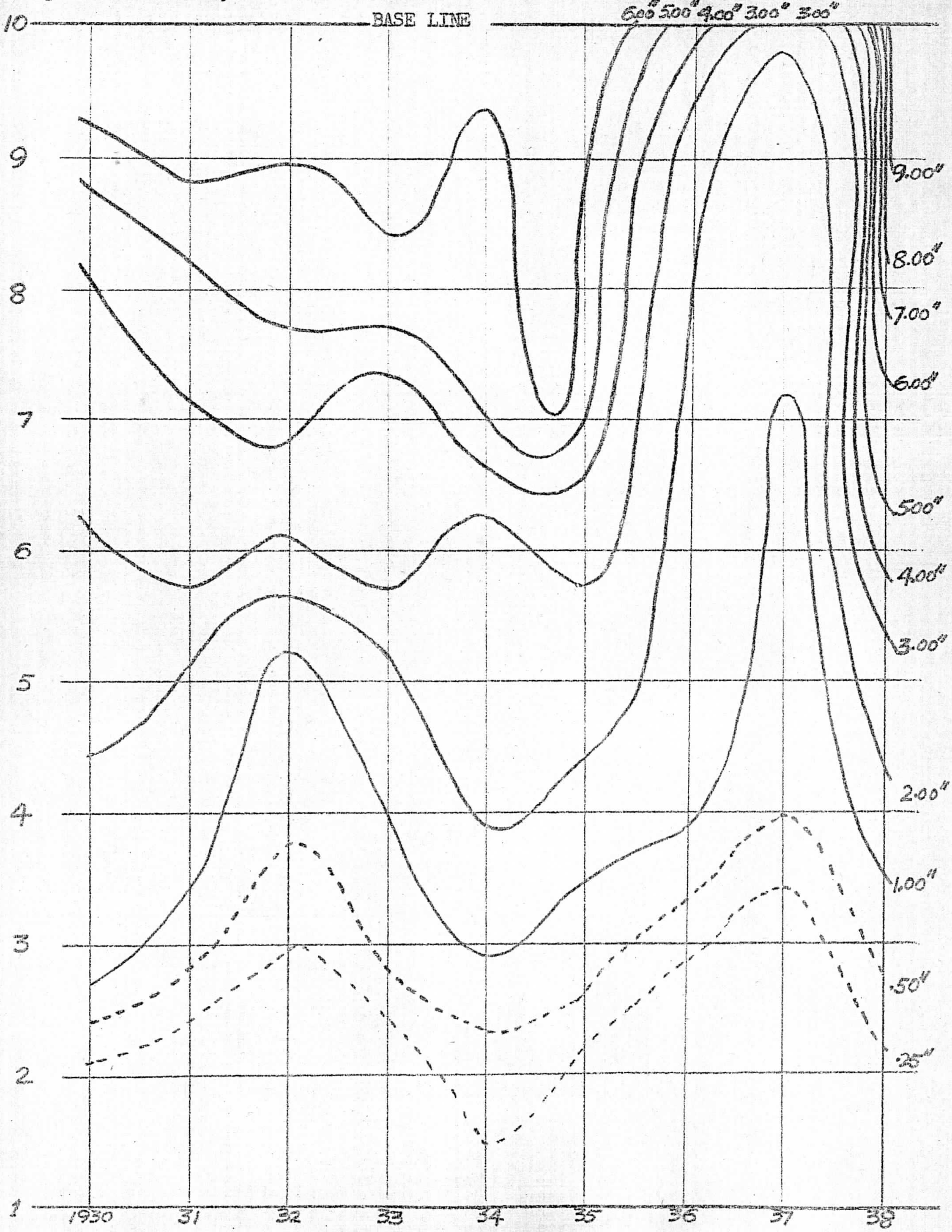
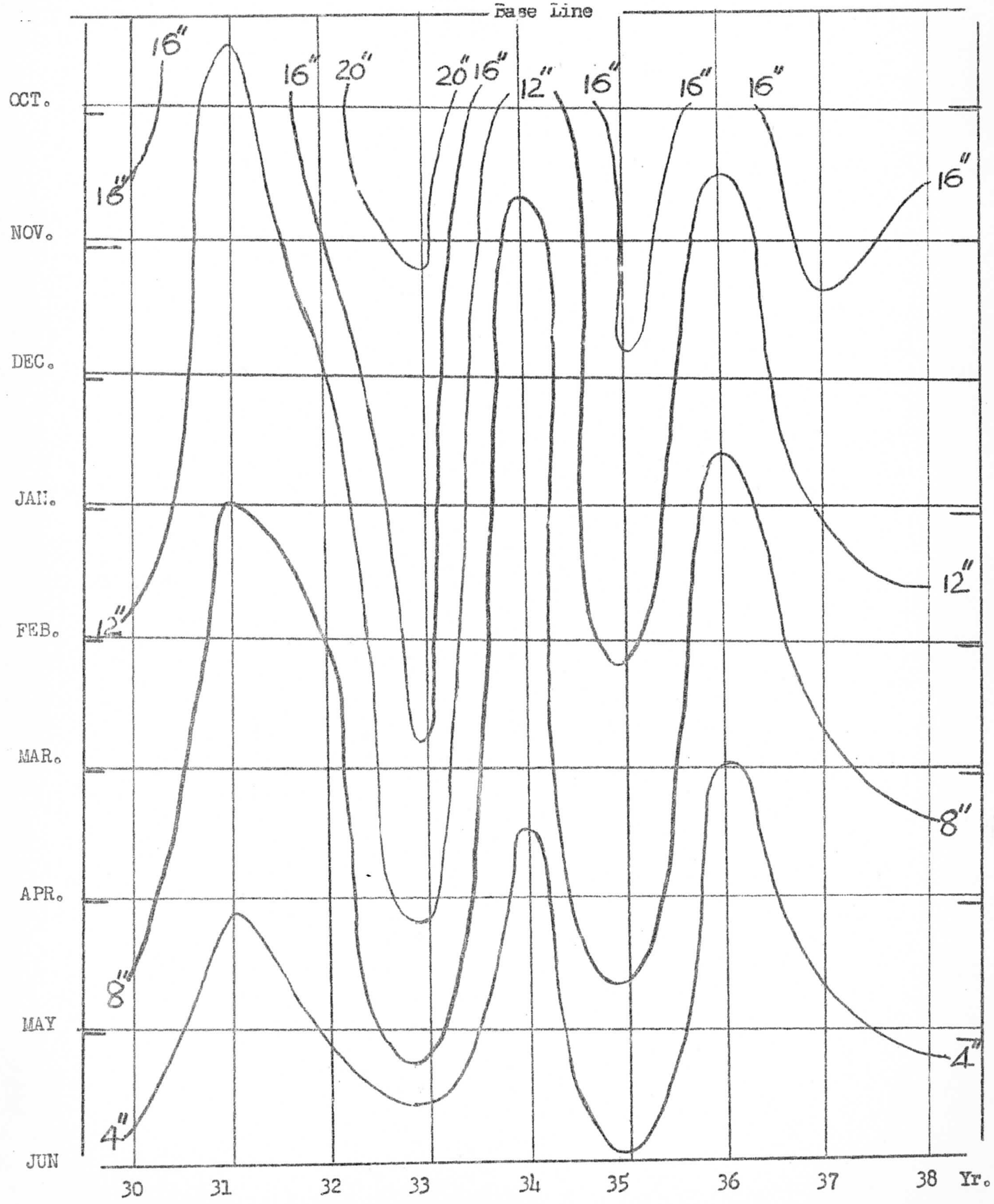


Chart 27

Accumulated precipitation prior to the transplanting of tobacco
(Begins from each month as indicated - Madison, Wisconsin (1930 - 38)



The same trend as in chart 26 is obtained, but this time not as conspicuous as before. Qualitatively, this shows a less positive correlation with yield than for relative minimum precipitation.

Again, repating the same method with relative humidity in weekly interval, a reverse result was expected, and is shown on chart 28.

Note the reversed position of the base line. Again, measuring the distance from the base line as before, the algebraic sum of the distances measured from each chart for each year can be called a "combined unit" and plotted against the sequence of years. This is shown on Chart 29.

It is clear that the yield of tobacco-leaf has a better correlation with the so-called "combined unit" than any one of the single meteorological elements used. It seems that an improved correlation can be secured if all environmental factors are considered. The advantages of this diagrammatic approach are that errors, correlations, etc. can be visualized readily, as well as simplicity of performance. In this connection the trial and "error" method can be used without too much cost of effort and time.

(ii) Multi-dimensional set up: It is possible to set up a two or more dimmensional diagram to show the combined effects of several factors interacting with each other. A model of the 4-dimensional set up for the relationship between yield of canning peas in Rosendale, Wisconsin, the percentage of possible sunshine, and the corrected precipitation during the growing season in weekly interval, is shown in Diagram 8.

The vertical axis (or the Z-axis) of the above diagram indicates the yield of peas in pounds per acre. The X - axis is the corrected precipitation in weekly interval, and the Y - axis is the percentage of possible sunshine. The time factor is included in both the X and Y - axis. This type of diagrammatic approach gives an overall visualization of the relationship, but it is rather hard to use.

Chart 26
Minimum Relative Humidity in week-interval related to the yield of Tobacco

(R.H. ≥ 44% per day as one unit) Madison, Wisconsin (1930 - 1938)

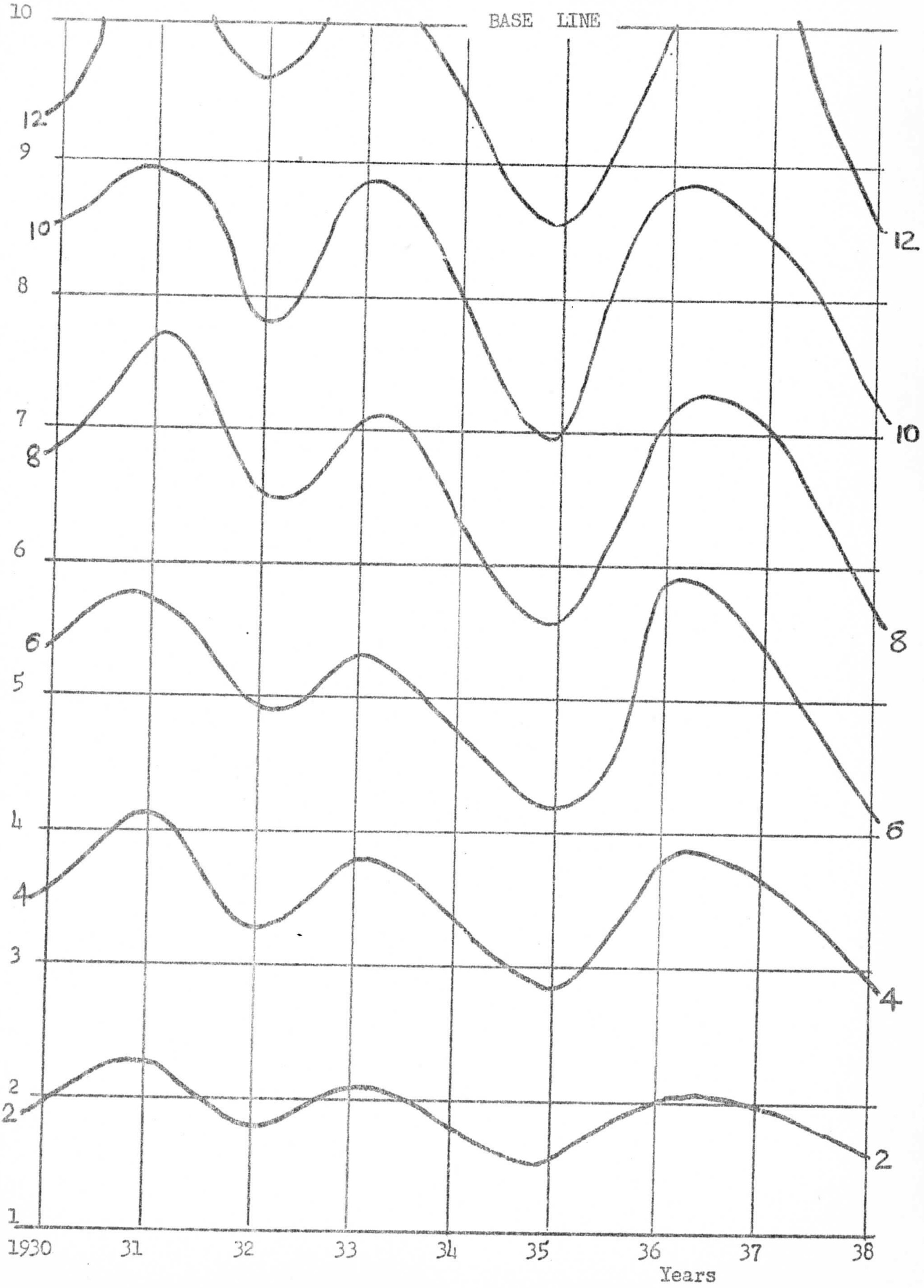


Chart 29

Combined unit versus Yield of Tobacco-leaf

Madison, Wisconsin (1930 - 1938)

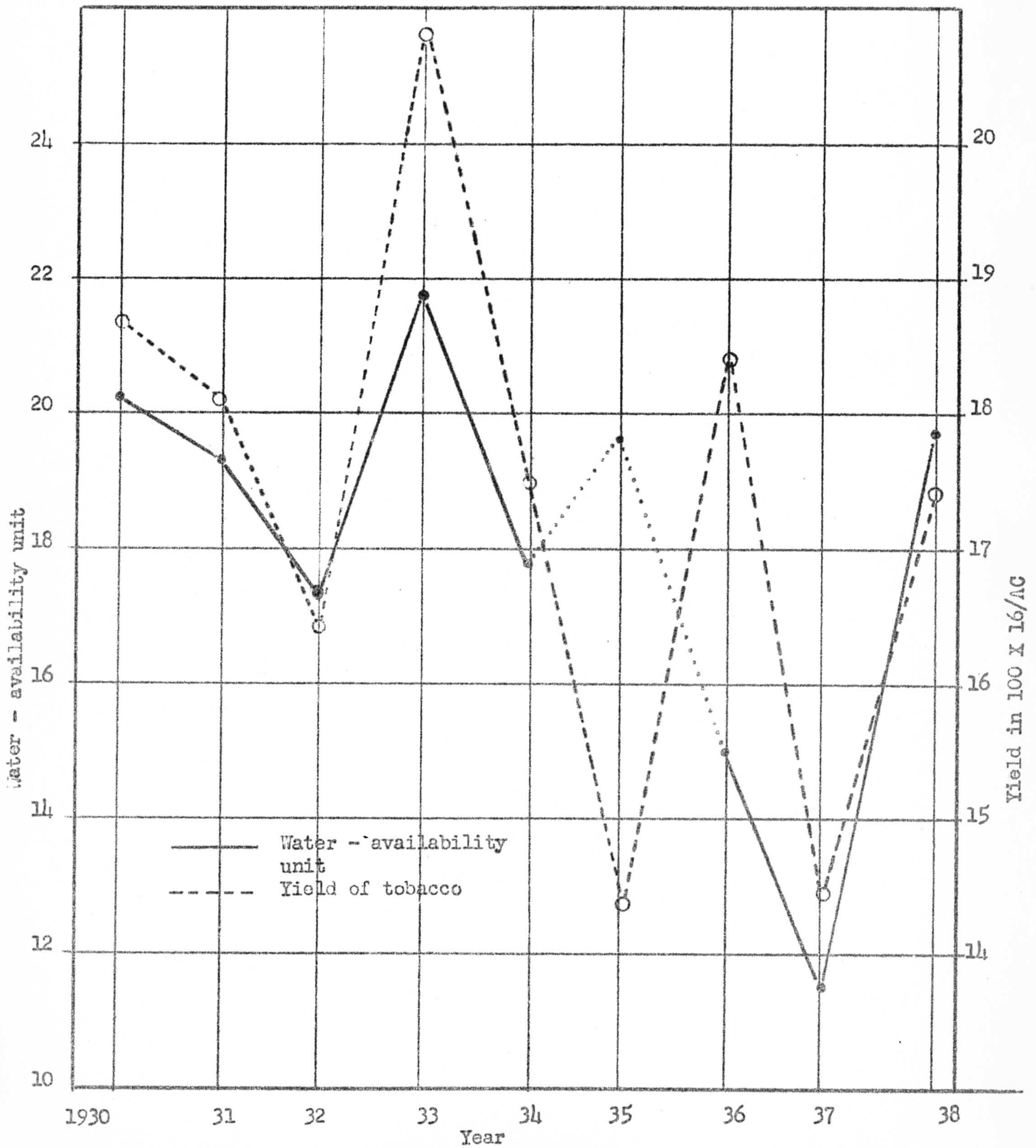
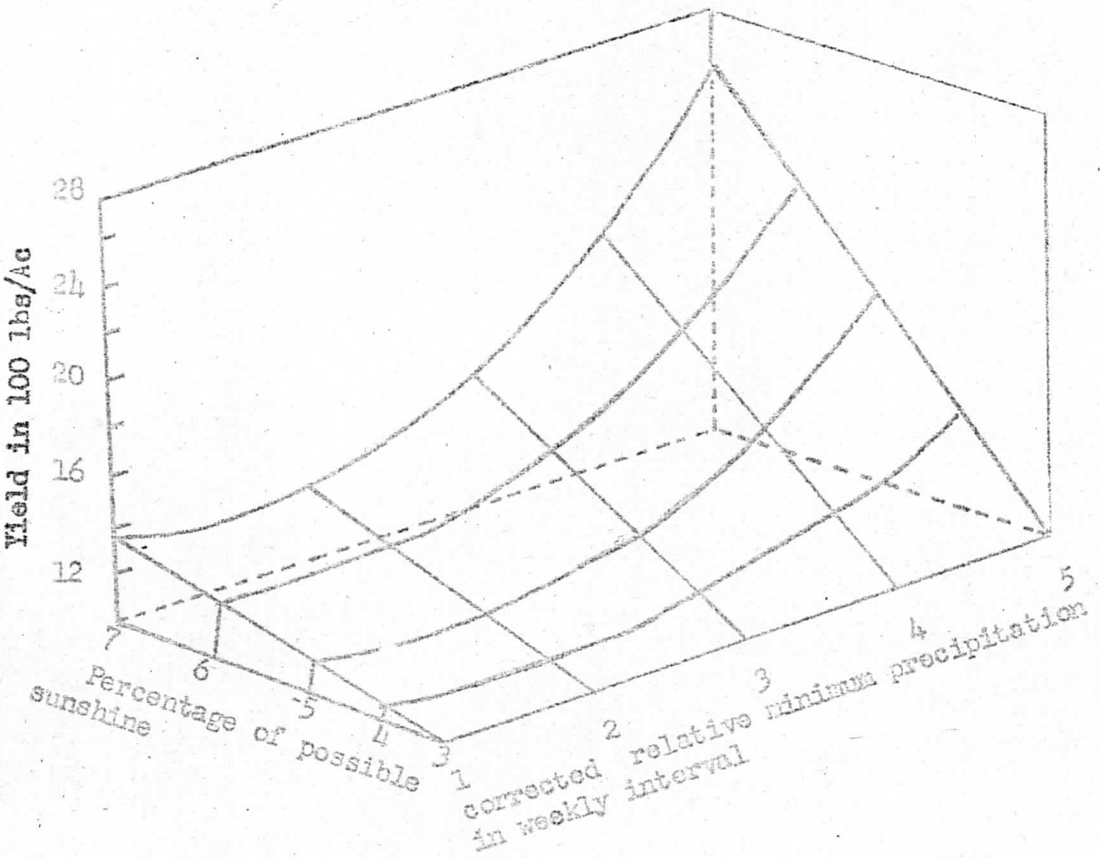


Diagram 8

Diagrammatic representation of the yield of Alaska Peas vs precipitation, percentage of possible sunshine and time.



The above picture shows the variation of yield of Alaska peas in Rosendale, Wisconsin constructed from various scatter diagrams as a function of percentage possible sunshine, precipitation in the growing season and time. The units used for X-axis is in inches, Y-axis in 154% per week and the Z-axis in 100 pounds per acre.

(c) Statistical approach—From scatter diagrams of the departure of yield versus each individual environmental factor, it is possible to evaluate the quadrant sum values by means of "A corner test for Association."* Since the quadrant sum values indicate the significant level of the scatter diagram, the arithmatic mean for a set of scatter diagrams for an environmental factor will give a measure of the closeness of fit. Again, the departure from normal of the yield of tobacco leaf, in Madison, Wisconsin during the years 130-38 is used as an illustration of the statistical approach here. Table 6 shows the quadrant sum values from the scatter diagrams of an accumulated precipitation prior to transplanting (P_a), the relation minimum precipitation in weekly interval (P_r) and the relative humidity in weekly interval at the noon hour (RH) versus departure of yield of tobacco leaf.

Table 6

Quadrant Sum of P_a, P_r, and RH Scatter Diagrams for Tobacco grown in Madison, Wisconsin (1930-38)

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Mean
Quadrant Sum, P_a:	-1	-1	2	3	2	4	4	5	1.75

Week	1	2	3	4	5	6	7	8	9	10	Mean
Quadrant Sum, P_r:	0	3	7	5	5	5	6	5	5	6	5.22
Quadrant Sum, RH:	8	6	5	8	5	5	7	6	4	5	5.90

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* (1) Wilcoxon, F., Some Rapid Approximate Statistical Procedures. American Cyanamid Co., 1949.

(2) Olmstead, P. S., and Tukey, J. W., A corner test for Association, Ann. Math. Statistics, 18, 495-513, 1947.

These quadrant sums may be used as weighting factors to set up a prediction equation. Taking the sum of the mean quadrant sums as 100 percent and expressing the individual values as percent of that value, these percentages may be used as weighting factors. For example, given here these values are 13.60 for Pa, 40.56 for Pr, and 45.84 for R.H. Thus, the yield equation for a given year can be written

$$\Delta Y = 13.60 \Delta Pa + 40.56 \Delta Pr + 45.84 \Delta R.H. \text{ ------ } (24)$$

There is another way of securing a mathematical expression using the type of curve in the scatter diagram. The curve in diagram 4 is a typical Sigmoid curve, illustrating the general variation of a number of climatic factors versus weekly interval for normal or optimal yield. Chart 15, and 16 are almost straight lines and chart 24 has been expressed as the straight line $y=4x-13$. Some other curves (See curves in the following chapter) can be expressed in the form of the so-called "Mitscherlich" exponential equation,

$$dy/dc = K (y_{max} - y) \text{ or } y = y_{max} (1 - e^{-KC}) \text{ \_ \_ \_ \_ \_} (25)$$

Where y_{max} represents the maximum yield obtainable under the conditions available, C is a combination of climatic factors. In this case, the combination of climatic factors can be obtained, separately through both meteorological and statistical means. Meteorologically, one can make a refined classification of air masses according to the meteorological factors which affect the growth and development of a plant. From the frequency of occurrences of this air mass, (so classified) the value can be established, for the air-mass, itself, represents a combination of a group of meteorological factors.

Theoretically, an exponential expression may be set up for both positive and negative environmental factors. Let α and β be a group of negative and positive factors correlated with yield, respectively. Y_t represents the total yield, then

$$Y_t = K e^{-a\alpha} (1 - e^{-b\beta}) - - - - (26)$$

Where K, a and b are constants to be determined.

Mathematically, the above equation gives the following information regarding the yield of crops:

(i) If b or $\beta = 0$, then also $Y_t = 0$, or, in other words this group of positive factors determine the yield.

(ii) If a or $\alpha = 0$, then $Y_t \neq 0$ and not a function of α. In other words, this group of factors are not critical to the yield.

(iii) At constant α, the yield increase logarithmically with the increase of β toward a maximum value $K e^{-a\alpha}$.

(iv) At constant β, the yield decreases logarithmically towards zero with increase of α.

Whether or not the above theoretical consideration will be valid in actual practice has to be verified.

The determination of the value of α or β is possible by statistical methods.

If two climatic factors are highly correlated a single factor may be used for these two. Information on this can be found in most statistic books, such as Brooks C.E.P. et al.: "Handbook of Statistical Methods in

Meterology", 1953.

Of course, there are many other refined statistical techniques which can be used for the combination of environmental factors and which have been tried by various authors. However, they cannot be included in the present short paper.

CHAPTER IV

SOME EXAMPLES OF ANALYSES OF ALASKA PEAS IN ROSENDALE, WISCONSIN

In the following yield analyses (See chart 7 and p. 37-42) for Alaska peas in Rosendale, Wisconsin, a 5% increase in yield as a result of the improvement of farm management during a 9 year period was assumed. Thus biotic factors have been partially eliminated. The 5% corrected yield was adopted for all the illustrations in the present chapter, though both 5% and 10% were tried.

The meteorological data was obtained mostly for El Dorado, Wisconsin, with additional data from Ripon and meteorological charts were prepared. They are similar to chart 9 (p. 46) but are too extensive to be presented in this chapter. Therefore, only results are tabulated.

Again, as was mentioned before, all scatter diagrams were fitted by least square, where possible. Examples given in Chapter III for Alaska peas in Rosendale, Wisconsin will be useful in this chapter and it is suggested that readers refer to those examples.

A summary of the yield analysis of Alaska peas expressed in pounds per acre at Rosendale, Wisconsin is shown in Table 7 as below:

1. RELATIVE-MINIMUM-DRAUGHT EVALUATION IN WEEK-INTERVAL FOR THE GROWING SEASON.--Methods suggested in the foregoing chapter (See page 45-50) for the evaluation of relative minimum weekly intervals of the amount of precipitation and number of crop rainy days are illustrated in the following paragraphs:

(a) Amount of precipitation. From the run-off regression lines in

Table 7

Yield Analysis of Alaska Peas in Pounds per Acre
Rosendale, Wisconsin (1946-1954)

Year and Sequences		Arithmatic Mean Yield	Apparent Yield in lb/AC/Day	Number of Growing Days	Mean of		Departure of Yield from		
					No. of Grow Day	App. Yield lb $AC^{-1}D^{-1}$	Arithmatic Mean	5% inc Yield	10% inc Yield
1946	S_T	2119					-5	45	92
	S_1	2416	34.47	73	68	34		283	340
	S_L	2013	33.54	63				98	140
1947	S_T	2054					-70	-35	5
	S_1	2095	31.22	70	65	32		-45	-25
	S_L	1849	32.87	59				-90	-50
1948	S_T	1713					-411	-387	-360
	S_1	1816	27.44	68	64	27		-342	-330
	S_L	1559	26.81	60				-390	-360
1949	S_T	2383					259	270	284
	S_1	2407	39.95	61	58	41		233	240
	S_L	2264	42.48	54				304	315
1950	S_T	2042					-82	-81	-81
	S_1	2022	36.11	56	55	37		-161	-170
	S_L	2042	38.53	53				70	70
1951	S_T	2415					291	283	288
	S_1	2584	41.19	62	59	40		381	360
	S_L	2246	39.57	56				260	245
1952	S_T	2226					201	80	55
	S_1	2226	35.10	62	61	36		12	-15
	S_L	2182	36.14	59				181	160
1953	S_T	2095					-29	-65	-105
	S_1	1781	27.28	62	56	33		-465	-490
	S_L	2011	39.20	49				0	-35
1954	S_T	2072					-52	-102	-151
	S_1	2300	31.43	70	61	30		60	10
	S_L	1596	29.33	51				-435	-480
Mean	S_T	2124		60.5		34.4			

Remarks:
1. S_A...For all sequence the arithmatic mean is 2124 lb/AC;
2. S_1, S_L For 1st and last sequence the arithmatic mean is 2183 and 1974 lb/AC;
3. Mean of Number of Growing days and apparent yield pounds per acre per day in the 5th and 6th column are the average of 1st and last sequence respectively.

Appendix II, the recorded amount of precipitation must be modified to some extent according to its amount and intensity. Following the procedures for the computation of the relative minimum weekly intervals, the amount of precipitation was obtained for the second throughout the eighth week-interval spread. Scatter diagrams of these are shown below.

Chart 30

Relative Minimum Precipitation in a two-week-interval
for Alaska Peas grown in Rosendale
1946-1954

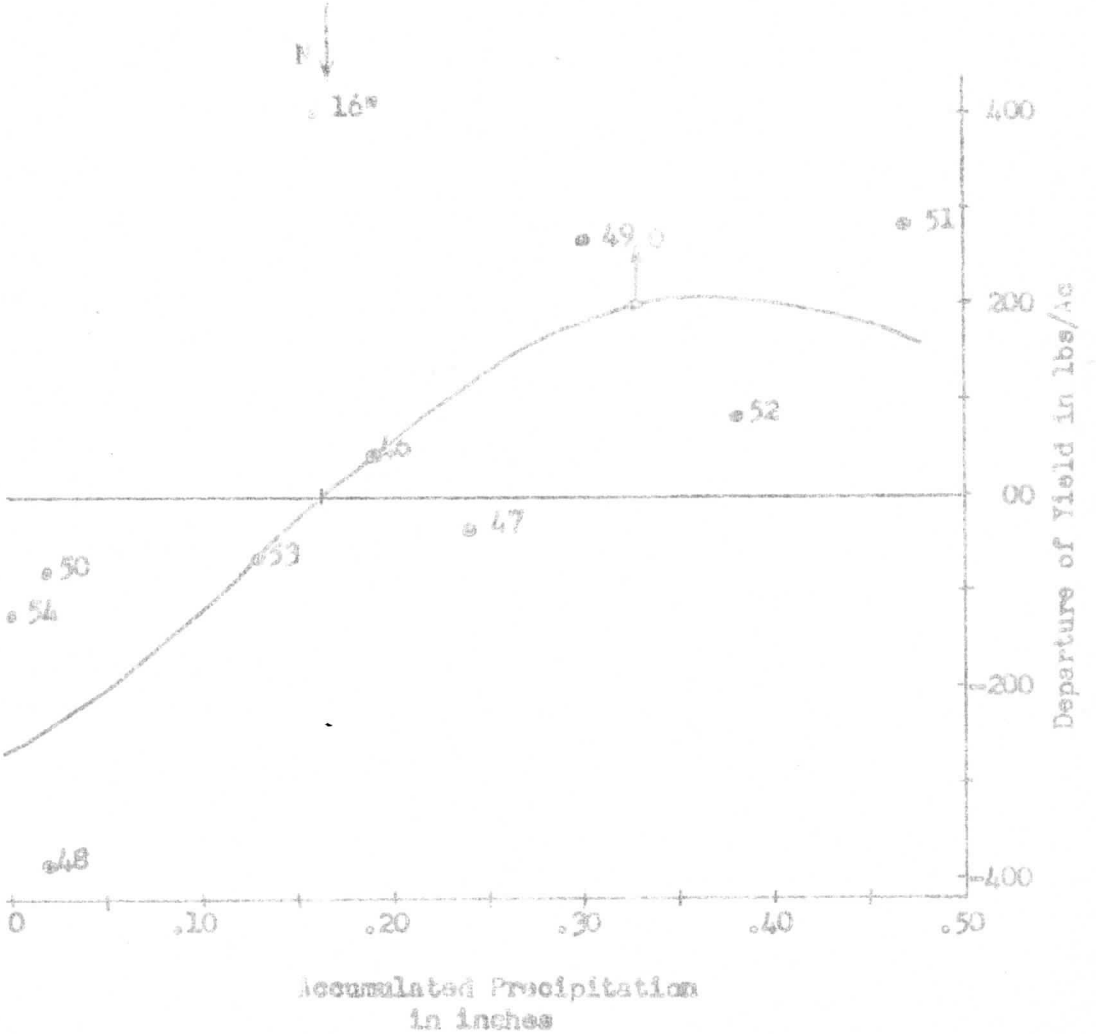


Chart 31

Relative Minimum Precipitation in a three-week-interval
for Alaska Peas grown in Rosendale (1946-1954)

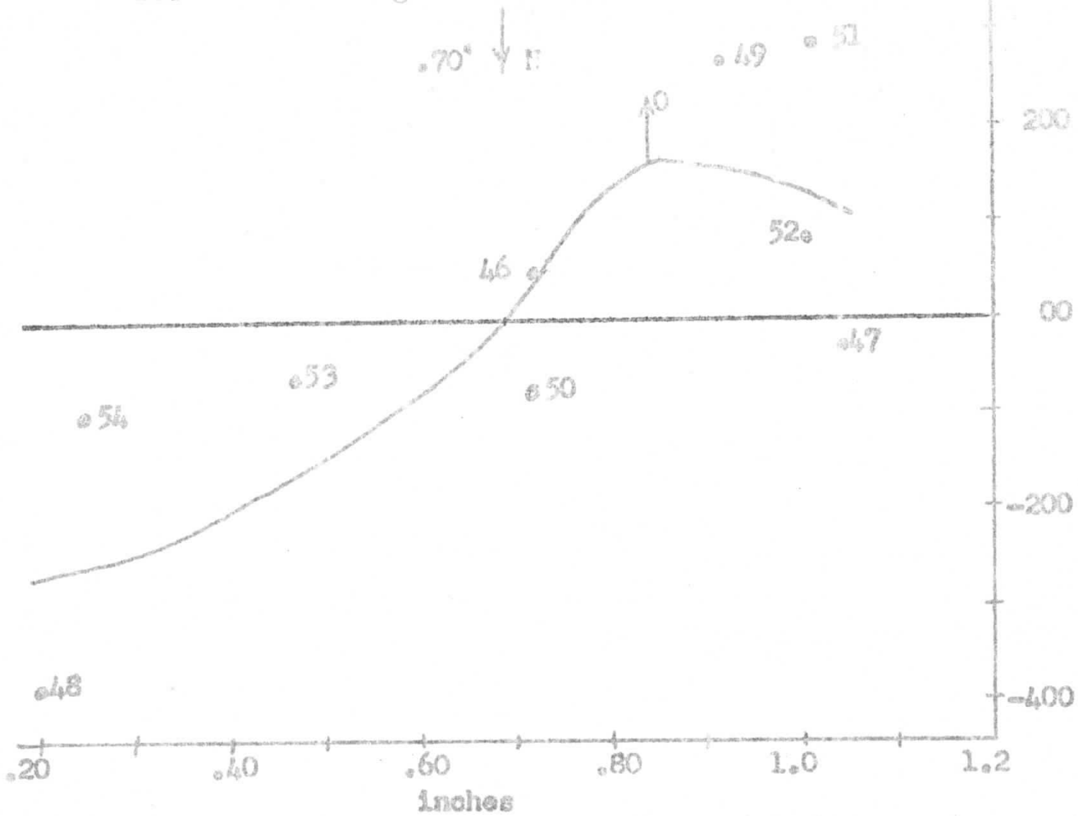


Chart 32

Relative Minimum Precipitation in a four-week-interval
for Alaska Peas grown in Rosendale (1946-1954)

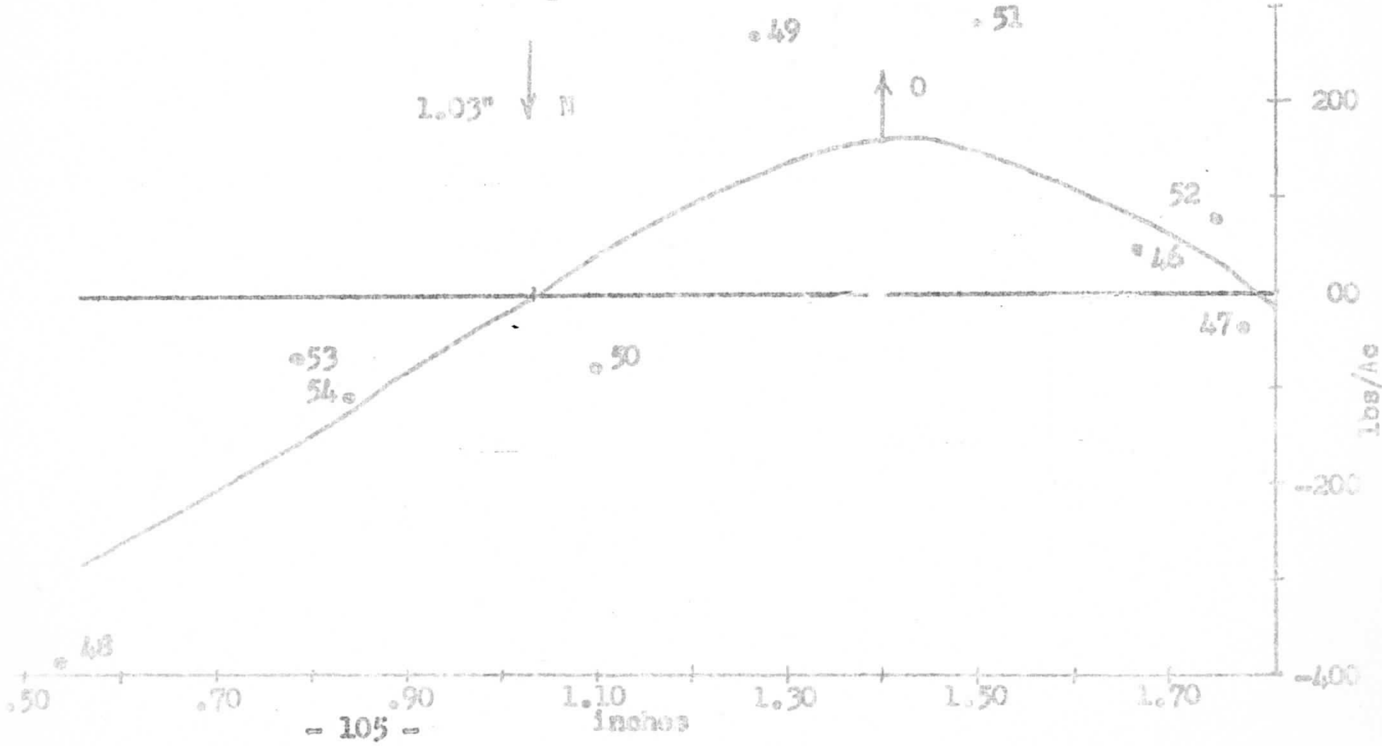


Chart 33

Relative Minimum Precipitation in a five-week-interval for Alaska Peas grown in Rosendale (1946-1954)

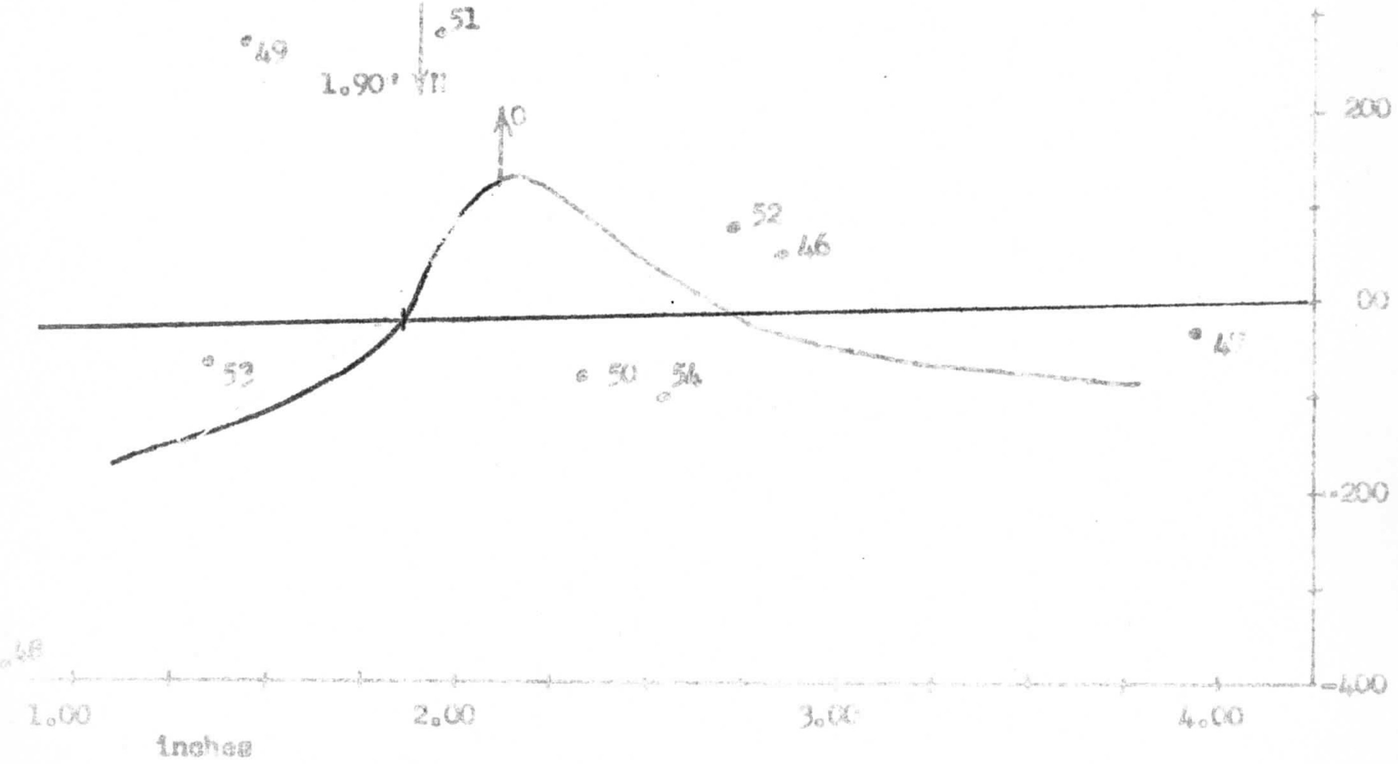


Chart 34

Relative Minimum Precipitation in a six-week-interval for Alaska Peas grown in Rosendale (1946-1954)

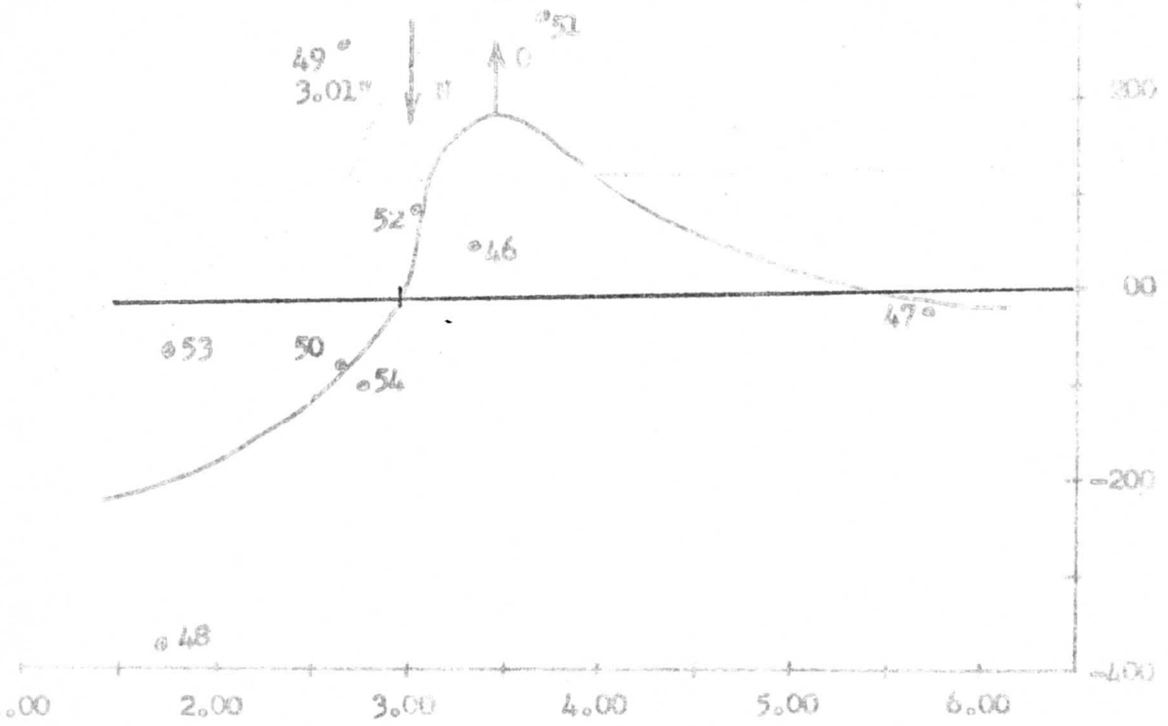


Chart 35

Relative Minimum Precipitation in a seven-week-interval for Alaska Peas grown in Rosendale (1946-1954)

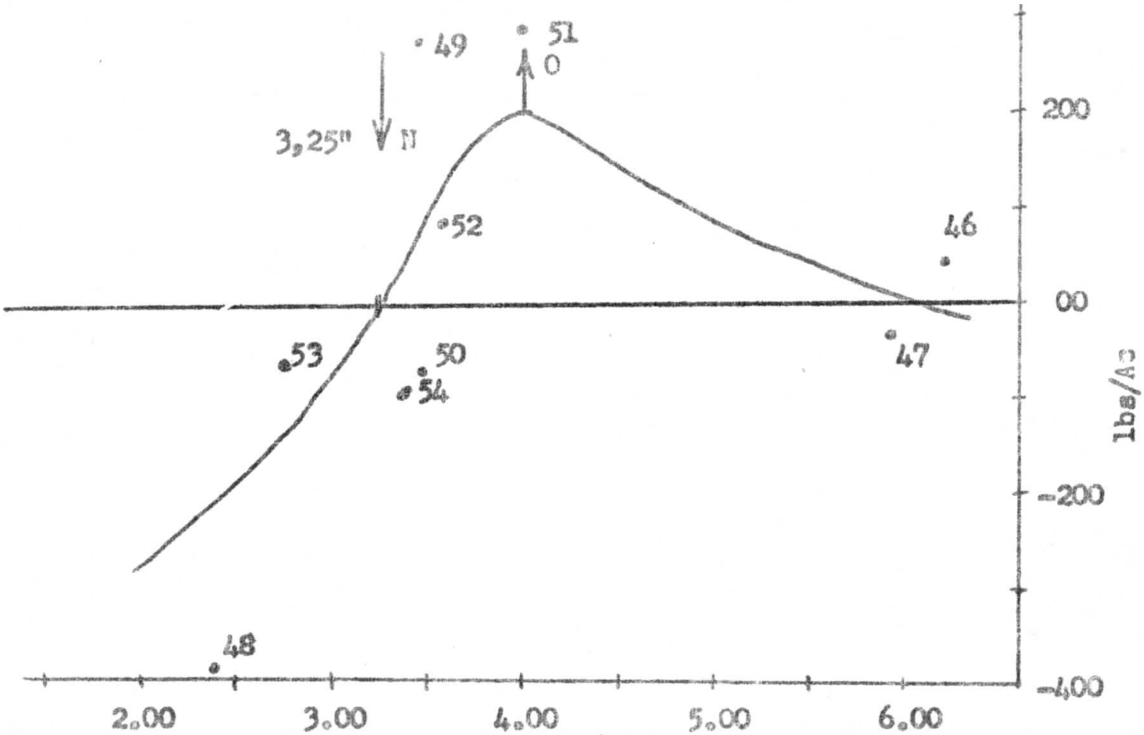


Chart 36

Relative Minimum Precipitation in an eight-week-interval for Alaska Peas grown in Rosendale (1946-1954)

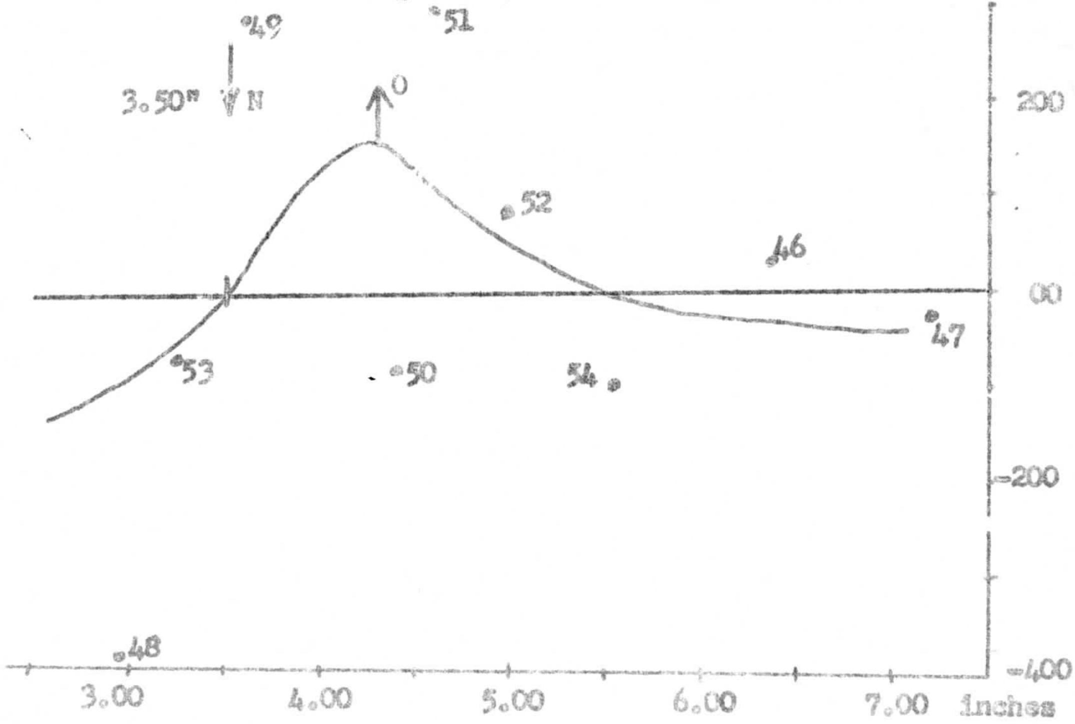
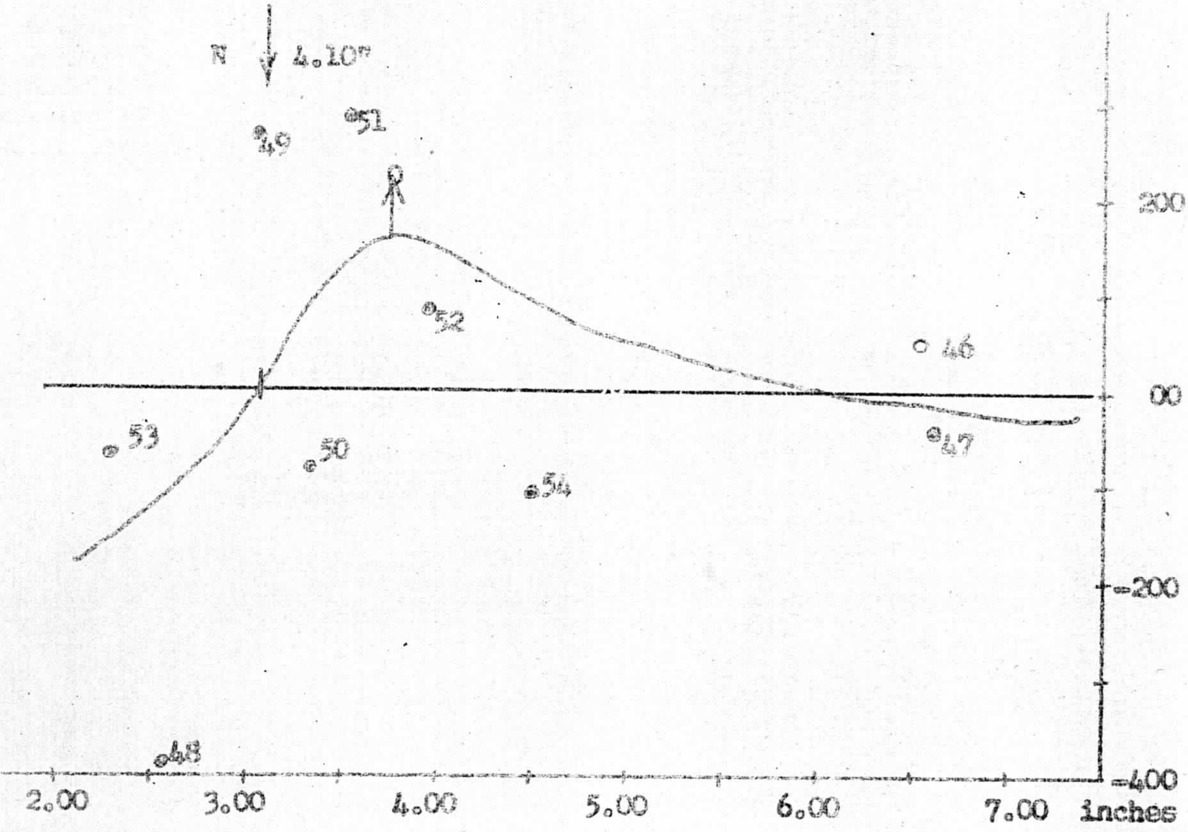


Chart 37

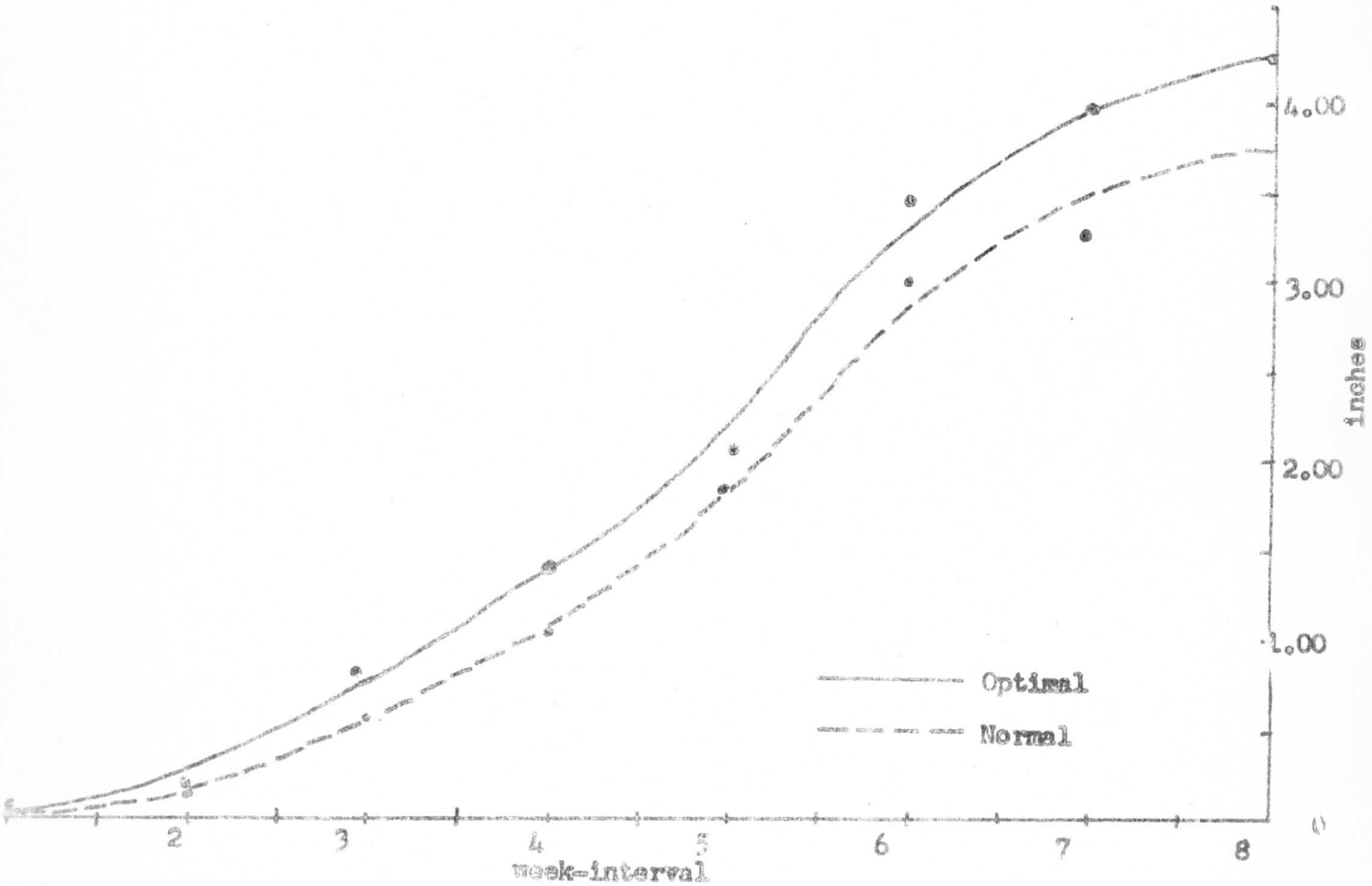
Total Precipitation in the Growing season for Alaska Peas grown in Rosendale (1946-1954)



From the optional and normal values of yield for the above scatter diagrams, a composite chart can be prepared with week-interval as abscissa and amount of precipitation as ordinate. This is chart 38.

Chart 38

Accumulated Amount of Precipitation in weekly intervals
for the Optimal and Normal yield
of Alaska Peas grown in Rosendale, (1946-1954)



The general trend of all the curves of the above scatter diagram indicate neither too dry nor too wet will benefit the yield of Alaska Peas. Only a rather limited range of precipitation shows the optimal yield. The summary chart gives a further smoothin of these curves and thus makes the scatter diagrams more consistant. Note that the optimal yield curve is located above the normal yield curve.

(b) Number of Crop Rainy Days.—According to the definition of crop rainy days given in Appendix III, the relative minimum accumulated crop rainy days in week-interval for the first to the eighth sucessive week were evaluated as in (a) above. Scatter diagrams as well as summary charts were prepared. They follow.

Chart 38

Relative Minimum Crop rainy days in two-week-intervals
for Alaska Peas grown in Rosendale, (1946-1954)

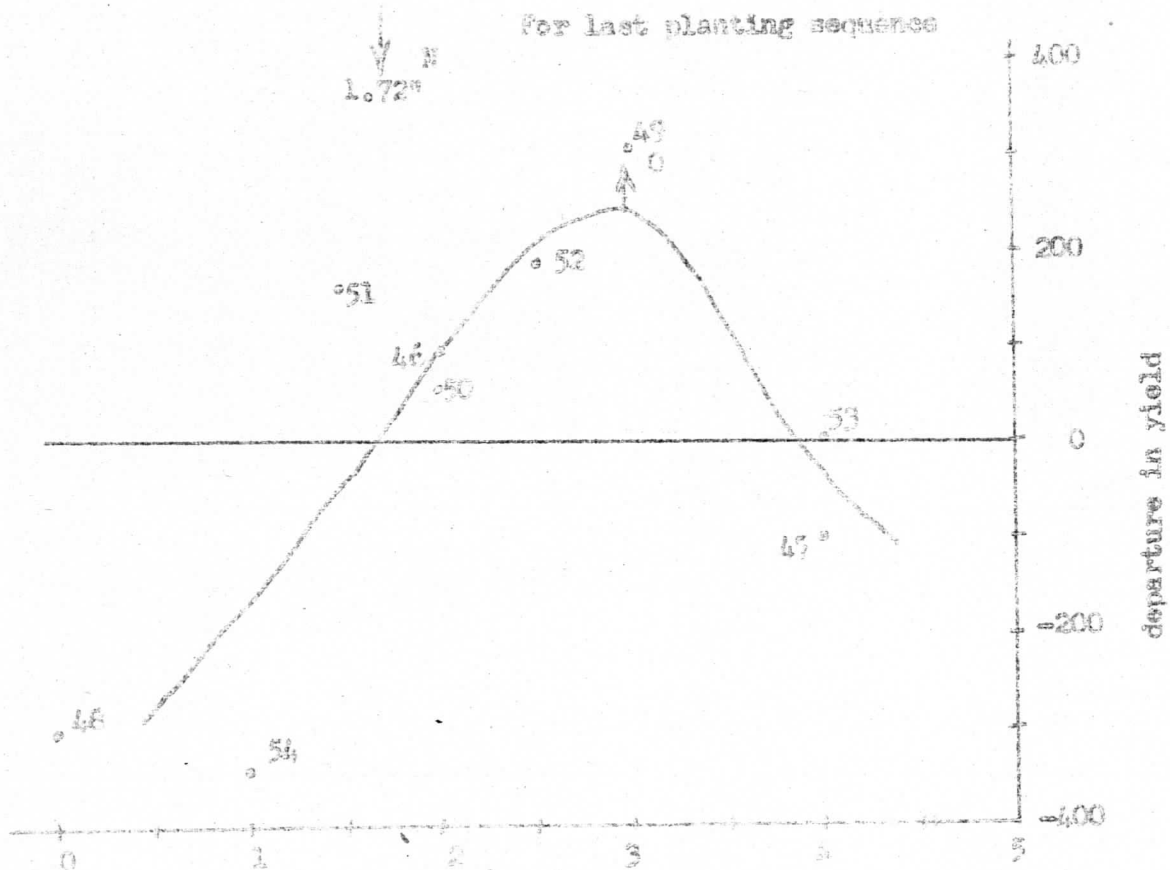


Chart 40

Relative Minimum Crop rainy days in three-week-intervals for Alaska Peas grown in Rosendale, (1946-1954)

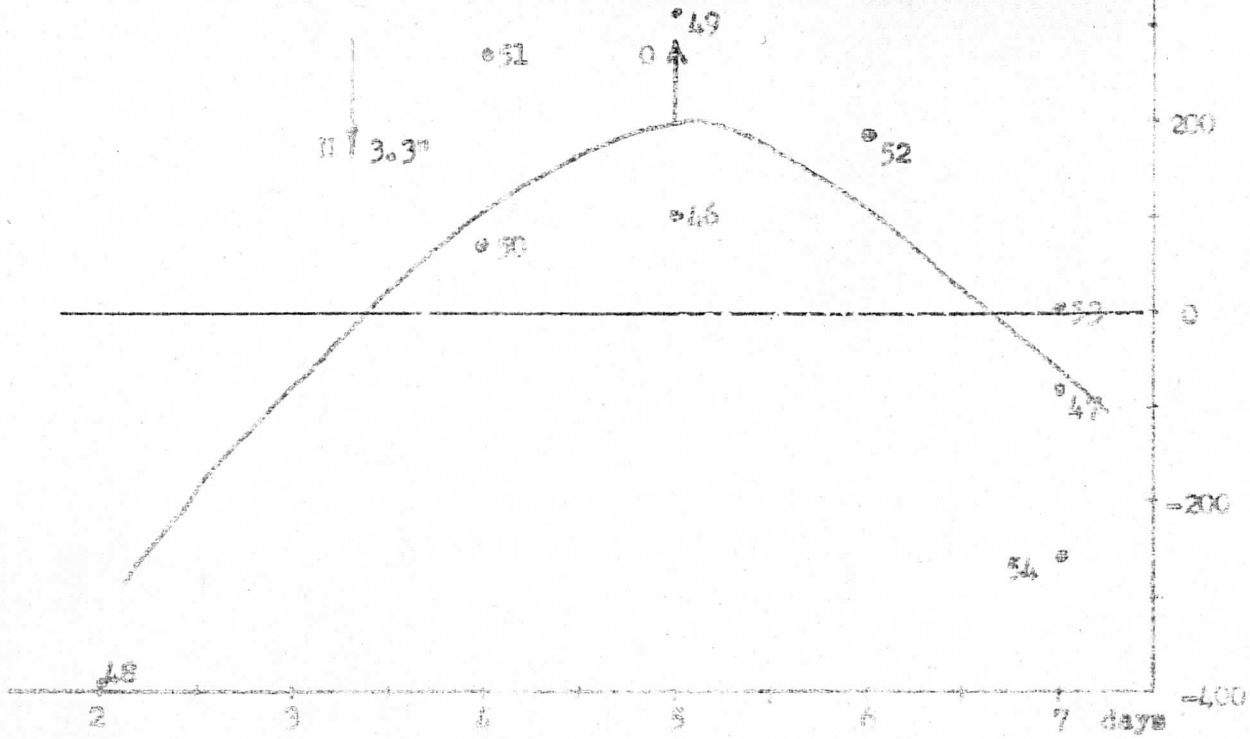


Chart 41

Relative Minimum Crop rainy days in four-week-intervals for Alaska Peas grown in Rosendale, (1946-1954)

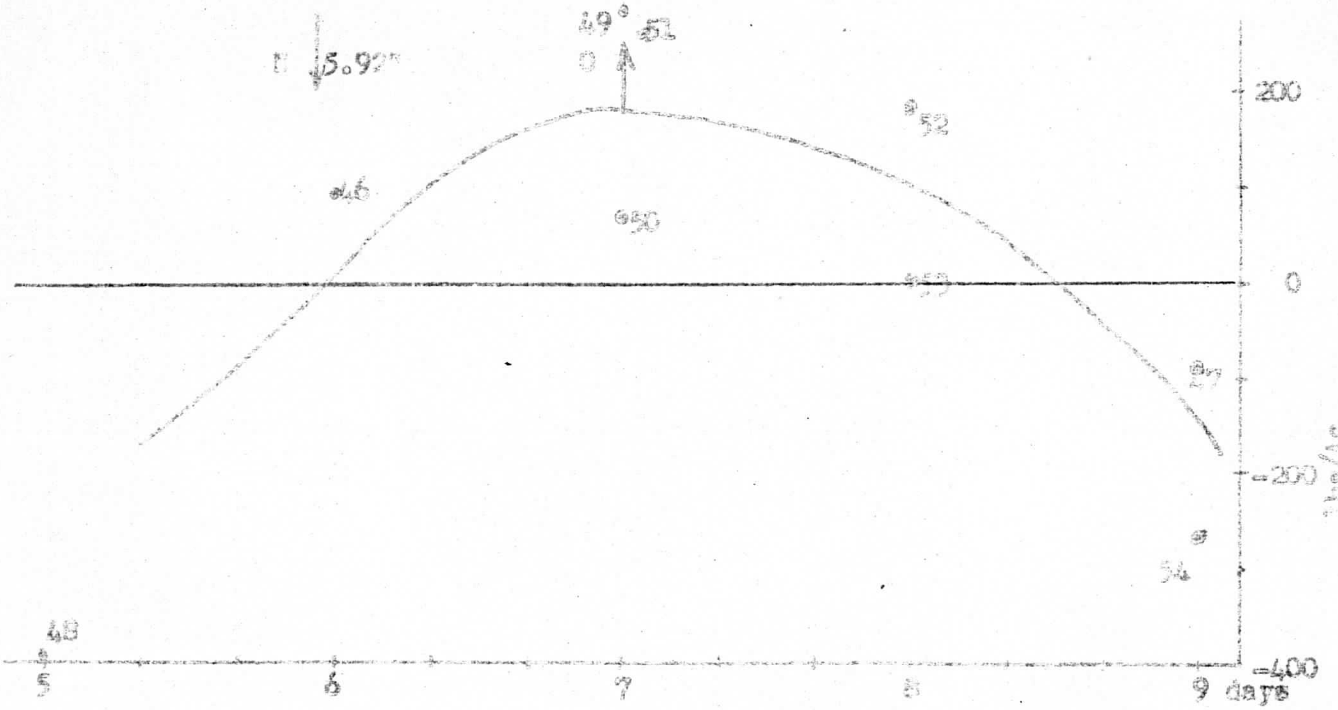


Chart 42

Relative Minimum Crop rainy days in five-week-intervals for Alaska Peas grown in Rosendale, (1946-1954)

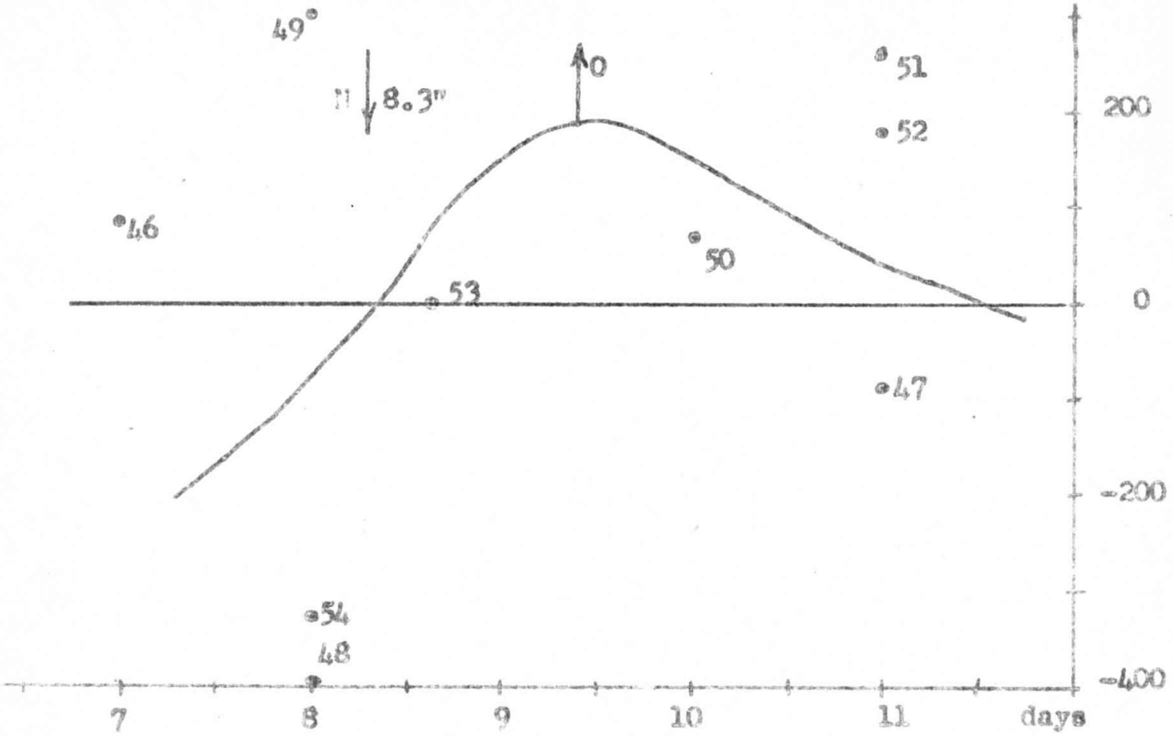


Chart 43

Relative Minimum Crop rainy days in six-week-intervals for Alaska Peas grown in Rosendale, (1946-1954)

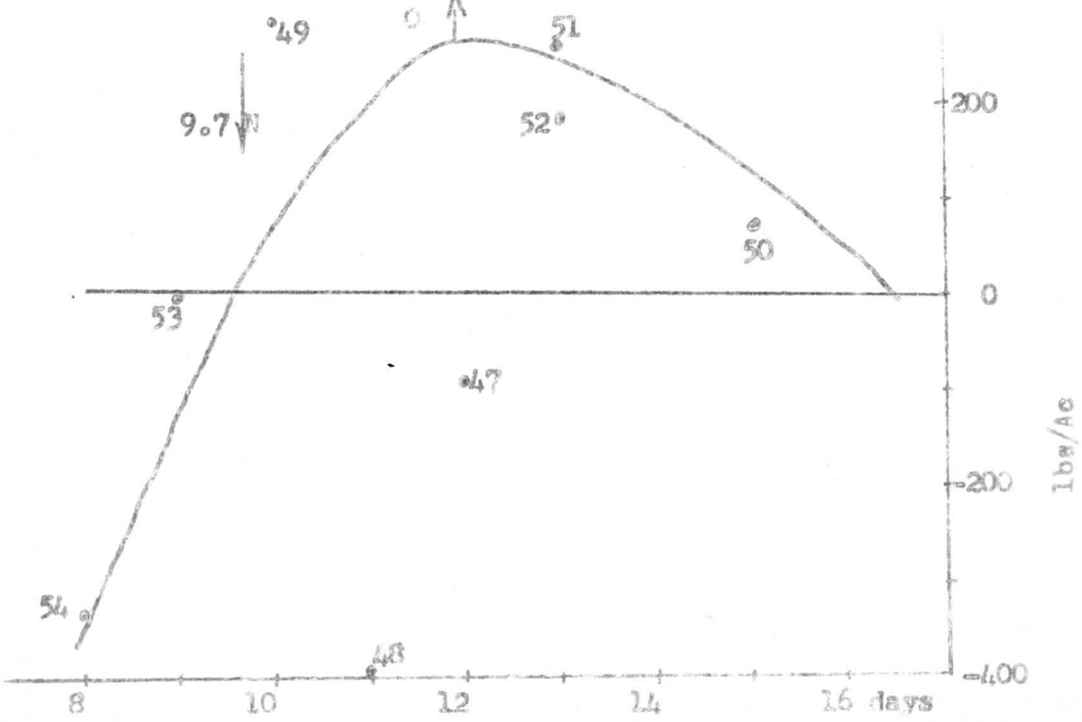
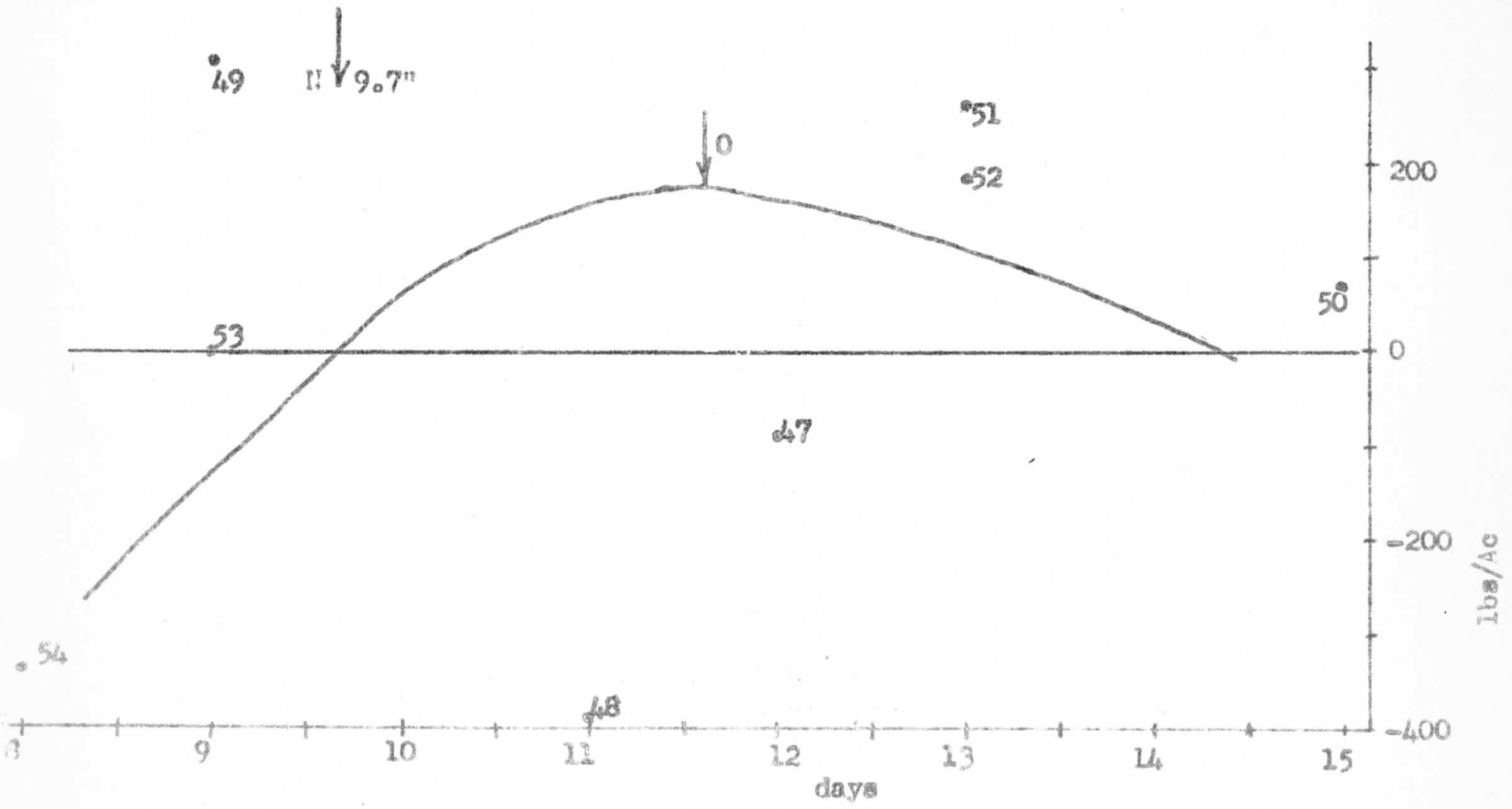


Chart 44

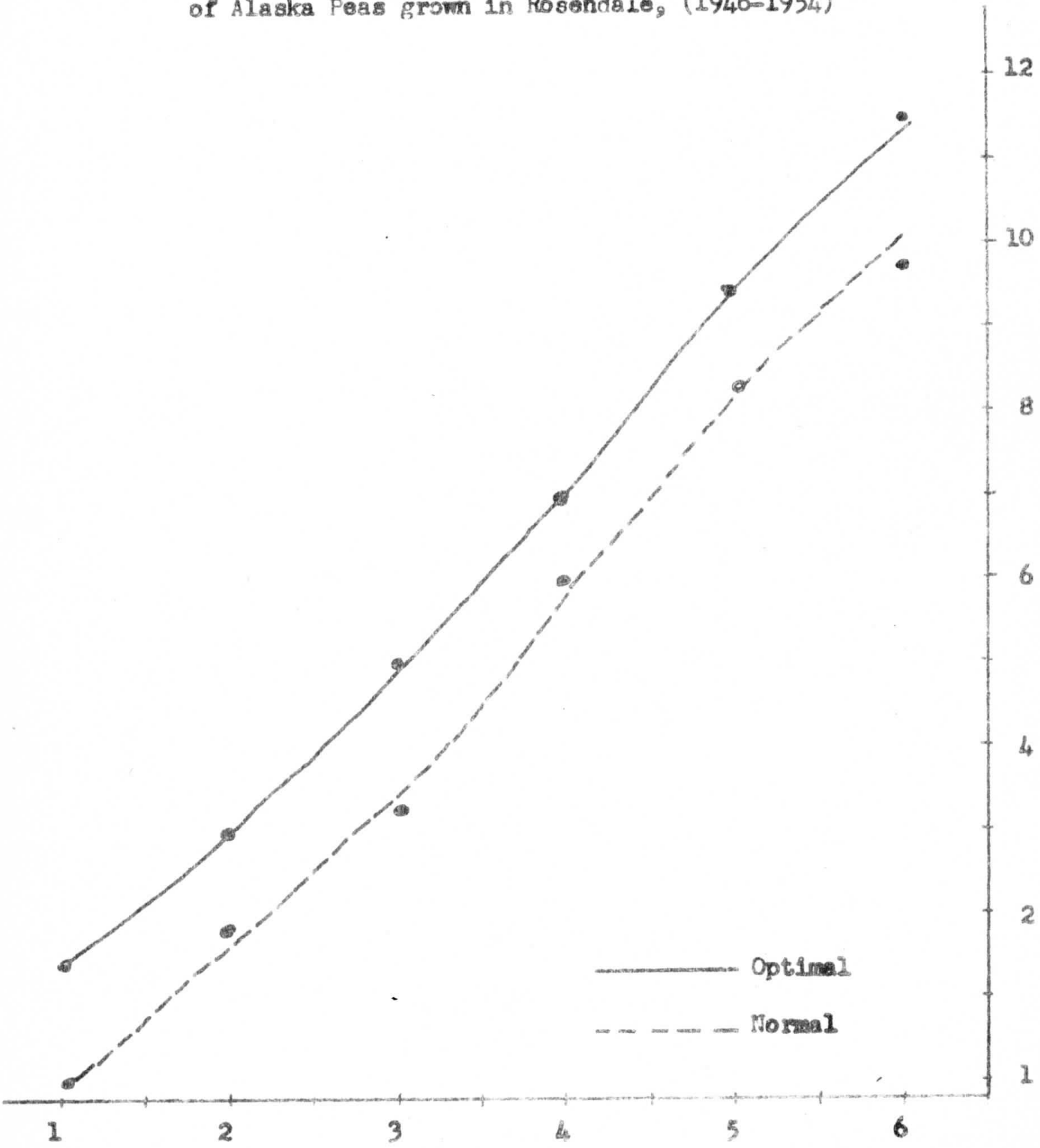
Total Number of Crop rainy days in the growing season for Alaska Peas grown in Rosendale, (1946-1954)



Similarly a summary chart of the crop rainy days for the Normal and Optimal yield is shown in chart 45.

Chart 45

Accumulated Number of Crop rainy days in weekly-intervals
for the optimal and normal yield
of Alaska Peas grown in Rosendale, (1946-1954)



Again the optimal yield curve is situated above the normal yield curve. On careful examination of either the optimal or the normal value for each group of successive week-intervals, one will find that many times a fractional value of number of rainy days will be obtained. This fractional value e.g. 2.4 crop rainy days does not make physical sense and should therefore be thought of as "2 to 3".

A summary of the amount and frequency of precipitation required for optimal and normal yield of Alaska Peas were tabulated in Table 8 as shown:

Table 8

Amount and Frequency of Precipitation
in weekly-intervals required for the yield
of Alaska Peas in Rosendale, Wisconsin, (1946-1954)

Week-interval	1	2	3	4	5	6	7	8
For Normal Yield:								
(1) Amount of precipitation in inches (mean of all planting sequences)	0	.15	.55	1.08	1.85	2.87	3.50	3.75
(2) Number of rainy days (Last planting sequence)	0	2	3	6	8	10	—	—
For Optimal Yield:								
(1) Amount of precipitation in inches (mean of all planting sequences)	0	.27	.76	1.40	2.19	3.29	3.96	4.25
(2) Number of rainy days (Last planting sequence)	1	3	5	7	9	11	—	—

2. CUMULATIVE SNOWFALL AND RAINFALL PRIOR TO DATE OF PLANTING.--

The total amount of precipitation accumulated from October first of the previous winter, from November first of the same and so forth were evaluated as below:

Chart 46

The Accumulated Total Precipitation
from the first of October of the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954).

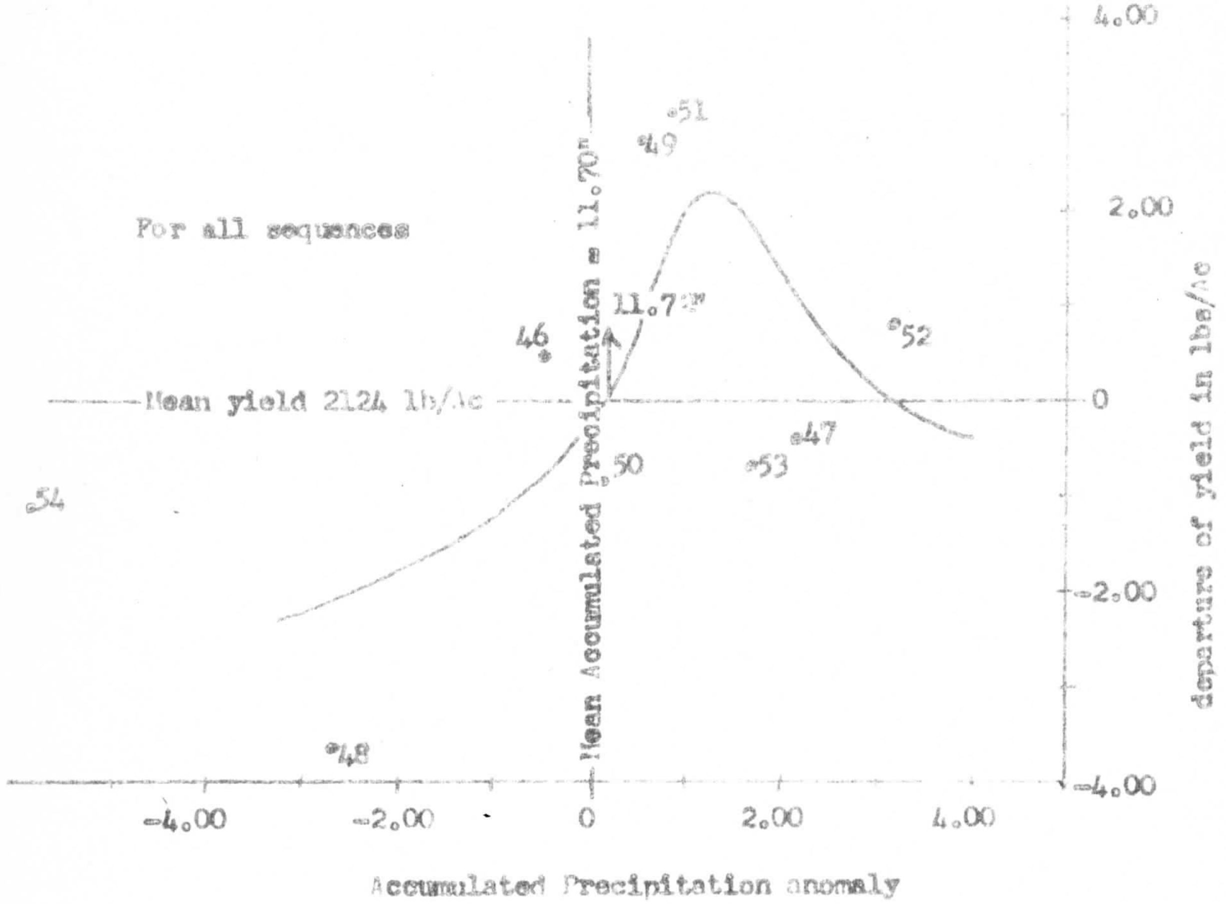


Chart 47

The Accumulated Total Precipitation
from the first of Novemberof the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954)

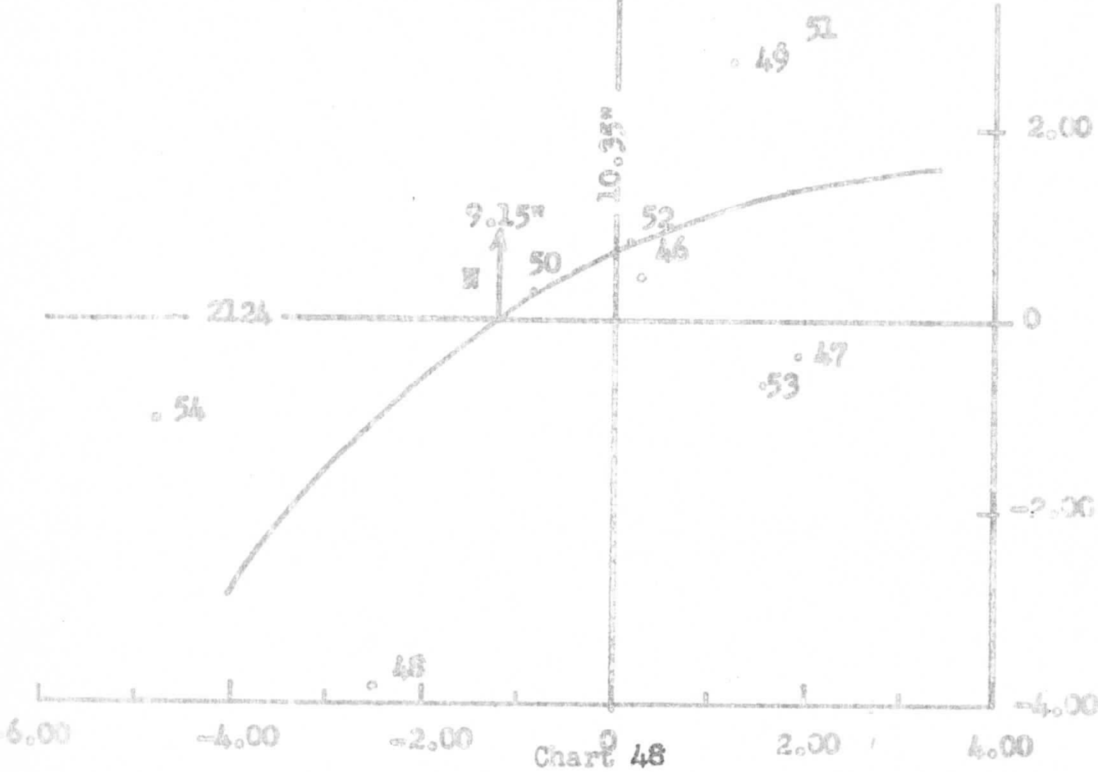


Chart 48

The Accumulated Total Precipitation
from the first of December of the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954)

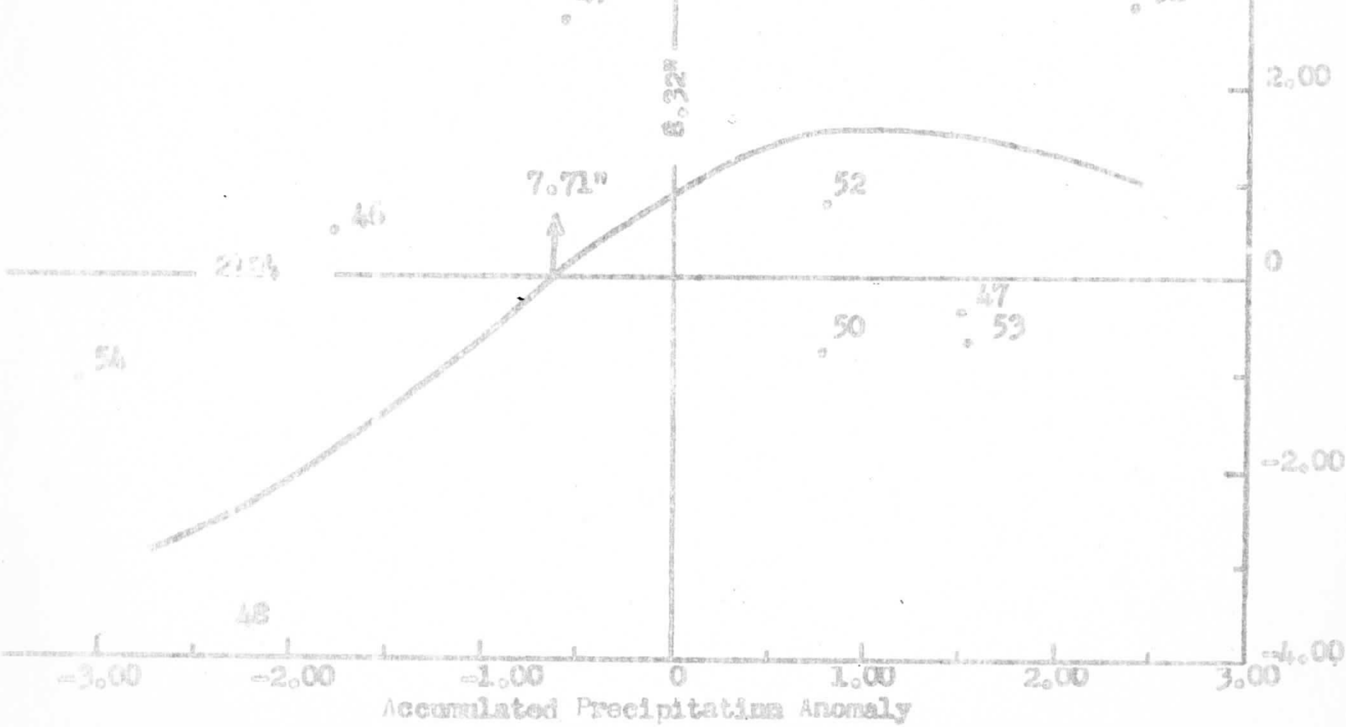


Chart 49

The Accumulated Total Precipitation
from the first of January of the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954)

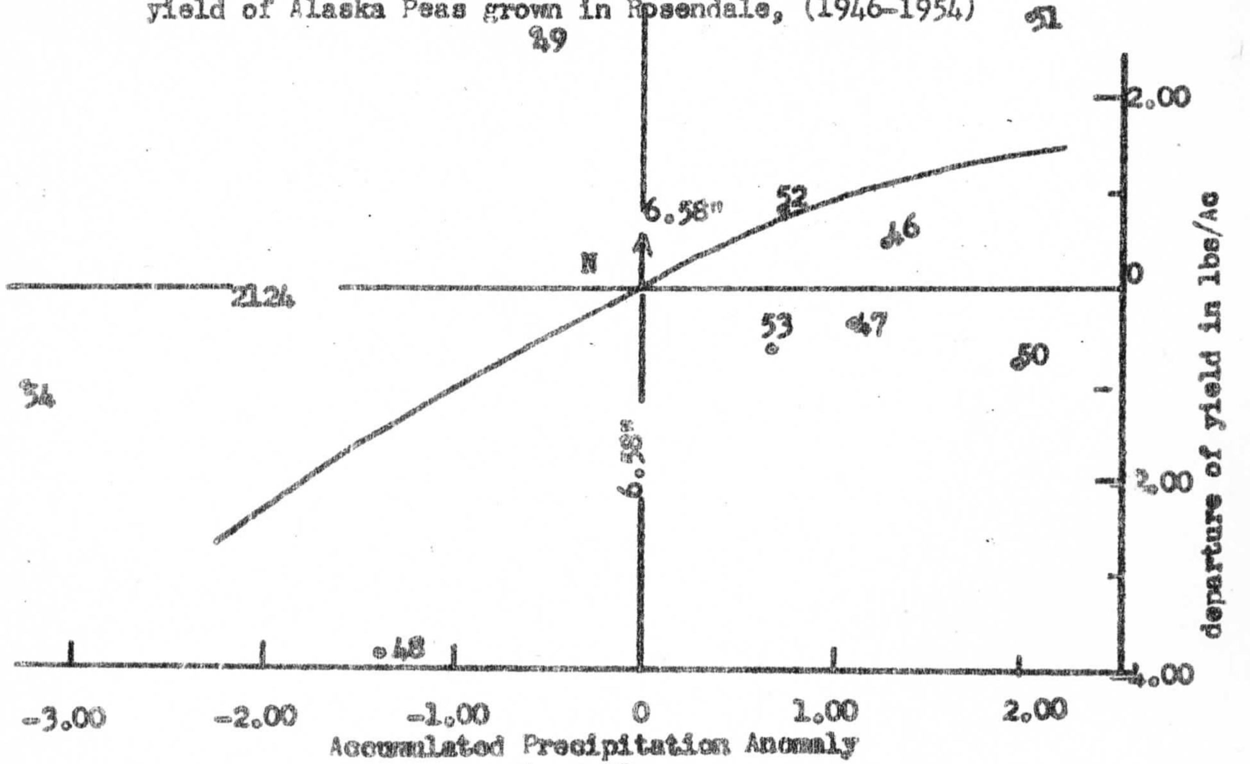


Chart 50

The Accumulated Total Precipitation
from the first of February of the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954)

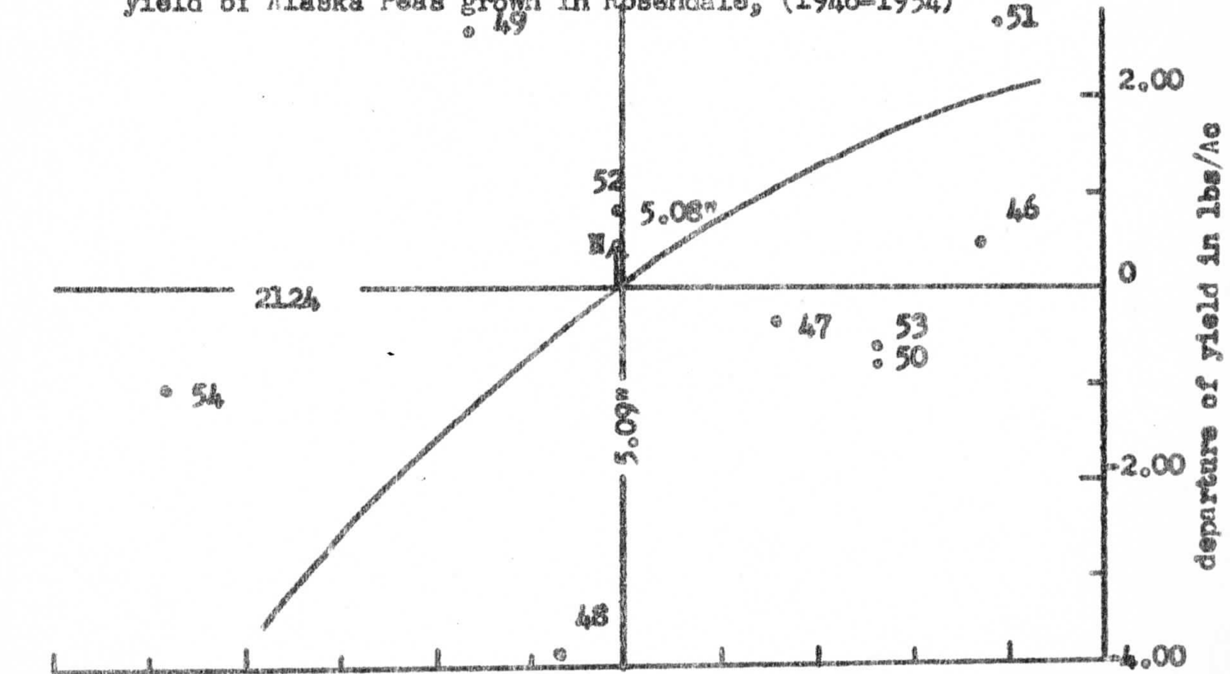


Chart 51

The Accumulated Total Precipitation
from the first of March of the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954)

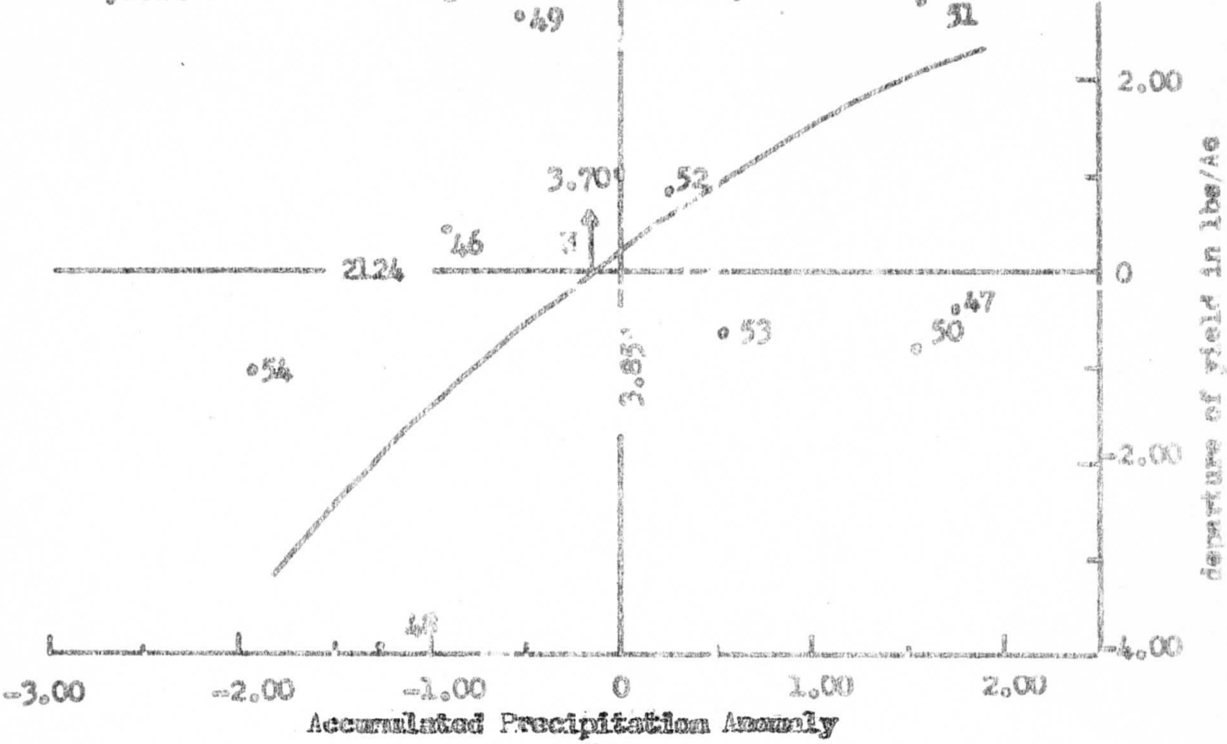
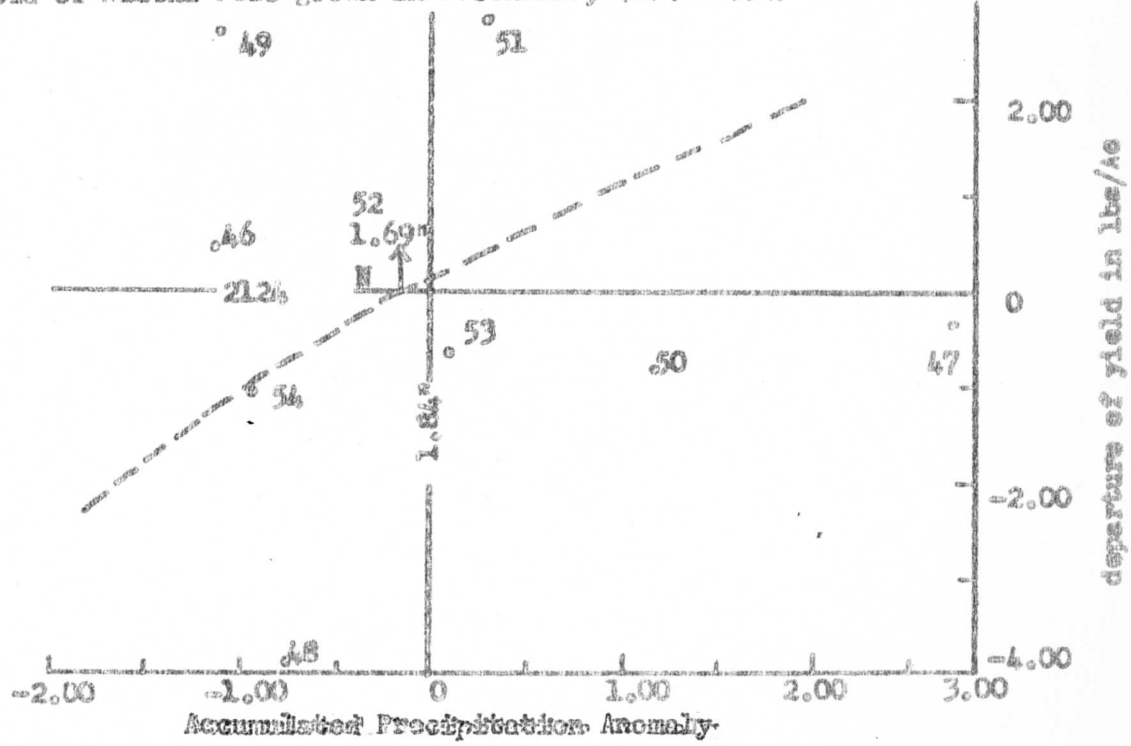


Chart 52

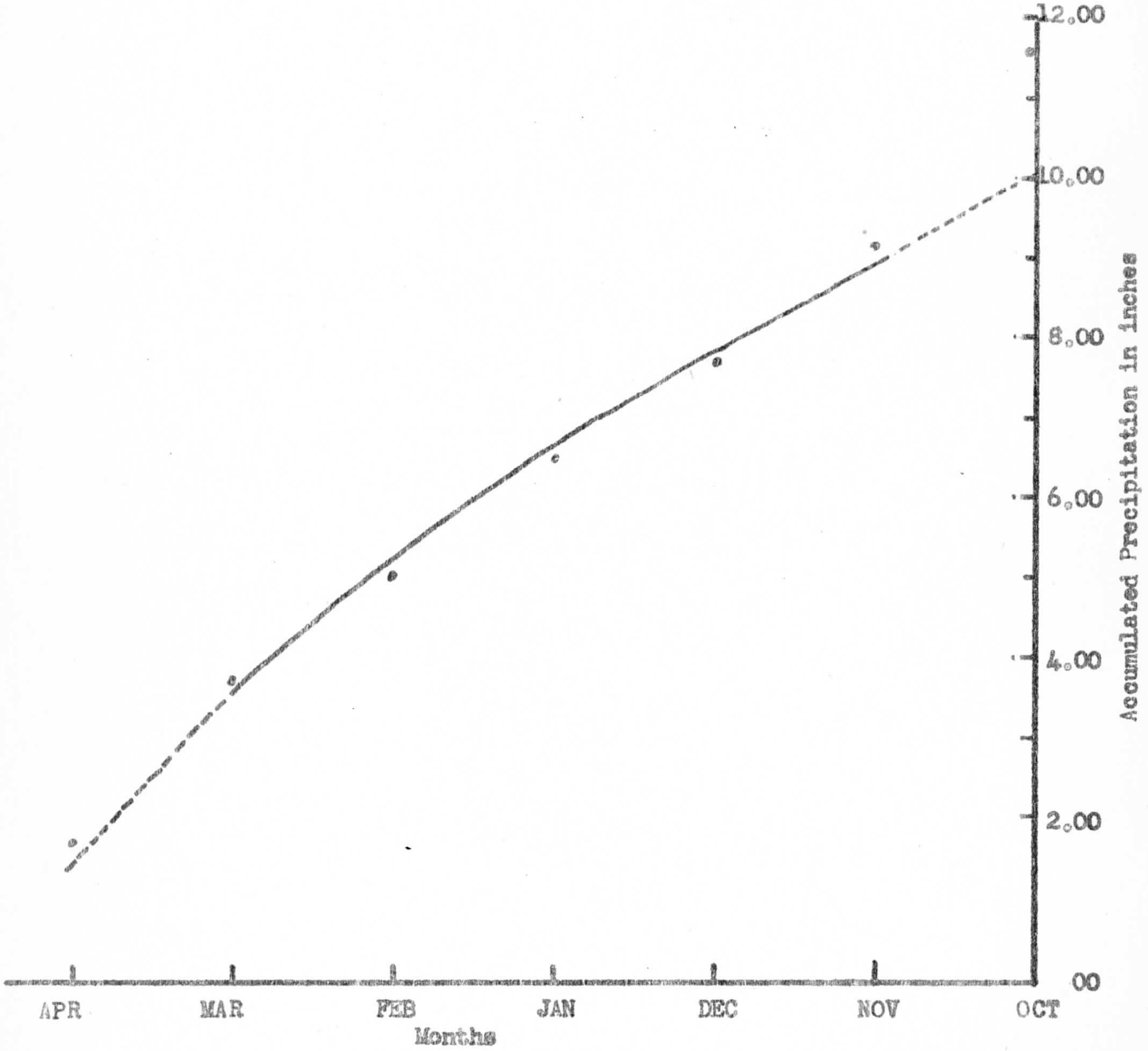
The Accumulated Total Precipitation
from the first of April of the previous winter versus departure of
yield of Alaska Peas grown in Rosendale, (1946-1954)



The summary of the above scatter diagrams is shown as follows:

Chart 53

The Accumulation of total precipitation prior to Seeding of Alaska Peas for normal yield, in Rosendale, (1946-1954)



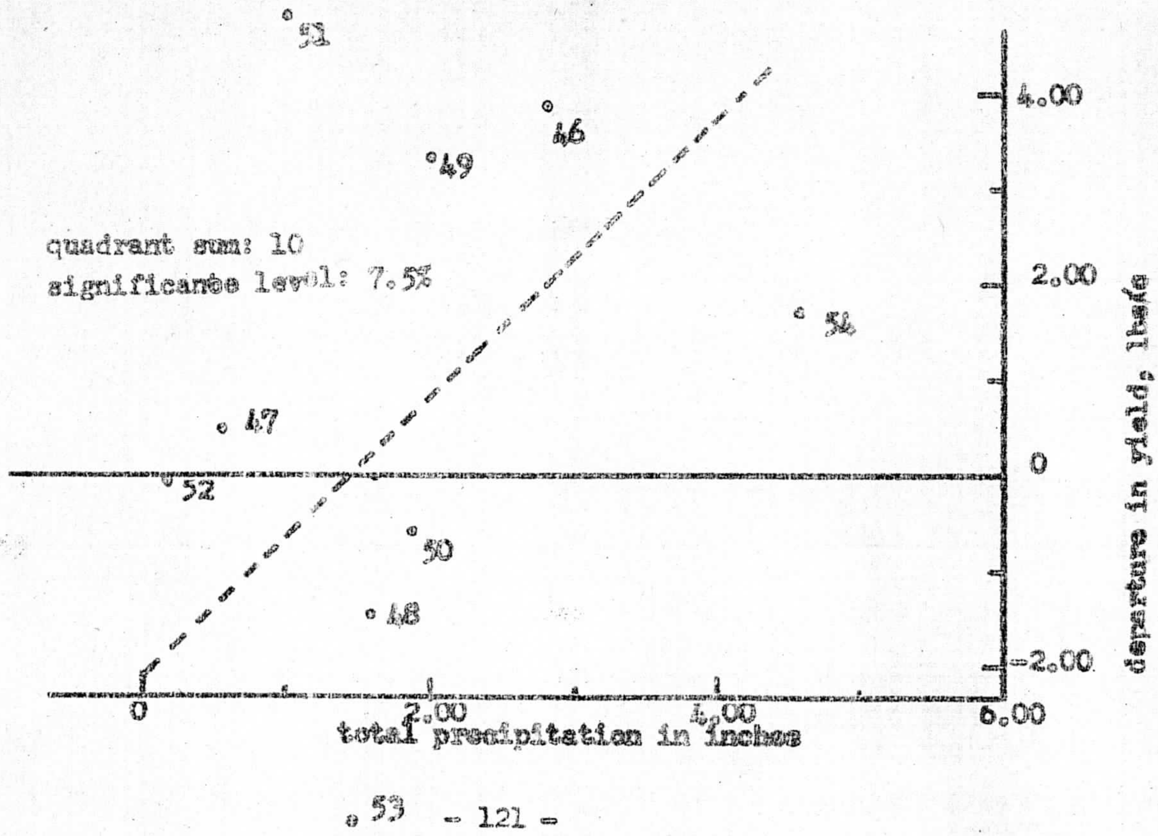
The scatter diagrams shown in this section are not as good as those for precipitation and crops rainy days. The quantitative evaluation of these two sets of scatter diagrams will be given in the last section of this chapter.

3. TOTAL PRECIPITATION IN THE REPRODUCTIVE STAGE.—

In order to determine the significance of total precipitation in the reproductive stage, it is necessary to test the total precipitation before and after the blossoming date as related to yield. For comparison precipitation amounts 21 days before and after the blossoming date for Alaska Peas in Rosendale, Wisconsin were used. The test is illustrated in charts 54-55

Chart 54a

Total Precipitation in the reproductive stage versus yield
of Alaska Peas, Rosendale, Wisconsin (1946-1954)
(First planting sequence)



quadrant sum: 10
significanbe level: 7.5%

Chart 54b

Total precipitation for the 21-days prior to blossoming date
versus yield of Alaska Peas, Rosendale, Wisconsin
(First planting sequence)

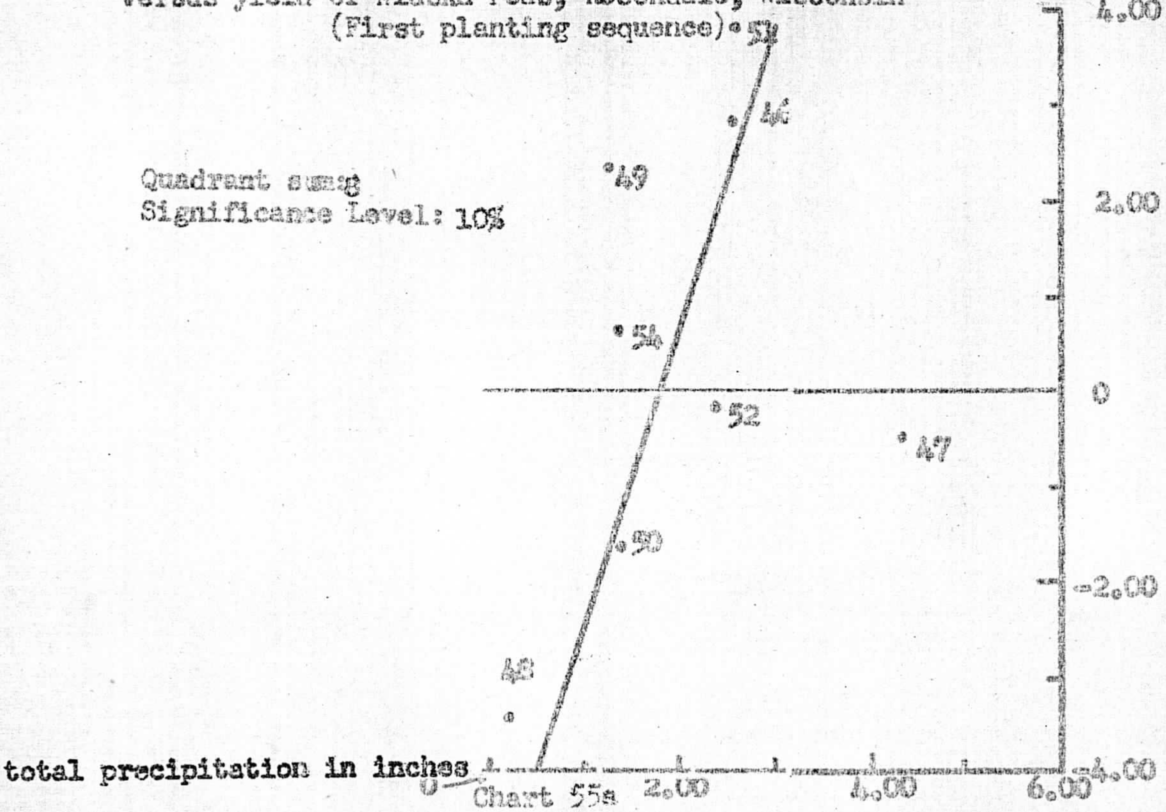


Chart 55a

53

Total precipitation in the reproductive stage versus yield
of Alaska Peas, Rosendale, (1946-1954)
(Last planting sequence)

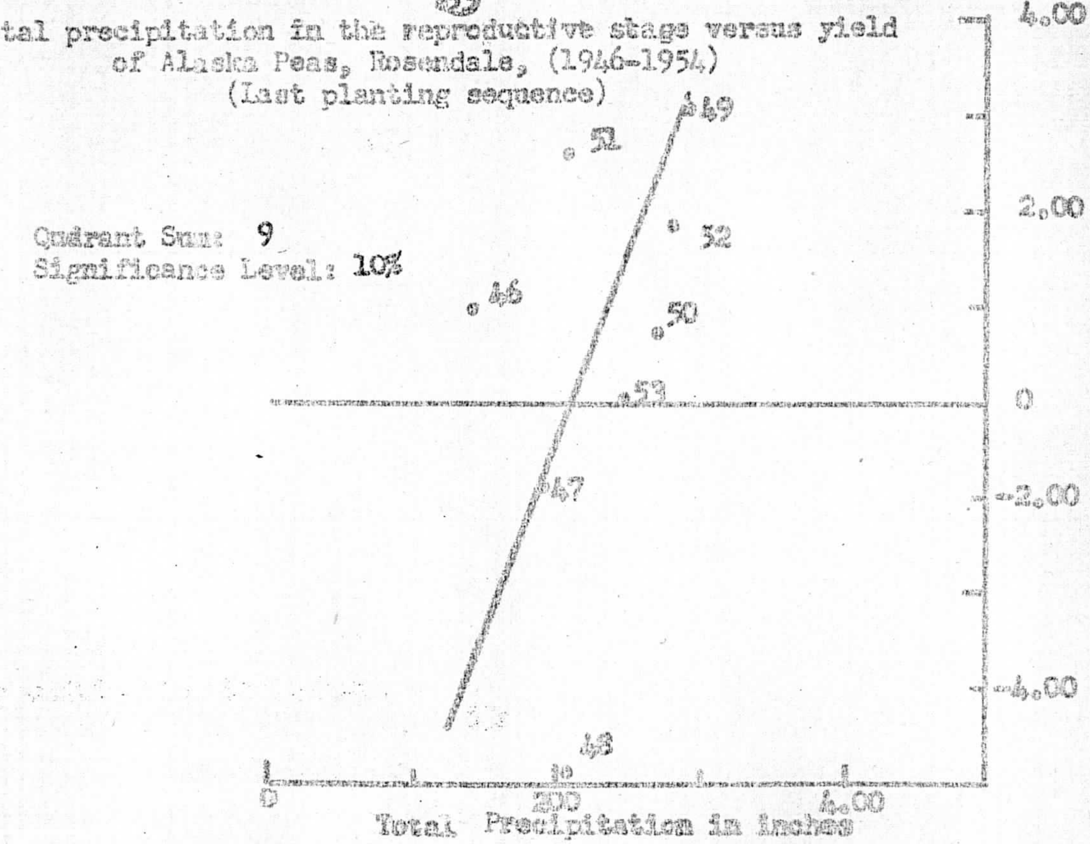
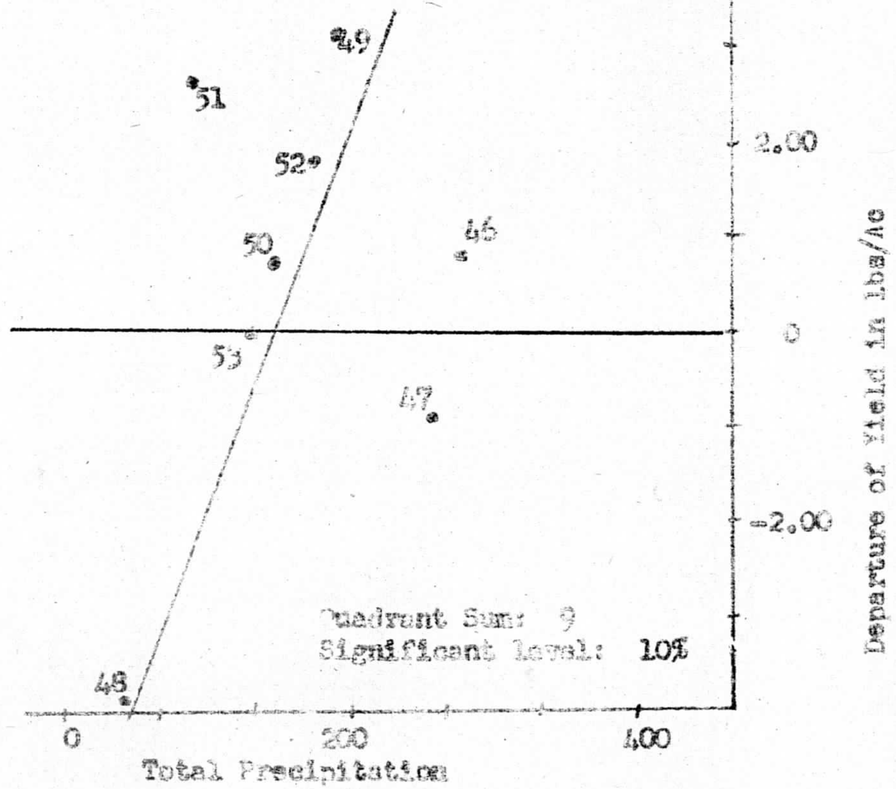


Chart 55b

Total precipitation for 21-days prior to blossoming date
versus yield of Alaska Peas, Rosendale, Wisconsin
(Last planting sequence)



It is obvious that the effect rainfall is more prominent during the 21 days prior to blossoming for the first planting sequence (See chart 54b) and in the reproductive stage for the second sequence (See chart 55a). This latter is most likely due to the temperature effect; that is to say, temperature is usually too warm during the reproductive stage of the second sequence and a certain amount of rainfall is needed to reduce transpiration in order to have a better yield.

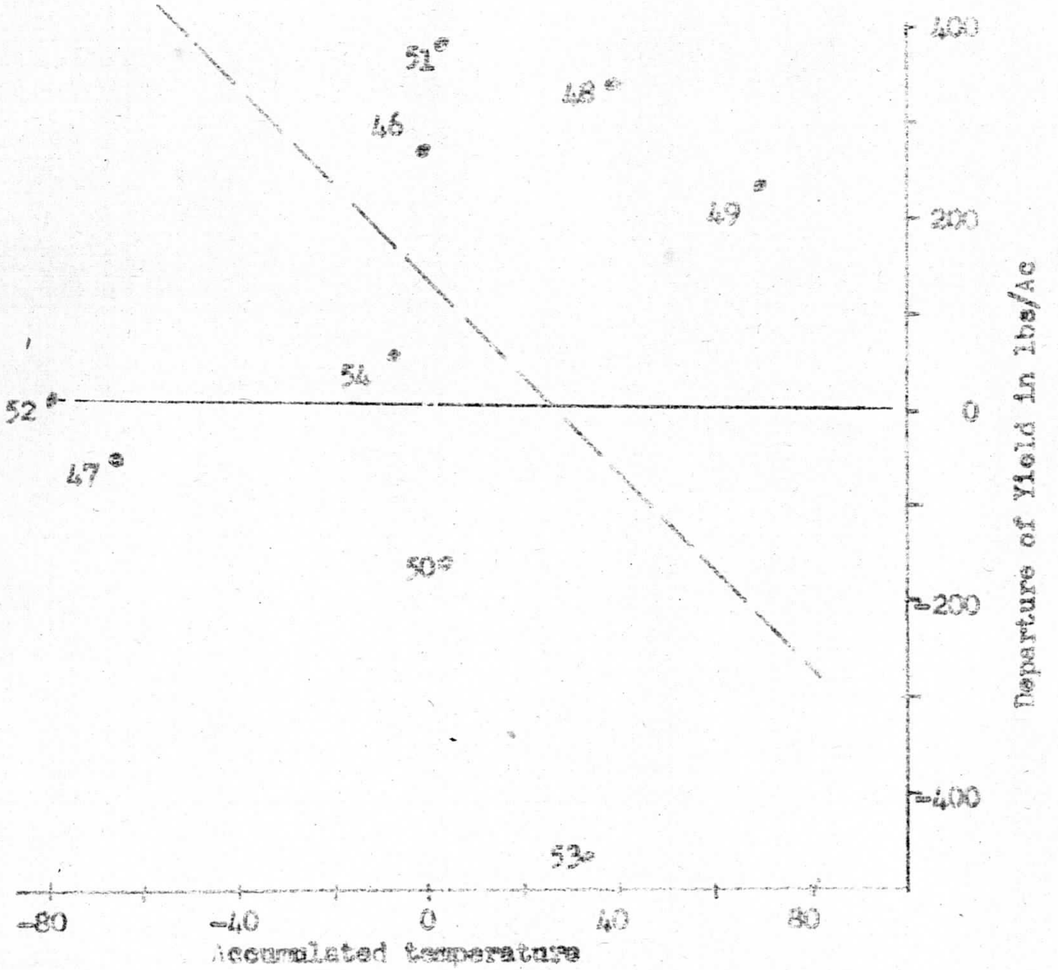
4. SUMMATION OF INTER-DIURNAL TEMPERATURE VARIATION FOR THE REPRODUCTIVE STAGE.—

The inter-diurnal temperature variation has been defined in Eg. (10)

and illustrated in chart 17, 18 and 19 for Alaska peas grown in Gillet, Bonduel and Rosendale, Wisconsin; and Belvidere, Illinois. These charts show a well-defined negative relation between the departure of yield and the inter-diurnal variation. All of these tests were restricted to the reproductive stage. It is now necessary to test this parameter for the period 21 days before blossoming as was done in the previous section for the productive stage. These tests are shown below:

Chart 56

Summation of Inter-diurnal temperature variation for 21-days prior to blossoming versus departure of yield of Alaska Peas in Rosendale



By comparison of chart 18 on page 67 with the present chart, it appears that the former is much better correlated with the departure of yield than the latter. This shows that the fluctuation of temperature during this stage has little effect on the yield of Alaska Peas.

5. NIGHT TEMPERATURE SUMMATION FOR THE GROWING SEASON.--

This has been well illustrated in chart 21a and b on pages 70 through 73. It is suggested that the reader refer to these pages. However, it is well to mention here that the official daily minimum temperature report may be used for these scatter diagrams instead of the mean night time temperature computed from the hourly temperatures.

6. PHOTO-THERMAL UNITS FOR THE GROWING SEASON.--

The photo-thermal unit has been defined by Eq. (12) and illustrated by chart 22a and b for details the reader may refer to pages 73-76.

In comparison of photo-thermal unit and the night temperature as related to the yield of peas in one locality, there appears little difference so far as their scatter diagrams are concerned. This shows again that the night temperature has a dominant influence on the yield of peas.

7. ENERGY-DEGREE UNIT COMPUTATION FOR THE GROWING SEASON.--

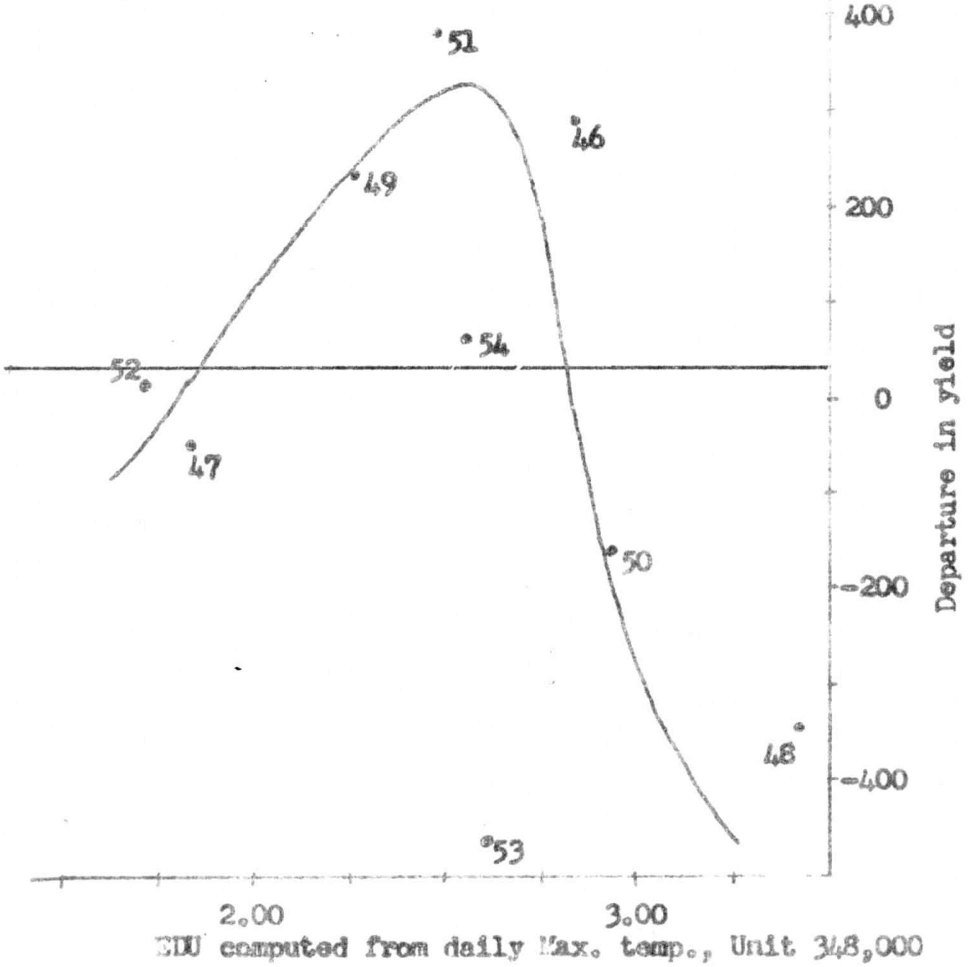
The energy-degree unit, EDU, has been defined by Eq. (13) as

$$EDU \equiv \sum_{i = D_p}^{D_m} (T_a - T_{c,L})_{T_{c,u}} E$$

Where i is the calendar date, D_p the date of planting, D_m the date of maturity according to tenderometer scale; T_a, the daily mean temperature in degrees Fahrenheit, E the solar radiation in Langleys per day and T_c the critical temperature (Subscript u designates upper limit; L, lower limit) in degrees Fahrenheit. For the present example 40°F is chosen for the lower critical temperature, $T_{c,L}$ while 90°F is chosen for $T_{c,u}$. These figures were obtained from the mean value of the lower and the upper threshold temperature as illustrated on diagram 2 page 28. Also, only 21 days prior to blossoming was used to represent the significant period of the growing season and, moreover, only the maximum temperatures were used instead of daily mean temperature. Thus instead of D_p, D_m and T_a we have D21, D_b and T_M, respectively.

Chart 57

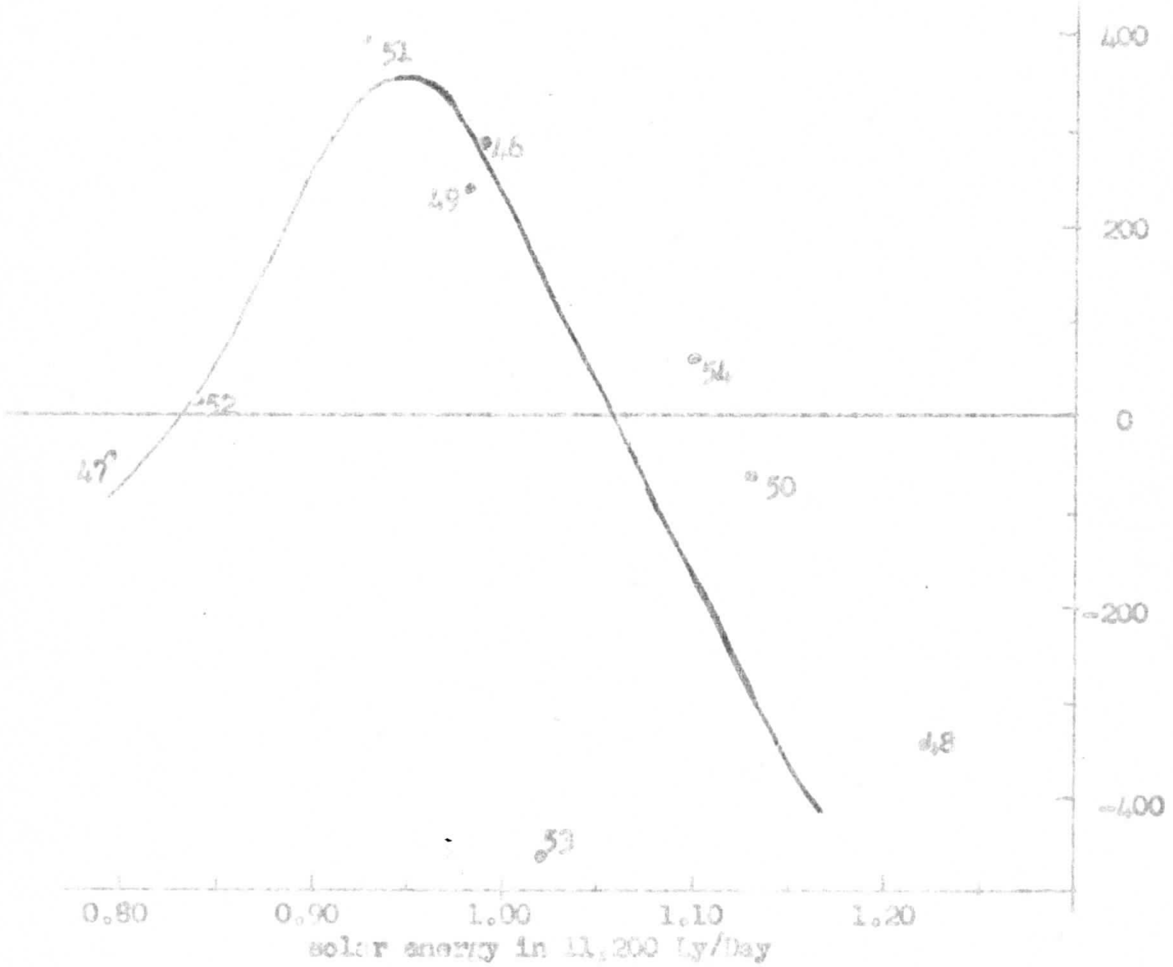
Summation of EDU for 21-days prior to blossoming
versus yield of peas in Rosendale, Wisconsin
(Computed from daily maximum temperatures)



It is interesting to note that the above diagram does not show as good a correlation as using the summation of solar radiation alone. The former has a quadrant sum of 8, while for the latter it is 13. The accumulation of solar intensity in langleys per day for 21 days prior to blossoming is given in Chart **58**.

Chart **58**

Summation of solar intensity for 21-days prior to blossoming
versus yield of peas in Rosendale, Wisconsin



Various trials have been made on this question besides what is shown on charts 57 and 58. They are a summation of EDU computed from minimum temperature with 40°F and 90°F as the lower and upper limit and the summation of maximum temperature with the same limits. Neither gives as reasonable a relationship as those shown in charts 57 and 58.

8. RELATIVE MINIMUM PERCENTAGE OF POSSIBLE SUNSHINE IN THE WEEK-INTERVAL.—

The results of Relative Minimum percentage possible sunshine in weekly intervals and the departure of yield of Alaska peas in Rosendale, Wisconsin has been given on chart 24 (page 80.) Since chart 24 was the accumulation of a series of nine scatter diagrams in weekly intervals, the illustration of these separate scatter diagrams is necessary in order to get a complete picture of how chart 24 was obtained. These scatter diagrams are shown in Charts 59 to 67.

9. A CHECK OF THE SIGNIFICANT ADVERSE WEATHER.—

Qualitatively, it is possible to make a budget for the negative effect due to the adverse weather. What we mean by adverse weather has been described on pages 82-83 as intense or severe environmental factors which retard or even halt the growth and development of a crop. A glance at the past records (1946-1954) of adverse weather versus departure of yield of Alaska peas (Rosendale, Wisconsin) is given on table 9, page 134.

Chart 59

Relative Minimum Percentage of possible Sunshine in one-week-intervals versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

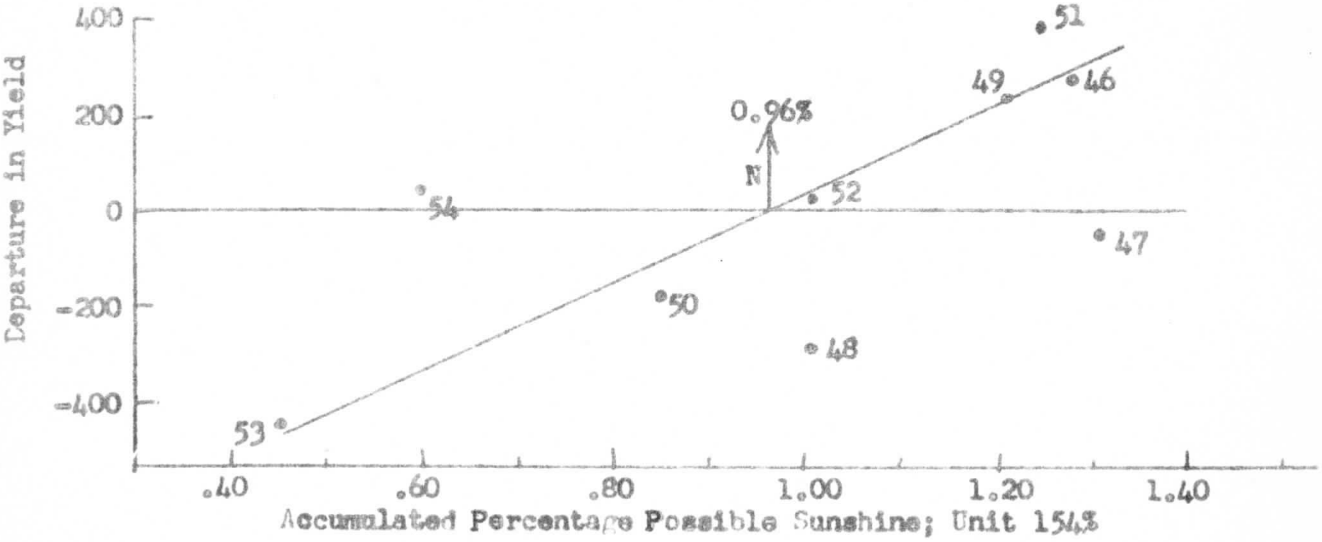


Chart 60

Relative Minimum Percentage of possible Sunchine in a two-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

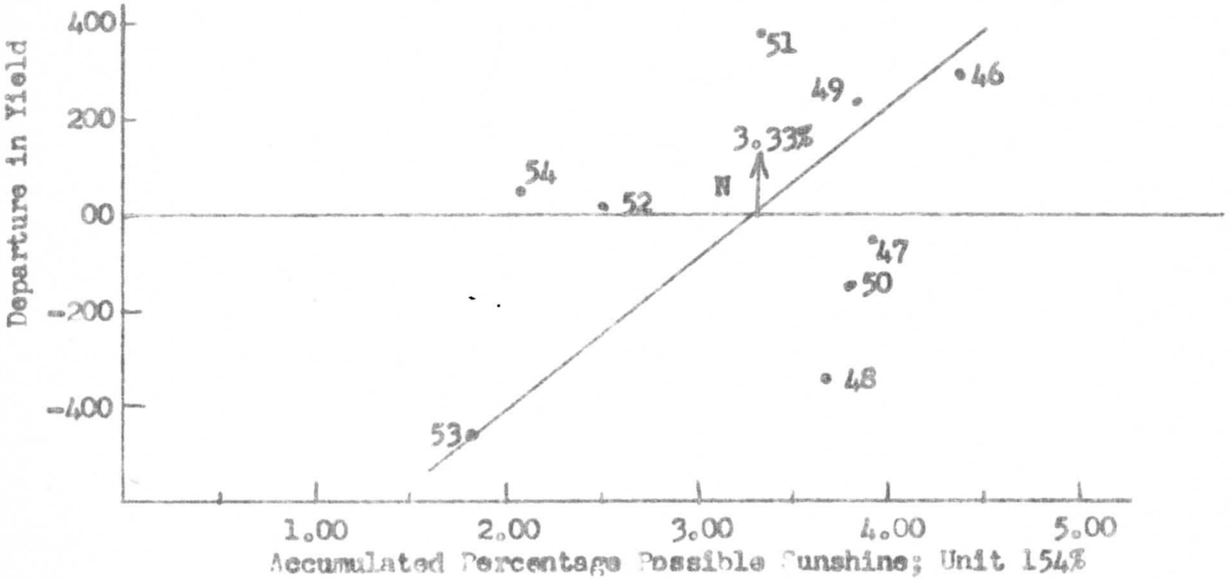


Chart 61

Relative Minimum Percentage of possible Sunshine in a three-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

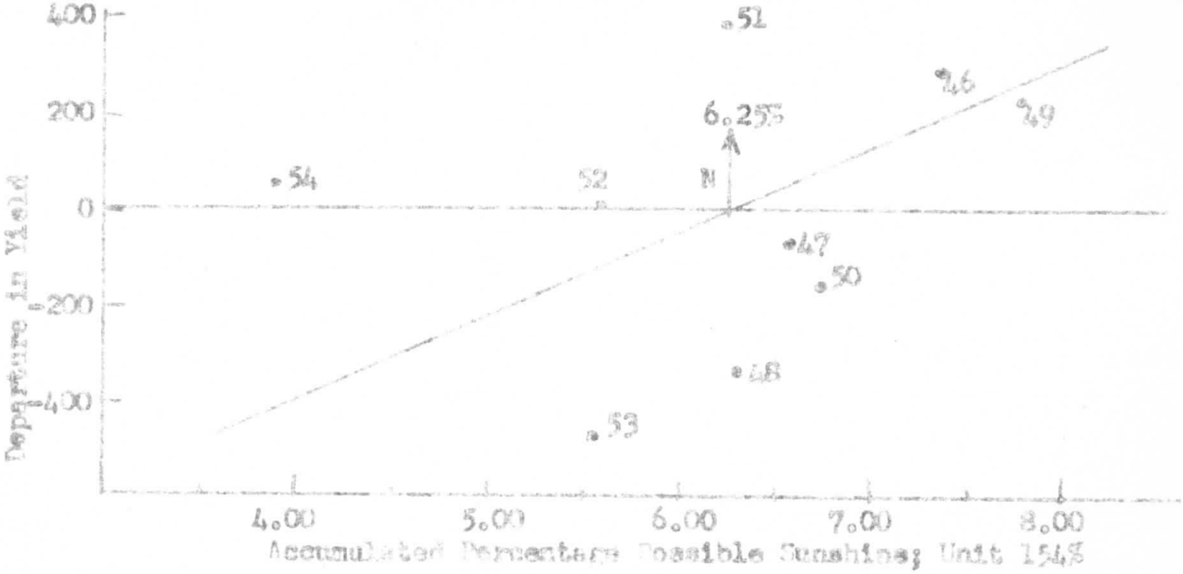


Chart 62

Relative Minimum Percentage of possible sunshine in a four-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

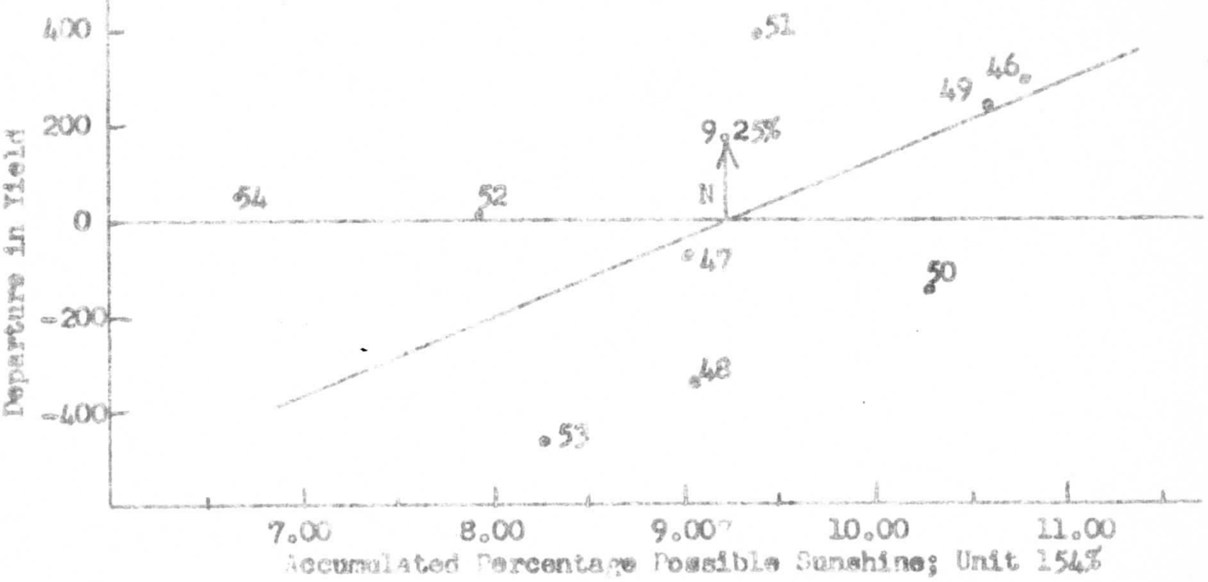


Chart 6~~1~~3

Relative Minimum Percentage of possible sunshine in a five-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

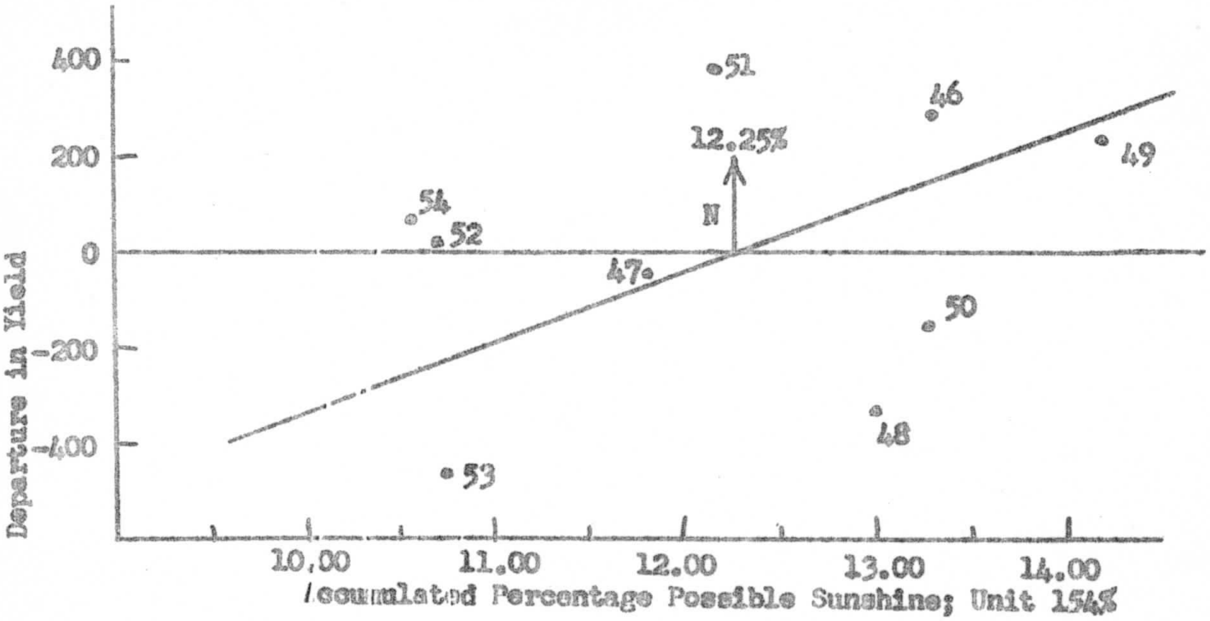


Chart 6~~2~~4

Relative Minimum Percentage of possible sunshine in a six-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

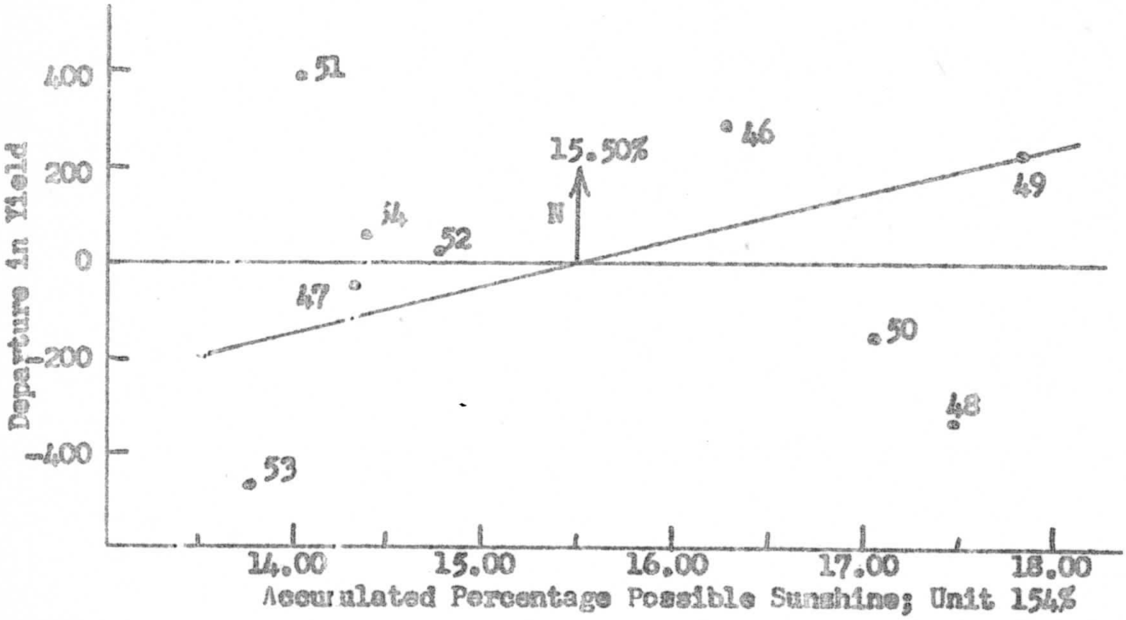


Chart 65

Relative Minimum Percentage of possible sunshine in a seven-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

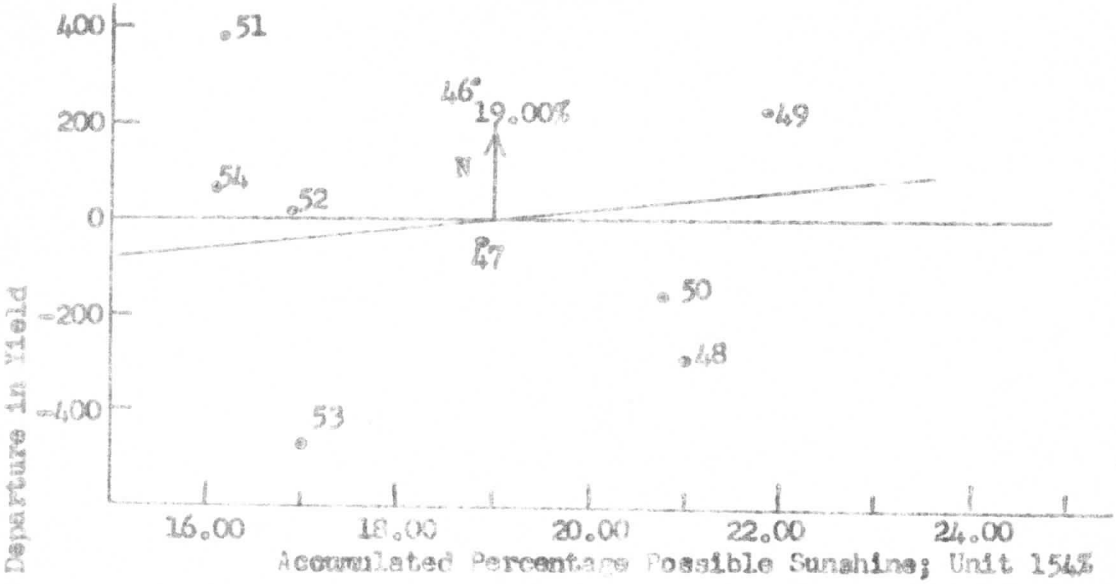


Chart 66

Relative Minimum Percentage of possible sunshine in an eight-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)

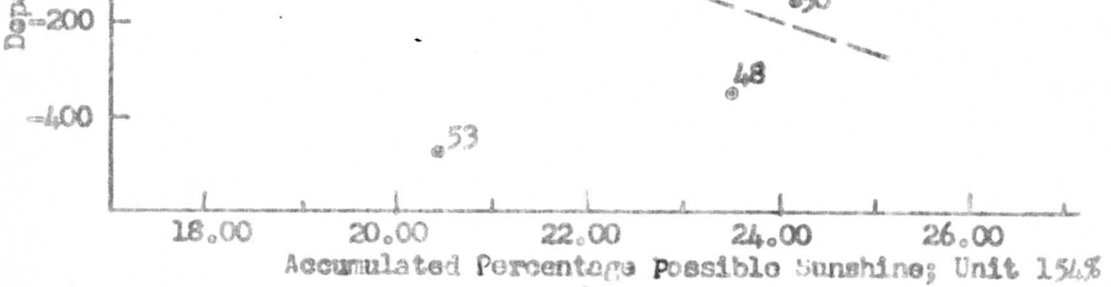
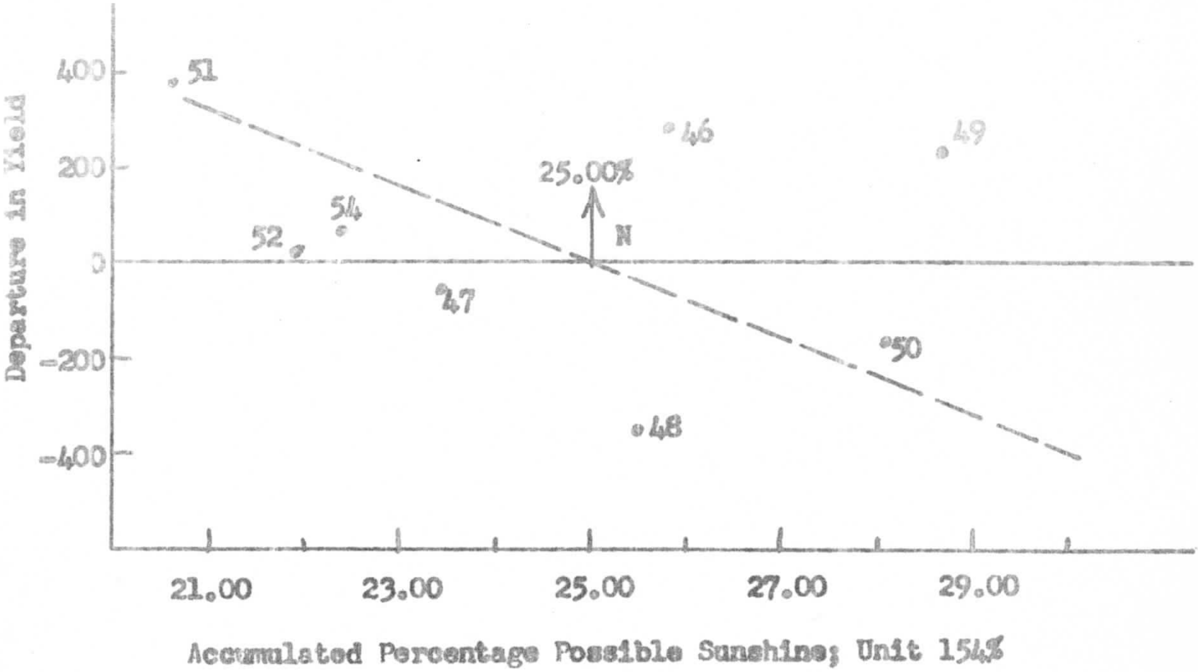


Chart 67

Relative Minimum Percentage of possible sunshine in a nine-week-interval versus yield of Alaska Peas in Rosendale, Wisconsin (1946-54)



Some of the discrepancies of the above scatter diagrams might be due to the difference in location of the meteorological data and crop data. The percentage of possible sunshine was observed at Madison, Wisconsin while the yield data is from Rosendale, Wisconsin.

Table 9

Occurrences of significant adverse weather and yield of Alaska Peas in Rosendale, Wisconsin (First planting sequence)

Year	Departure in Yield (pounds per acre) corrected for		Adverse Weather Records		
	5% increase in yield	10% increase in yield	Last frost in spring (days from planting)	Precip. with 36 hours after sowing	No. of cases of day and night temp. $T_M > 89$; $T_E > 70$
1946	283	340	12 days $T_m = 23^{\circ}F$	0	T_M (1)
1947	-45	-25	12 days $T_m = 26^{\circ}F$	0.16"	T_M (1); T_E (1)
1948	-342	-330	23 days $T_m = 26^{\circ}F$	0.26"	T_M (3)
1949	233	240	0	0.14"	T_M (3)
1950	-161	-170	1 day $T_m = 29^{\circ}F$	0.21"	T_M (4); T_E (3)
1951	381	360	0	0	0
1952	12	-15	0	0	T_M (4)*
1953	-465	-490	7 days $T_m = 28^{\circ}F$	0.67"	T_M (4); T_E (2)
1954	60	10	0	0.62"	T_M (3)

* This particular case most of the warm spell occurred at the early stage of planting;
Symbols used in this chart: T_m the minimum temp. record, T_M the maximum temp. and T_E the night temp., figures in parenthesis are the number of cases.

In general, the above table shows that the last frost in spring during the growing season, the precipitation over 0.20" after sowing as well as the number of cases of warm spells in the day and the night tend to reduce the yield. It is impossible to establish a quantitative relationship between these adverse weather elements and the yield because, for one thing, the intensity of this adverse weather is not really quantitatively indicated and other adverse weather occurrences are not recorded. But for a qualitative check, they are useful.

10. COMBINATION OF ENVIRONMENTAL FACTORS.—

The methods for combinations of environmental factors have been described in the previous chapter (See page 84-101) to some extent. Any complete example for the illustration of any of the above methods will be possible only when adequate environmental data are available. This is impossible for a summary paper like this, and further study on the combination of factors is necessary in the future.

CHAPTER V

CONCLUSION

Some unavoidable errors, significant points and a general summary and detailed discussion of the present paper compared with previous work are included in this chapter.

SOURCES OF ERROR.---There are at least three possible sources of errors involved in the entire study. They are:

(1) Errors in crop data.-- The inconsistancy in farm managements from year to year, the reduction in yield and quality by disease and insects, the technique in picking and transportation and the accuracy in measurement are all possible sources of error in the crop data. Others are the erosion of top soil, the treatment of seeds (such as, methods of storage, means of innoculation, etc.) and the accuracy in testing maturity of peas. For most of the pea data in this paper the maturity test is not specified, except data from Gillet and Bonduel, Wisconsin. Acoholic Insoluable Product (AIS) is reported much superior to tenderometer reading (TR). Thus, the former test should go with the latter as a check. Phenological records of crops are invariably inadequate. Even a major phenological event, such as date of blossoming is usually missing. In this connection, the assumption made in this paper that the date of blossoming is 21 days from the date of maturity is far from accurate. For an accurate test of crop data not only

detailed phenological data are needed but also the use of the organ of the pea most sensitive to the environment is necessary. For instance, Clements in Hawaii has found the sugar content of the sheath of sugar cane was a better indicator of the environmental effects than any other organ of the plant. Clues for detecting a special organ can be obtained by chemical and physiological as well as morphological means.

(2) The environmental data.— The two most frequent difficulties in the introduction of Meteorological data for agricultural uses are: (i) the neglect of micrometeorological effects; (ii) the lack of adequate and continuous records. The data used for Rosendale were obtained from El Dorado for temperature, El Dorado and Ripon for precipitation, Madison for percentage sunshine and solar intensity. Both temperature and precipitation are subject to large variations with distance. Therefore, the actual meteorological condition for the crops are not fully described. Factors such as soil temperature and moisture, evaporation and transpiration, wind and relative himidity in terms of water deficit and dew, etc., are not observed. Continuous recording instruments were not available for most of the places, therefore, the diurnal variation of the environmental factors must be inferred. Furthermore, the accuracy of the instrument, personal error in observation, etc., will contribute a certain amount of error.

(3) Accuracy of techniques.— Most of the methods used for analyses in this paper are based upon scatter diagrams and diagrammatic presentation. With the aid of the quadrant sum test, subjective error can be made as little as 10% or so. Therefore, the range of normal and optimal conditions

can be described with an approximate boundary. Moreover, the so-called normal or optimal environmental conditions for the yield or quality of peas is not an absolute value for a given factor. It is evident that this may be due to group effects (interrelation and interaction of several factors). Therefore, for a set of data the optimal or normal value can be a certain value and for another set of data, another value. Errors of this sort can not be avoided until the combination of factors is made.

The mathematical treatment of data, on the other hand, is far more accurate than the diagrammatic analysis, if the representation of data in space as well as the accuracy of measurement are good. This technique is subject to much less error. However, it must be subject to physiological considerations. In other words, the mechanical manipulation of mathematical rules must be accompanied by biological limitations. The choice of biological limitations is difficult, for neither the green house trial nor the field trial can be adopted as an absolute value. Therefore, most of the possible errors introduced in the mathematical approach come from the set up of boundary conditions.

As to the statistical approach the emphasis is on the majority of data and the minority of data, or the special cases, may be sacrificed. In view of the numerous errors described in the preceding section it seems obvious that one method of reducing these difficulties would lie in the wider use of carefully instrumented and observed test areas or "check plots."

CHECK PLOT DESIGN.--

Most historical yield data is very raw and poorly suited to analysis. It consists usually of a pounds per acre or similar figure along with a date of harvest (sometimes) and a rough or overall measure of quality (occasionally). Environmental data may be entirely lacking or consist only of the U. S. Weather Bureau cooperative observation station up to 40 or more miles away.

It would seem advisable to set aside a check plot in the most representative or "modal" location on the farm or in the area. On this plot careful observation of such factors as runoff, percolation, soil temperature, soil moisture and all pertinent meteorological parometers should be made and recorded on a carefully designed form or punch cards. In addition, cultural practices and phenological events, as well as yield details should be carefully observed and described. Notes on differences between check plot and general crop area round out the record.

DISCUSSION OF PRESENT FINDINGS AND PREVIOUS WORK.--

Since most previous work was concerned with a single environmental factor and crop relationship, a comparative study of the present findings and the past work must retain this single environmental factor framework.

For the water requirement of peas the studies, such as those of King (45), Briggs and Shantz (8), etc., found relatively higher transpiration ratio for various varieties of peas than for average vegetable crops. This does not mean in itself that peas need more water than other crops. For the transpiration ratio, itself, indicates the economic use of water by the plants. Shuttleworth (45) pointed out in 1899 after his subwatered cylinder experiments that peas definitely need more water than small grains, such as oats and wheat. All the studies of the water requirements of peas in the present work showed a good correlation with the water supply. Walker (55), tested the relation of yield of peas and the rainfall of the significant month in Erie County, New York. The yield was closely correlated, 0.89±0.1, with the rainfall during the month of June. In a similar manner three kinds of tests have been made in the present paper. (i) a rough check of the significant (or effective) month for the yield of peas. By significant month we mean the month about the blossoming stage of peas. The effective monthly precipitation versus yield of peas in eight different states in this country was tested for the years 1951 through 1953. This was shown in chart 3. The result was poor. This might be due largely to the space variation of rainfall, particularly in the western states, such that state-wide averages of precipitation are not representative. (ii) total precipitation in the reproductive stage versus quality and departure of yield of Alaska peas in Gillet and Bonduel, Wisconsin from 1946 through 1955. A 21-day period was assumed as the reproductive stage. The findings were shown on chart 11. A quadrant sum of 6 was obtained for TR 100-119 and TR 110-119. But only a 4 quadrant sum can be obtained for TR 90-99. This shows that the correlation is rather low, not reaching the 10% significance level. Nevertheless, a much higher correlation was found in the second planting sequence of Alaska peas grown in Rosendale, Wisconsin. This is shown in chart 55a. There, the quadrant sum is 9 and the significance level is 10%. (iii) Total precipitation in the pre-productive stage versus departure of yield of Alaska peas in Rosendale, Wisconsin. This is shown in chart 54b. The pre-productive stage is defined as 21-days prior to date of blossoming. A quadrant sum of 8 and a significance level of larger than 10% were obtained. All the above findings show that that period is important to the yield of peas. In fact, Azzi* has tested for over 30 years the significant period of various crops with good results. He calls the significant period the "critical period" and, of course, the length of time is different for different crops.

Both relative Minimum rainfall and crop rainy days in weekly intervals (See chart 30-45) were tested in the present paper. These essentially represent a relative draught period of various lengths. The correlation of yield with this relative draught works very well for 2-4 week-intervals and has a mean quedrant sum of 16, in other words, the significant level is better than 1%. The mean quadrant sum for a 5-7 week interval is 5, that is more than 10% significant level. While for 8 sucessive weekly interval and the total precipitation in the growing season the mean quadrant sum is as low as 4 which is not significant. As for the correlation with crop rainy days, all scatter diagrams for different week-intervals are almost the same with a range of quadrant sum from 7 to 9. That means the significant level is higher than 10%. This indicates that the crop rainy days is not as good a parameter as the amount of rainfall in the growing season. Other parameter, such as the total precipitation prior to the date of sowing, are nearly as good as crop rainy days. (See charts 46-53) The trends of all the scatter diagrams from chart 30 through 53 tend to show neither too dry nor too wet will aid the growth and development of peas. In other words, only

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* Azzi, Girolamo, AGRICULTURAL ECOLOGY. Constable & Company. 424 pp. 1956.

relatively moist conditions between the drought line and the flood line give optimal yields. Although these two lines were not drawn in each of the scatter diagrams, they can be visualized as lines parallel with the Y axix and intersecting the zero-yield departure line where the curve crosses the zero-yield departure line. The one to the left can be considered the drought line and the one to the right the flood line. The above statements hold true for the results of several investigators of peas (13, 28, etc.).

It is interesting to note the statement about peas made by Brown and Hutchison in their book called, "Vegetable Science" that "....rains following within a few minutes after the seed is planted often cause a marked reduction in germination. If rain does not follow for 36 hours after the seed is planted, the germination is rarely reduced to any serious extent." This statement has been checked in this paper as shown in table 9. Instead of the rate of germination, since no record was available, the yield was used as a measurement for the effect of rainfall within 36 hours. The result agrees for most of the cases with rainfall of more than 0.20" in a day. No conclusion can be made quantitatively as to how much reduction of yield will be caused by rain within 36 hours after sowing.

As for the thermal field, peas have long been recognized as a cool season crop and this is particularly true so far as the night temperature and soil temperature are concerned. The responses of canning peas to their surrounding temperature vary with the phases in their life cycle.

A summary of various authors' views (5, 9, 21, 35, 45, etc.) on the irritability of canning peas for thermal phases was illustrated in diagram 2, page 28. As previously stated, most workers in this country have applied the heat unit system to the yield and quality of canning peas. Despite some dissatisfaction, heat sum workers have established a good system for scheduling planting sequences as well as predicting yield and quality. This is about the only tool canners are using nowadays in this country.

The present paper, on the other hand, deals with (i) The summation of inter-diurnal temperature for the reproductive stage, as well as for the pre-reproductive stage. (ii) The summation of night temperature in the growing season above and below the lower and the upper limit of critical temperature respectively. (iii) The relative maximum nocturnal temperature im weekly interval. The result is that the summation of night temperature is exceedingly good with a quadrant sum of 20 or significant level less than 0.8%. Further study of night temperature alone should be encouraging and fruitful.

The relative Minimum weekly interval of relative humidity observed at noon has been testod in the present paper for the Alaska peas grown in Gillet and Bonduel, Wisconsin. An accumation of relative humidity versus weekly intervals for a normal yield of peas, as shown in chart 16, is almost a linear function. As previously explained relative humidity itself is a function of air temperature, air pressure, and the wet bulb temperature. Thus relative humidity represents a meteorological complex instead of a single factor.

For the photo field, the length of daylight, the percentage of possible sunshine, and the intensity of solar energy have been studied in the present paper. As for the length of day, Reath and Wittwer (34) have given experimental evidence (with respect to time of flowering, edible maturity, pod characteristics and vine heights) that Alaska peas are day-neutral, if night temperatures are maintained at 60°F but a long day plant if night temperatures are 50°F. In this connection, the photo-thermal unit (PTU), as defined in Eq. (12) page 73, has been adopted in this paper with the lowest threshold temperatures used is 39°F while the upper limit of the threshold temperature is 50°F for the first planting sequence and 45°F the last planting sequence. (For detail see page 73-76) The mean difference of the first and last planting sequence at Rosendale, Wisconsin is 20 days for a period of 9 years (1946-54). The average night temperatures near the harvest time are much higher for the July sequences than for the June days of the first planting sequence. Since only the minimum temperatures were available for the El Dorado station, a lower value for the upper limit threshold temperature was chosen, namely 45°F, for the last planting sequence. This value was obtained empirically and 45°F was found to be the best value. Chart 22a and 22b showed an excellent correlation with a quadrant sum of 16 or 0.8% significance level for both the first and the last planting sequence. Thus the findings of Reath and Wittwer agree well with the present work, though from a different approach.

The percentage of possible sunshine was studied and is illustrated in chart 24 as well as charts 59 through 67. The intensity of sunshine in langleys per day was tested in chart 58. In comparison of these two parameters the percentage of possible sunshine is found inferior to the intensity of sunshine. Even the summation of Energy degree unit, as defined in Eq (13), (illustrated in chart 57) is not as good as that for solar intensity alone. Thus the work on solar energy is promising and more research should be performed along this line.

In conclusion the authors wish to express recognition that this paper need many improvements, including;

(a) More crop data for the verification of various techniques established in this paper, particularly, experimental data with micro-environmental records;

(b) A more systemmatic way to coordinate all significant parameters for the growth and development of peas;

(c) Experimental field test data instead of greenhouse data on critical values.

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APPENDIX I

A SUMMARY OF HIGGINS'S METHOD
for
MAKING PHENOLOGICAL OBSERVATIONS

In the Laboratory of Climatology of the Johns Hopkins University, Seabrook, New Jersey, J. J. Higgins (19) has worked out instructions for making phenological observations of garden peas for selected volunteer observers to use. His work is summarized in the following items: (1) planting and labeling of peas, (2) phenological observations of peas. For details, the reader is suggested to refer to the original paper which includes a series of pictures showing each developing stage of peas and is cited at the end of the present paper.

(1) Planting and Labeling of peas:

A series of plantings of the same seeds is made throughout the entire growing seasons. After the first planting is started early in the spring, successive new plantings are made when the plants of the previous plantings have reached the fifth node.

The peas are planted about 1/2 inch deep and 1 - 1/2 to 2 inches apart in three parallel rows approximately 25 feet long with about 5 inches between rows. The middle row is the "test row" while the other rows are the "guard rows." A space 2 - 1/2 to 3 feet is left between successive plantings.

Ten plants are selected at random throughout the test row for observation. They are numbered consecutively down the row and marked with stakes. The plants are also marked and numbered. Inasmuch as the first nodes become indistinguishable as the plant mature, tags are attached to the plants at a definite node, as soon as it appears on the plants being observed. Nodes 5 and 10 are recommended for tagging.

(2) Phenological observations of peas:

The following six observations are to be made: (i) Planting data and time of day, (ii) emergence date, (iii) daily plant development, (iv) blossoming dates (v) date fruit matures, (vi) date growth stops.

(i) planting date and time of day: The peas should be planted as specified and the date and time of day recorded on the data sheet.

(ii) emergence date: After planting, peas germinate and emerge in 5 to 15 days depending on climatic conditions. Emergence date should be recorded when <u>shoots of the majority of seeds</u> are just visible above ground.

(iii) daily plant development: In order to record the development of the plant at the growing tip beyond the last recognizable node, ten stages have been identified. The stages may be indicated in tenths of a node by simple decimal figures, i.e., 0.1, 0.2, 0.3....1.0. Each complete node may be identicated with single figures, i.e. 1, 2, 3, ..., etc. Thus, 4.6 designates that plant has completed 4 nodes plus 0.6 of the development to the fifth node. These 10 stages are described as follows:

0.0 - This shows a completed node at the tip of a plant at which point occurs a mature leaf composed of 4 leaflets and a tendril. Between the lower pair of leaflets is an immature stem which supports a small tightly closed leaf bud.

0.1 - Bud begins to develop. It increases in size and the tendril unfolds from between the first pair of leaflets.

0.2 - Second pair of leaflets which are held closely together begins to show between the first pair.

0.3 - Second pair of leaflets and tendril elongate.

0.4 - Second pair of leaflets separate. Elongation of these and the tendril takes place.

0.5 - Second pair of separated leaflets and tendrils elongate.

0.6 - Second pair of leaflets begins to separate from the first pair.

0.7 - Second pair of leaflets becomes completely separated from the first pair.

0.8 - Second pair of leaflets begins to unfold and become separated further from the first pair. The first pair of leaflets remains tightly closed.

0.9 - Second pair of leaflets unfolds completely while the first pair begins to unfold.

1.0 - Both pairs of leaflets have fully expanded and between the first pair of leaflets is a tightly closed leaf bud. This a complete node.

Variations in the pattern of nodal development happen occasionally. In some instances the lower pair of leaflets opens before the upper pair. When this happens, the developing node is considered complete and counting in tenths is begun on the newly exposed node. In other instances, a leaf bud or immature leaf may protrude from between the lower pair of leaflets before they have opened. When this happens, the developing node is considered complete and counting in tenths is begun on the newly exposed node. When the lower pairs of leaflets finally opens and new node may have completed 5 tenth of its development. Any branching or new shoots should be ignored in all phenological observations.

(iv) blossoming dates: Blossoming occurs first at nodes 9 or 10 for Alaska peas and may occur at all successive nodes. All blossoms are tabulated on the day they appear and the nodal number is also recorded. For example--B-8 indicates a blossom on the eighth node on the day it is recorded.

(v) date fruit matures: The harvest date of an entire planting is the date fruit is mature.

(vi) date growth stops: It is recorded when five observed plants have stopped growing naturally--usually growth does not stop before nodes 12 to 15. A pea plant has a particular appearance at the terminal growing point when growing has stopped naturally. When the lower pair of leaflets of a newly formed leaf opens, a small stumpy structure appears where the leaf bud normally occurs. Since this structure ordinarily does not produce any new growths, it is not recorded. However, in some instances a dwarf leaf may appear which is also ignored. Thus, the last completed node is recorded on the data sheet when growth has stopped. When growth stops for a particular plant under observation due to injury or disease before node 12 is readhed.

A new plant in a similar stage of development should be substituted for it. A record of this should be made by marking "New Plant."

APPENDIX II

AN EMPIRICAL METHOD IN THE EVALUATION OF RUN-OFF

Data was obtained from La Crosse Experimental Stations, Soil and Water Conservation Research Branch, USDA Agricultural Research Service. An Observation of 16-year record (1939-1955, with 1944 excluded) was used to evaluate the regression lines of run-off vs. total amount of precipitation according to the duration of maximum rain-fall in: (a) 15-minute-interval and (b) 30-minute-interval. Run-off measurements were made at a farm containing Fayette Silt loan with a general slop varying from 3-8%. Amount of run-off in inches was estimated as an average of 3 plots at 72.6 feet in length. The system of cultivation on the farm was a rotation of barley, corn, oats, and hay. Barley was cultivated annually, up and down the slope, in one set of data. Oats and corn were in a 3-year rotation, contour cultivation,is in another set of data. In still another set of data, the rotation is done by successive cropping with corn, oats, hay and hay. Scatter-diagrams were made by throwing in all kinds of cultivation, as well as all different types of slopes (3-8%) together. Scales for intensity, as well as for the total amount of precipitation, are listed as below: (Appropriate scales were made as class interval in order to facilitate the analyses).

Scale for the Total Amount of Precipitation in 24-hour periods at 0.40"/Scale:

Scale Number	Range of Total Precip. (in inches)
T - 0	0.35 - 0.90
T - 1	0.91 - 1.30
T - 2	1.31 - 1.70
T - 3	1.71 - 2.10
T - 4	2.11 - 2.50
T - 5	2.51 - 2.90
T - 6	2.91 - 3.30
T - 7	3.31 - 3.70
T - 8	3.71 - 4.10
T - 9	4.11 - 4.50
T - 10	4.51 - 4.90
T - 11	4.91 - 5.30

Scale for Intensity of Precipitation at 15 and 30-minute Intervals of Maximum Intensity:

Scale Number	Range of Intensity (in inches)
I - 1	0.05 - 0.35
I - 2	0.36 - 0.66
I - 3	0.67 - 0.97
I - 4	0.98 - 1.28
I - 5	1.29 - 1.59
I - 6	1.60 - 1.90

Figure I

Run-off vs Total Precipitation for all Intensities at 15-Minute-Interval

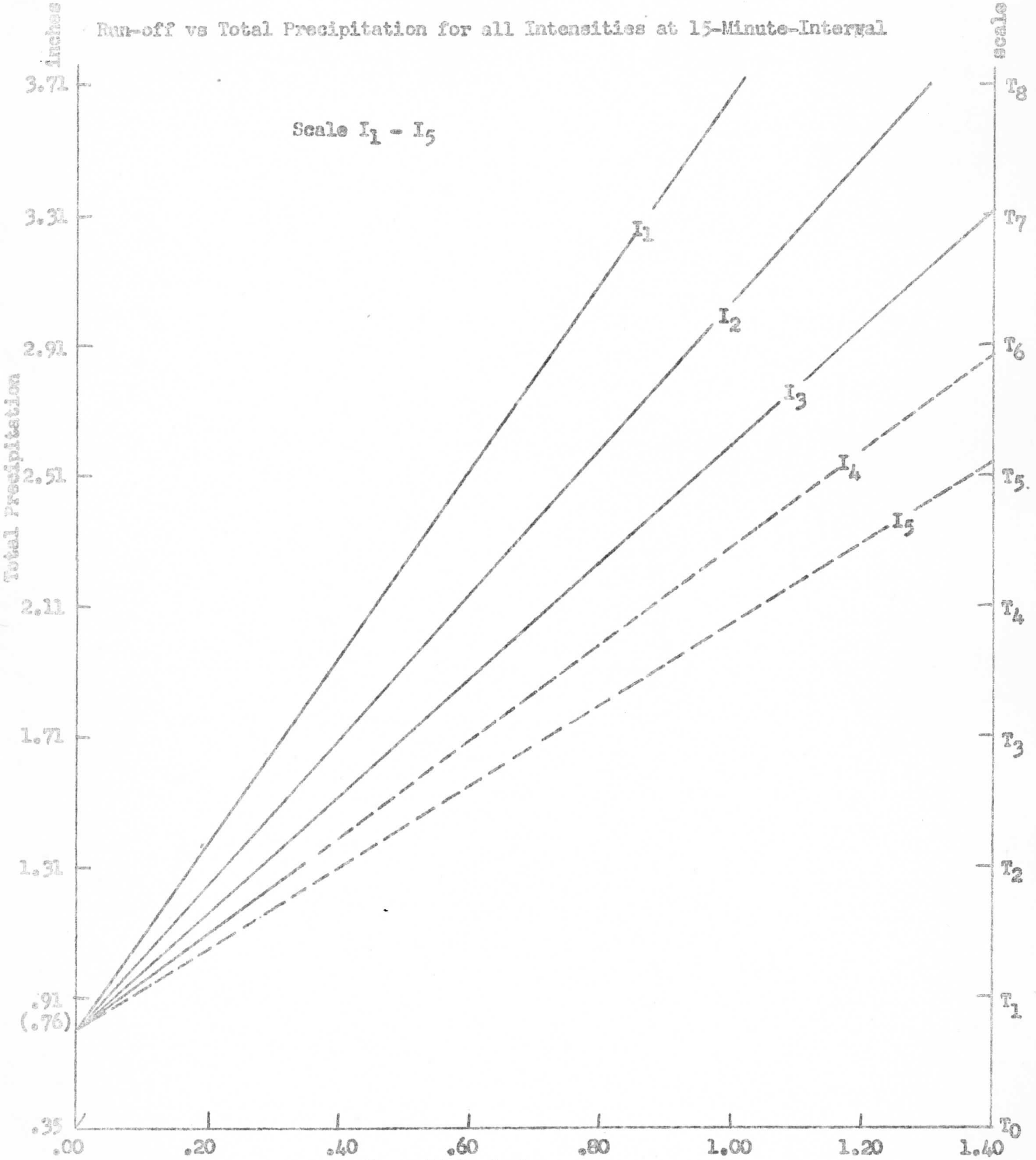
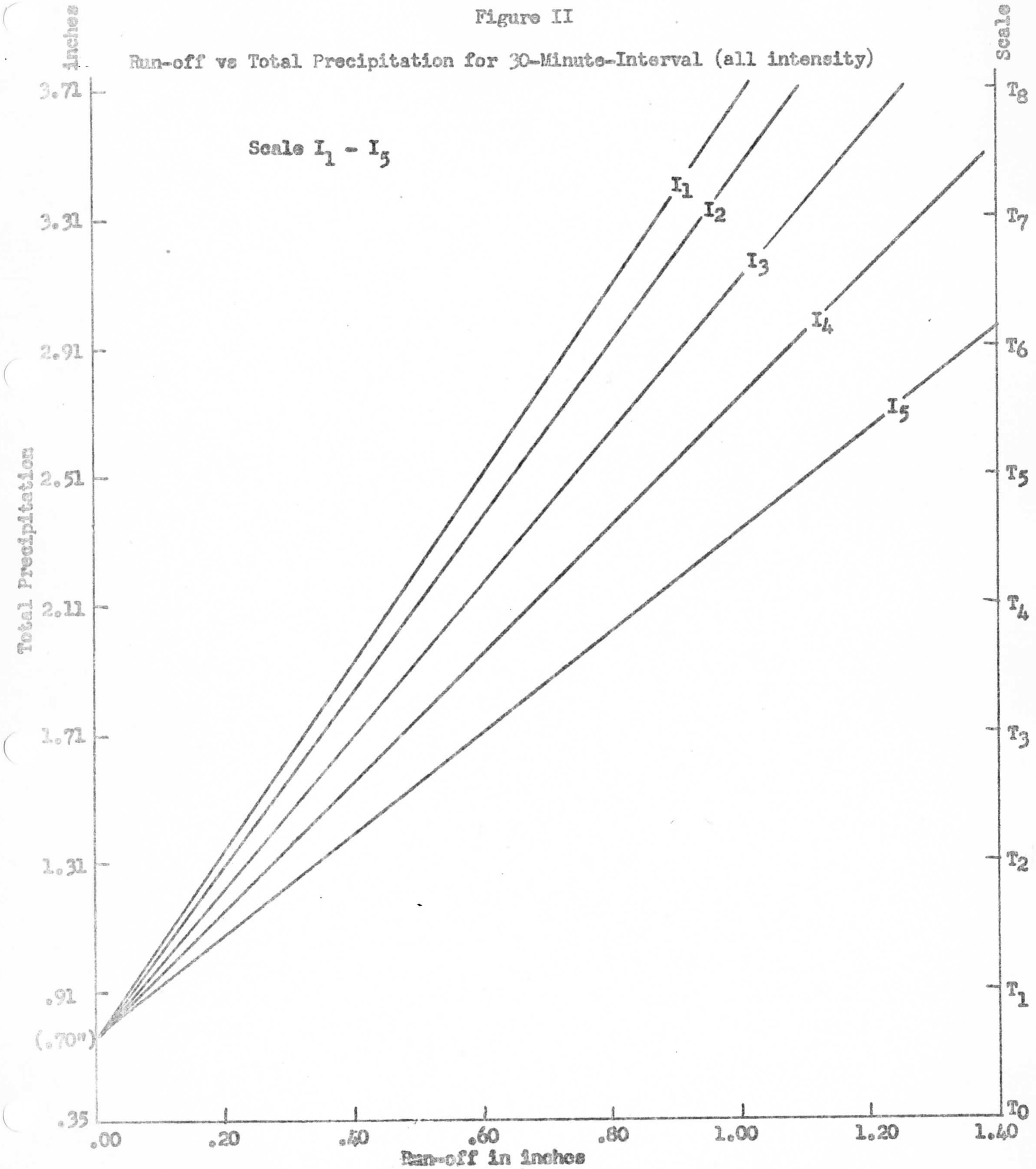


Figure II

Run-off vs Total Precipitation for 30-Minute-Interval (all intensity)



APPENDIX III

CRITERION FOR THE DEFINITION OF A CROP RAINY DAY

For the study of Phytoclimate a "Crop Rainy Day" should be established in view of the root-system, the crown (or the interception), and the types of plants with respect to the amount, the duration, and the intensity of rainfall. General official definition of a "Rainy Day" is too limited and does not fit into the picture. It cannot be considered. The U.S. Weather Bureau as well as most English Speaking Meteorological Offices define a "Rainy Day" as "A day with 0.01 inch or more of precipitation." Equally the popular conception of a rainy day which is "A day with more or less continuous rain", should also be neglected. It is quite difficult to define a "Crop rainy day" because of a number of biotic, edaphic, and meteorological complex factors are involved. Yet, limits can be developed for the definition by adjusting to average conditions.

The definition of a "Crop rainy day" R_c adopted here is the minimum effective quantity of rainfall available for the use of a plant. R_c can be determined by the total amount of rainfall P_T in 24 hours, and its duration P_D accorbing to whether it is an isolateb rainy day or a contiguous rainy day.

A. Isolate Crop Rainy Day:

a. An isolated rainy day is a day with an effective amount of precipitation or more, and is separated from the rest of the rainy days, both before and after, by one or more days.

b. Parameter for the evaluation of an isolated crop rainy day, within 24 hours, depends upon the total amount of precipitation:

(i) $P_T \geq .20"$ counts as 1 crop rainy day (or 1 R_c);
(ii) $.15" \leq P_T \leq .20"$, and the separation from a rainy day is not more than 2 fair days, then counts as $1R_c$, if it does not count otherwise.
(iii) $P_T \leq .15"$ do not count.

B. Contiguous Crop Rainy Days:

a. $P_T \geq .10"$ count as 1 R_c;

b. $.05" \leq P_T \leq .10"$ and the total amount for the two successive days precipitation is more than 0.30", then count these 2 days as 2 R_c, provided the greater total falls on the first day. These two days will count only as 1 R_c when the smaller total falls on the first day. (Here it is assumed that there is no rainy day previous to this lesser one.)

c. $P_T \leq .05"$ do not count.

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