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Factors influencing the need for supplemental irrigation in Massachusetts.

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FACTORS INFLUENCING THE NEED FOR SUPPLEMENTAL IRRIGATION IN MASSACHUSETTS

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Part I

INTRODUCTION

Responses of plants to soil-moisture conditions are generally well known to farmers in irrigated areas of the world. The plants show various symptoms under dry soil conditions. A rapid recovery and resumption of growth follow the application of water after a dry spell.

The concept of the soil as a reservoir for water is probably more clearly recognized in irrigated sections than in areas having frequent summer rains because of the necessity of replenishing the supply at intervals. In areas where rainfall occurs during the growing season, this concept is perhaps not so widely recognized because the reservoir is replenished by rain and is generally filled or partly so, except when long rainless periods occur.

The soil reservoir is fixed within the upper and lower limits of the soil moisture constants which are of practical importance for consideration in connection with plant growth. The upper limit is the field capacity while the lower is the permanent wilting percentage. The study of these factors which affect the soil-moisture reservoir is valuable in every area to determine whether it is advisable to supplement the natural rainfall through irrigation.

Objective:

Factors influencing the need of crop plants for supplemental water through irrigation can be grouped under three general headings of climate, soil, and cultural practices. Included under climate are rainfall both total and seasonal distribution and air temperature. Air temperature is important because it influences the rate of water loss through evaporation. Soil factors include soil texture, structure, organic matter content, moisture equivalent value and permanent wilting percentage. Cultural management practices are largely of indirect importance that the nature of the crop grown and the manner in which it is cultivated has a profound effect on many of the soil factors listed. For example, the structure and the organic matter content of a soil will be improved under a grass sod but under continuous cultivation soil structure will deteriorate and the organic matter content will decrease.

The principal objective of this investigation was to determine the relative importance of each of the above mentioned factors in influencing the need for supplemental irrigation for field crops in Massachusetts. Once the important factors have been determined, the problem of satisfactorily meeting the moisture requirement of our various field crops will be much better defined. If farmers over the state can be shown the relative frequency of serious drought periods in their particular areas and the number of times during the growing season their crops would materially benefit from irrigation, they would be in a better position to evaluate the practicability and profitableness of large investments in irrigation equipment.

Review of Literature

Smith[31] in1915 reported that onion growers have been practicing irrigation in Massachusetts to control the supply of moisture and to avoid the blowing of seeds and fertilizers as well as to check damage from thrips.

Wells[41] 1938 reported that stabilization of agriculture in many parts of the United States would be aided greatly by supplementing the natural precipitation during the dry periods in normally humid areas.

Roe[22] 1950 stated that supplemental irrigation in the humid regions is needed because periods of intense drought occur during the critical growing or maturing periods with disastrous results.

Sanderson[24] 1950 reporting from Southern Ontario, Canada, states that the deficiency of water causes the failure of early fruits and reduced yields of hay and grains, and deficiency at maturity causes poor quality and reduced yield in vegetables, late fruits and tobacco.

Thornthwaite[32,33,34,35] has carried on intensive studies on the loss of water from free water surfaces, soil surfaces and transpired water from plants. These water losses represent the transport of water from the earth back to the atmosphere-the reverse of precipitation. He has combined the losses of water from the soil and the plant into one expression - evapotranspiration. Evapotranspiration losses are primarily a function of air temperatures and day length. Thornthwaite has devised a formula for computing what he has called "potential evapotranspiration values "which can be expressed on a daily, weekly or monthly basis. These values represent the maximum losses of water from the soil and the plant to the atmosphere when soil moisture content is at field capacity, i.e., the water reserves in the soil are adequate.

When Thornthwaite's evapotranspiration values are used in comparison with precipitation data, it is possible to determine with relatively high degree of accuracy how closely the potential evapotranspiration losses are met by the rainfall. Not only can periods of moisture deficits be determined but the magnitude of these deficiencies can be measured as well.

Sanderson[25] has used Thornthwaite's procedure in studying the effect of climate on soil plant moisture relationships in widely separated parts of Canada. After three years of study she concluded that Thornthwaite's methods were applicable over a wide range of climatic conditions.

Musgrave[19] reported that the need of water can be predicted by a series of evapotranspiration curves and the application of irrigation is necessary before the plants suffer from lack of moisture.

Shaw[26] stated that rainfall in Massachusetts has been below normal during the growing season in practically all areas of the state and that periods of drought are common.

Material and Methods

I. Soil Studies.

Soil samples were collected from five locations within

Massachusetts from Williamstown (representing the western uplands); from Northampton (representing alluvial soil of the Connecticut River Valley); from the University Farm in Amherst (representing aeolian deposits of the Connecticut Valley and eastern uplands); from Bridgewater and Marion (representing light sandy soils of the southeastern section of Massachusetts). At each location, with the exception of Northampton, one series of soil samples was taken from an area which has been under continuous cultivation for many years, while another series was taken fron an adjoining area which had been under continuous grass for many years.

The analytical methods which have been used to study the characteristics of the above mentioned soil samples are briefly described as follows.

A. Soil Texture.

The texture of a soil is important because there is a direct relationship between texture or particle size and the moisture holding capacity. Soils with a high clay content have a much greater water-holding capacity than those with a low clay content. The texture of a soil is determined by means of a careful mechanical analysis(1) the fractional separation of soil particles on the basos of particle size. This analysis gives the relative proportion of sand, silt and clay which a soil may have which in turn determines the soil class to which it belongs, i.e., sandy loam, loamy sand, silt loam, clay loam, etc.

The procedure used involved the treatment of the soil with hydrogen peroxide to destroy the organic matter followed by separation of the mineral fraction into appropriate size classes. Graduated sieves are used to separate coarser fractions while the finer material is fractionated by the evaporation of pipetted samples taken at definite time intervals from a suspension of the soil in water.

B. Soil Structure.

Soil structure relates to the aggregation of individual particles into aggregates or granules. The ease with which water enters a soil and percolates down through it, and also the moisture holding capacity is closely related to soil structure. It was important to learn whether or not soil structure is an important factor in soil moisture relationships with some of the regional soils of Massachusetts. Is the structure so poor that any considerable portion of the rainfall is lost because it runs off the surface?

Structure was indirectly determined by means of the core percolation method[36]. Soil cores 3 inches in diameter and 3 inches deep were taken by means of a specially designhed sampling device. By determining the rate at which water would percolate down through these cores after they had been completely saturated with water, it was possible to determine whether or not a soil would absorb all or most of the water from a normal rain storm. Since the variation between different samples of the same soil was great, at least 10 cores were taken from each sampling area. Cores with what appeared to have abnormal percolation values were broken apart to determine whether a stone, worm hole or root channel was the cause. In instances where any of those were found, the determinations for the samples were discarded.

After the percolation rates were determined the cores were dried and used for volume weight or Porosity determination.

C. Soil Organic Matter Content

It was important to learn to what extent, if any, the organic matter content of a soil influenced its water-holding capacity and also other factors associated with soil moisture relationships. The organic matter content of each soil sample was determined by means of Wakely and Black's titration method [20]. This method involves the oxidation of organic carbon with chromic acid. The amount of carbon (organic matter) is determined by ascertaining the quantity of unused or non-reduced chromic acid left in a solution of known concentration. After a 30 minutes digestion the unused chromic acid is then determined by titrating the solution with a known concentration of ferrous ammonium sulfate with diphenylamine as an indicator.

D. Moisture Equivalent.

The moisture equivalent of a soil is commonly defined as the amount of moisture held by a layer of soil one centimeter thick which has been saturated and subjected to a centrifugal of 1000 times gravity. In other words the moisture equivalent value represents the relative storage or reservoir capacity of a soil for water. Each soil was handled as follows: Duplicate samples were placed on opposite sides of the centrifuge head of a machine designed for this purpose and centrifuged for 40 minutes at 2440 r.p.m. After centrifugation the cups were removed and the moisture percentage was calculated on the basis of oven-dry weight when dried at 105°C.

E. Permanent Wilting Percentage

The permanent wilting percentage refers to the percentage of water in a soil at which permanent wilting of a plant occurs. The permanent wilting percentage of each soil was determined by the procedure developed by Veihmeyer and Hendrickson[10]. About 500 grams of soil were placed in moisture-proof pint containers and planted with a mixture of oats and sunflowere in the green house. When the sunflower plant had developed three sets of leaves, water was added and the soil surface of each culture was sealed off by means of a layer of paraffin. When the sunflower plants began to wilt they were placed in a moist, dark chanber. If they did not recover, the soil was removed and its moisture content determined. If the plant recovered the culture was returned to the greenhouse bench and left until wilting reoccurred.

F. Moisture Extraction Curve.

The moisture extraction curve was also determined by the method of Veihmeyer and Hendrickson. About 400 grams of soil were placed in a metal container. One sunflower was

was planted per culture. When the sunflower had developed the third set of leaves, the soil in each culture was brought up to field capacity and the surface sealed from the air by means of a paraffin layer. Weights were taken daily to measure the rate of moisture loss. A moisture extraction curve was determined for all soils studied.

G. Water Requirement

A green house experiment was conducted to learn whether or not relationships exist between different soils or soil types and water requirement (water necessary to produce a unit of dry weight of a given crop). In the experiment corn was used as the test crop. Gallon pots containing seven pounds of soil were planted with corn which was thinned to one plant per pot. Klages[13] reported that variations in transpiration coefficient of plants grown on different soil types were due to fertility differences rather than to the influence of soil type. In this experiment lime and fertilizer were added and nutrients were added by watering with Hoagland solution[11] three times to eliminate differences in the natural fertility levels. The experiment was continued for twelve weeks until the plant had reached the tasseling stage. The water required to produce one pound of dry matter in the stalk, leaves, and roots was then calulated.

II. Climatological Studies.

All weather data were taken from the reports of the United States Weather Bureau. The three stations selected were Williamstown, Amherst and Taunton. For Amherst a 63-year record was available; for Williamstown, a 60-year record; and for Taunton, a 23-year record.

Thornthwaite's methods of analysis were followed in evaluating the influence of air temperature on evaporation losses. These losses are expressed as evapotranspiration values. A detailed explanation of the procedure followed, will be given along with the results obtained in the next section.

Part II

PRESENTATION OF RESULTS AND DISCUSSION

I. Soil Studies

Results from the studies made on the soil samples collected from five different locations in the state are presented in the following tables and discussion.

A. Soil texture

A complete mechanical analysis of all samples included in this study are shown in Table 1. and Figure 1.

Table 1. Mechanical analysis of soil samples taken from five locations in Massachusetts

Fraction	Location of area sampled				
	Mt. Hope Farm	Northampton Meadow	University Farm	Sievers Farm	Hiller's Farm
	%	%	%	%	%
Very coarse sand 2.1 mm	2.3	2.1	4.5	.9	7.1
Coarse sand 1-½ mm	2.9	.4	6.6	4.0	27.8
Medium sand .5-.25 mm	1.9	.3	3.3	5.7	19.6
Fine sand .25-0.1 mm	6.1	8.8	8.4	28.6	20.9
Very fine sand .10-.05	9.6	26	24.8	25.1	2.4
Silt .05-.002	58.4	55.8	45.4	29.9	19.7
Clay below .002	18.8	6.6	7.0	5.8	3.5

The results given in Table 1. show wide differences in texture in soil samples from the five different locations.

The Mt. Hope Farm soil (Williamstown) has a high content of clay and silt and low content of sand. The samples from Northampton Meadows ahd the University Farm have a very high proportion of very fine sand and silt but a low content of clay and the coarser sand fraction. The Sievers Farm (Bridgewater) and Hiller Farm (Marion) soils are coarse textured, the Marion soil being the coarser of the two. The clay content is very low. The silt content is relatively low and its proportion of coarse sand is relatively high compared with the Connecticut Valley samples. Taking the state as a whole, as one proceeds from west to east, the clay content of most types decreases and the total sand content as well as the size of the sand particles increases.

It will be shown that these differences in soil texture have a very important influence on the moisture characteristics of these soils. Differences in soil texture are more closely related to the irrigation requirement for crops than any other soil factor.

B. Permeability studies.

It is important to know what proportion of the water which fall on a soil as rain will penetrate into the soil and also the rate at which water penetration takes place. It was necessary to learn whether or not an appreciable quantity of water would be lost as runoff from a heavy rain, simply because the infiltration rate was too low.

Uhland and O'Neal (36) have classified soil permeability from a nation-wide standpoint. They proposed a system of seven permeability class ranging from "very slow" to "very rapid. This classification is shown in Table 2.

Table 2. Permeability classes and index and the percolation rate in inches per hour

Permeability class	Permeability Index	Percolation rate in inches per hr. under ½-inch head of water
Very slow	1	less than 0.05
Slow	2	0.05 to 0.2
Moderately slow	3	0.2 to 0.8
Moderate	4	0.8 to 2.5
Moderately rapid	5	2.5 to 5.0
Rapid	6	5.0 to 10.0
Very rapid	7	More than 10.0

Permeability differences were found in the infiltration rates for the five soils studied. The results are shown in Table 3.

Table 3. The percolation rate per hour and the organic matter content in five soils

Location of area sampled	Organic Matter percent	Percolation perhour ininches	Porosity %
Williamstown cultivated	1.84	2.8	46
Williamstown under grass	2.02	3.8	49
Northampton cultivated	0.74	0.5	42
Northampton under grass	.58	0.6	48
Amherst cultivated	1.03	0.9	42
Amherst under grass	1.15	0.8	48
Bridgewater cultivated	1.69	1.9	42
Bridgewater under grass	2.29	8.2	48
Marion cultivated	.87	3.3	44
Marion under grass	1.04	7.0	45

The heavy loam soil from Mt. Hope Farm had a permeability index of 5 or a moderately rapid rate. This means that this soil had been well managed and that the structure was excellent. The infiltration rate for the soil under sod was 35 per cent greater than for cultivated soil However, the infiltration capacity was high enough to permit the penetration of practically all the water from normal rainfall. Of course, on steep slopes and in cases of very heavy rain showers, runoff losses would be appreciable.

The percolation rates on the Northampton meadow soils were moderately slow with a permeability index of 3. These soils have been intensively cultivated for many years. As seen in Table 3, the organic matter content is very low, both in the cultivated soil and the soil under sod. The low organic matter content of the soil under sod is explained by the fact that the sod was only two years old. This would indicate that the increase of organic matter content in a soil under permanent sod increases very slowly.

The Northampton meadow soils are alluvial soils, built on the flood plain of the Connecticut River. As shown in Table 1, they are very high in the very fine sand and silt fraction but quite low in clay and coarse sand. Since both the clay content and the organic matter content is low, there is very little material in the soil to build the fine sand and silt particles into aggregates. The structure of these soils is therefore very poor. Farmers who have used irrigation water on potatoes on these soils have observed the slow infiltration rates of these soils for a number of years. They have observed how water will remain in the furrows between the potato rows for hours and sometimes for a day or two after a heavy rain shower. This is particularly true for rows through which the spray machinery passes. Fortunately the land is quite level so that runoff losses are reduced to a minimum notwithstanding its slow rate of infiltration.

The moisture characteristics of these soils could be greatly improved by modifying the current cultural practices. Just the growing of a sod for two years improved the infiltration rate appreciably but if the sod were plowed and allowed to decompose, a much greater improvement could be expected. If a grass sod could be rotated with cultivated crops one year out of three or four, a tremendous improvement in soil structure would undoubtedly result with a corresponding betterment of soil-water relationships.

The Experiment Station Farm soils were similar to Northampton meadow soils. The infiltration rate was slightly better with a permeability index of 4 instead of 3. The organic matter content was higher but still at a relatively low level. Since these two soils are quite similar in texture, organic matter, and porosity, to the Northampton meadow soils, all that has been said with respect to the cultural management of soils would apply also to the Experiment Station plot soils. Even the experimental plots could benefit from changes in cultural management practices as far as soil-water relationships are concerned.

The Bridgewater and Marion soils have a high proportion of coarse sand particles. Therefore, even the soils under continuous cultivation have a moderate to moderately high infiltration rate. There is little danger of excessive run-off with either of these soils. The improvement in infiltration rates for the soils under grass is particularly noticeable. The permanent grass sod in each case was many years old, thereby giving it sufficient time to effect noticeable improvement in organic matter content, structure, porosity, and infiltration rates. A crop rotation of sod would help greatly to maintain improved soil-water relationships also.

The beneficial effects of an old permanent grass sod were observed in every instance. The rate of imporvement under a permanent grass sod is evidently quite slow since a two-year old sod showed only moderate improvement in such soil properties as infiltration rate, porosity, and organic matter content. If a grass sod is allowed to develop for a year or two and then plowed under so that large masses of raw organic matter can decompose in a short period of time, it is quite likely that the same degree of improvement in these soil properties would be brought about as would eventually result from leaving the soil under a permanent sod for a long period of time. Russell[23] has shown that the beneficial effects of organic matter come from its decomposition in the soil and at a fast rate rather than from its presence in the soil as a raw undecomposed material.

All the effects of a high water infiltration rate in a soil are not favorable. The high infiltration rates of the light sandy soils would markedly increase the leaching losses of plant nutrients, from manures or fertilizers compared to lower infiltration rates for the heavier loam soils.

C. Moisture Equivalent Determination

Plants need soil moisture in all the stages of growth, from germination to maturity. When water is applied to a soil, the pore spaces are almost filled for a short time to the depth wetted. If drainage takes place, the gravitational water will move downward and the amount of water held by the soil after draining is called the field capacity. It is from this source that plants get most of their water. Many investigators[38] have attempted to determine the field capacity by means of a laboratory procedure. The field capacity is frequently expressed in terms of the moisture equivalent.

An empirical method has been devised for measuring what is called the "moisture equivalent value" of a soil. Table 4 shows the results obtained for the moisture equivalent values for soils under investigation.

The cultivated Williamstown soils show the highest moisture equivalent value of 24.4 per cent followed in turn by the Bridgewater soil with 17.4 per cent, the Northampton soil with 16.7 per cent, the Amherst soil with 15.4 per cent, and the

Marion soil with 9.2 per cent

The difference can be explained by the textural differences between the five soils as revealed by the mechanical analysis. In the five textured soils such as Williamstown which has large portions of silt and clay, the soil particles are very small and hold much more water against the centrifugal force than do the Marion soils which have a large percentage of sand.

It is interesting to note that in each case, moisture equivalent was greater for the soil which was under grass than for the cultivated soil. However, the differences are not large and it is obvious that increasing the organic matter content of a soil does not compensate for textural differences. It is not possible to increase the moisture equivalent value of a sandy soil to that of a loamy soil simply by increasing the organic matter content by cultural means.

These differences in soil moisture equivalent values which in turn are closely associated with textural differences of the soils are very closely related to irrigation requirements. Soils with low moisture equivalent value need more frequent applications of water than soils with high moisture equivalent values for the same crop.

Moisture equivalent values have been criticized by some investigators. Smith[31] pointed out that the moisture equivalent values may not agree with the field capacity value of the soil in place in the field. Veihmeyer[38] suggested that the moisture equivalent value is close to the field capacity when the value is over 12 to 14 per cent in five textured soils. It is safe to say that this value for Williamstown, Amherst, and Northampton soils can be taken to represent rather accurately the field capacity. In the Marion soil, the value was less than 12 per cent and since the soil is sandy with 7 per cent of coarse sand, the moisture equivalent is undoubtedly less than the field capacity.

D. Permanent Wilting Percentage

Plants use the soil moisture in the root zone until the moisture is reduced to a given degree of dryness. Soil moisture is held so tightly by the soil particles when the moisture content is in the range of wilting that plant roots cannot absorb water rapidly enough to compensate for the water lost by transpiration. Therefore, the plant wilts. The plant can survive for some time but if the water is not applied to the soil relatively soon, the plant dies.

The moisture content of a soil at which the plant ceases to grow and loses its vigor and turgidity has been the subject of a great deal of research work. The most important early work on the availability of water to plant is that of Briggs and Shantz[2,3,4,] who studied 20 soils and made some 1300 trials. They concluded that on a given soil all plants can reduce the moisture in the soil at the time plants wilt permanently, therefore, is an important soil property. Caldwell[7], and Shive and Livingston[27] disagreed with the Briggs and Shantz concepts and stated that permanent wilting was determined by climatic and not only by soil moisture conditions. Veihmeyer and Hendrickson[10] found that the residual soil-moisture content at permanent wilting is remarkably constant for a given soil under any evaporating conditions likely to exist with plants growing in the field. Furr and Reeve[9] reported similar results and they use the term permanent wilting point to indicate soil moisture content at the time the basal leaves of sunflowers wilt permanently. Kramer[14,15] stated that permanent wilting does not mark any definite limit in the movement of water from soil to plant, it simply marks the moisture content at which absorption becomes too slow to replace the water lost by transpiration.

The permanent wilting percentage in the five Massachusetts soils (Table 4, shows a variation between the different soil types within a range of 5 per cent. The permanent wilting percentage of Williamstown, Northampton meadows, College Farm, Bridgewater and Marion soils under cultivation are 6.3%, 4.3%, 4.2%, 4.7%, 1.9% respectively and for the same soils under grass, 8.8%, 4.3%, 5.1%, 6.4%, and 3.8% in the same order.

The moisture equivalent to permanent wilting percentage ratios for these soils ranged from 2.6 to 4.8. Veihmeyer and Hendrickson[37] investigated 60 soils and found the ratio to range from 1.4 to 3.8. Duncan[8] found that the ratio of moisture equivalent to permanent wilting percentage ranged from 1.57 to 5.65, varying with soil type and horizon.

The upper limit for water to be easily absorbed is the field capacity when the soil contains ample water and air for plant growth. Veihmeyer(10) has used the term "readily available" water to mean that water between the field capacity and the permanent wilting percentage. The readily available water in the present investigation for Massachusetts soils is shown in Table 4. As would be expected, these values for the five soils follow in the same order as their moisture equivalent value.

E. Soil Moisture Extraction Determination

The results of the soil moisture extraction determinations are given in Table 5 and Figure 1. The extraction curves show a relative steep curve for the soils with a high moisture equivalent value such as the Williamstown soils and a flat curve for the soils with a low moisture equivalent value such as Marion soils. The slopes of the curves for the Amherst, Northampton, and Bridgewater soils are intermediate.

In the beginning the rate of water extraction was high and most of the available water was lost within a few days. After this the rate of loss was greatly reduced until the permanent wilting percentage was reached. The second period of water loss was reached much sooner with the Marion soil than with the Williamstown soil. The other soils were intermediate.

The results indicate that light soils such as the Marion soils require more frequent applications of water than heavy

Table 4. Moisture Equivalent and Permanent Wilting Percentage for Five Soils from Five Localities in Massachusetts

Locality		M.E. Moisture Equivalent	% Increase under grass	P.W.P.	% Increase under grass	M.E./P.W.P.	Available Moisture %	% Available Moisture to M.E.
Williamstown	Cultivated	24.43	-	6.3	-	2.57	18.13	74.2
	Grass	24.83	1.6	8.81	39.8	2.81	16.02	65.5
Northampton	Cultivated	16.64	-	4.24	-	3.91	12.39	74.5
	Grass	17.08	2.6	4.29	0.94	3.08	12.79	74.9
Amherst	Cultivated	15.44	-	4.16	-	3.71	11.28	73.0
	Grass	16.87	9.3	5.13	23.31	3.29	11.74	69.6
Bridgewater	Cultivated	17.41	-	5.65	-	3.08	11.76	67.5
	Grass	19.01	9.2	6.44	13.9	2.92	12.57	66.1
Marion	Cultivated	9.2	-	1.89	-	4.86	7.29	79.4
	Grass	10.9	18.7	3.76	98.9	3.44	7.14	65.5

soils such as Williamstown soil to maintain satisfactory moisture levels. These curves show also why it is important to supply supplemental water to the soil some days before the permanent wilting percentage is reached. Plants will survive for several days at low moisture levels in the soil but their rate of growth is far below optimum.

Table V Water Loss in Relation with Time of Five Soils in Mass.

Location of area sampled	Time per Day							
	1	3	5	7	9	11	13	15
Williamstown Cultivated	%24	19.74	15.76	12.16	8.70	5.9	4.85	
Grass	25	19.80	14.72	10.72	7.76	5.9	4.86	
Northampton Cultivated	%17	13	9.31	6.35	5.08	3.91	3.04	2.64
Grass	%17	8.16	8.24	5.72	4.48	3.88		
Amherst Cultivated	%16	13.24	10.50	7.88	5.05	4.6	3.57	
Grass	%17	12.78	9.68	7.68	5.8	4.48	3.17	
Marion (H) Cultivated	%10.49	7.44	4.88	4.15	3.52	2.93		
Grass	%11	8.14	6.7	5.32	5.04	4.25	3.89	
Bridgewater Cultivated (S)	%18	12.14	9.32	8.20	7.56	7.10	6.66	
Grass	%20	14.93	10.88	9.01	8.23	7.50	6.83	

F. Water Requirement

Living plants contain a large percentage of water. This is particularly true in the case of fresh vegetables, fruits, and forage crops. A continuous need of water supply should be present to frunish the plants with water in all stages of growth. The plant roots absorb the water from the soil. The water takes part in all the metabolic processes by which the plant can grow from the seed germination to maturity. A great quanity of water passes through the plant and is lost in the atmosphere for every pound of dry matter produced. The water required by the corn plant to produce a pound of dry matter when grown in the five soils investigated is shown in Table 6.

Table 6. Amount of water required by corn to produce one pound of dry matter when grown on five different soils

Source of Soil		Yields of dry matter produced	Water evaporated from the bare soil (check)	Amount of Water transpired	Water Required dry matter
		lbs.	lbs.	lbs.	lbs.
Williamstown-	cultivated	.0409	10.17	14.00	342
	under grass	.0614	10.71	17.89	291
Northampton -	cultivated	.0614	12.5	18.75	305
	under grass	.0724	11.28	20.87	268
Amherst	cultivated	.0448	10.4	14.1	314
	under grass	.0417	11.20	14.9	356
Bridgewater	cultivated	.0434	9.70	13.60	312
	under grass	.0432	9.19	14.62	330
Marion	cultivated	.0447	8.42	11.91	266
	under grass	.0469	9.42	12.83	274

Although there is a difference in the quantity of water needed by the different soils there is no consistent difference or trend either between different soils or cultural treatments. As much water was lost by evaporation in the bare soil (check) by this process as was transpired by the corn plant.

II. Climatological Studies

A. Precipitation

The amount of rainfall and its distribution are of primary importance in crop production.

The mean monthly precipitation for 63 years at Amherst is shown in Table 7 and Table (1,2,3,) in the appendix. The Table shows an even distribution of rainfall throughout the years. This would give a monthly mean of 3.62 inches, if the annual rain was equally distributed over the year.

In Williamstown and Taunton the monthly mean precipitation (Table 8,9) also shows an even distribution.

A study of the actual monthly precipitation for individual years, however, shows a wide variation from the monthly mean, especially during the growing season. This condition is shown in Table 10.

Table 10. Monthly Extremes in Rainfall for the Three Summer Months at Three Locations in Mass.

Month	Minimum and Maximum Precipitation		
	Amherst Inches	Williamstown Inches	Taunton Inches
June	0.76 - 9.68	0.87 - 9.07	.92 - 8.89
July	0.70 -14.51	1.23 -10.82	1.01 - 6.17
August	0.31 - 8.40	1.12 - 8.51	0.97 -10.66

Table 7. Annual Monthly Mean Precipitation and Monthly Precipitation in Dry Years at Amherst, Williamstown and Taunton

Month	Amherst 63 years Av.	Amherst Wet 1903	Amherst Dry 1947	Williamstown 80 years Av.	Williamstown Wet 1938	Williamstown Dry 1929	Taunton 23 years Av.	Taunton Wet 1931	Taunton Dry 1944
	in.	in.	in.	in.	in.	in.	in.	in.	in.
January	3.48	3.28	3.37	2.70	3.49	3.34	3.52	3.13	1.91
February	3.09	4.27	1.96	2.43	2.03	3.28	2.75	1.77	1.69
March	3.87	6.40	3.29	2.97	1.68	4.63	3.68	5.16	3.97
April	3.37	2.30	4.59	2.86	3.19	5.96	3.86	2.84	3.90
May	3.70	.48	4.63	3.06	2.69	3.32	3.44	5.78	0.42
June	3.76	7.79	3.22	3.56	6.59	3.74	3.73	7.15	2.94
July	4.16	4.64	2.73	4.11	7.20	1.33	3.52	4.73	1.84
August	3.88	4.92	1.69	3.85	4.03	1.12	3.98	5.51	1.14
September	4.02	1.66	2.84	3.59	9.85	1.69	3.63	1.75	9.29
October	3.13	2.72	2.04	2.90	1.43	1.53	4.06	3.81	2.90
November	3.62	2.04	5.63	2.99	3.22	2.29	5.26	1.01	7.13
December	3.38	3.95	2.33	2.85	3.08	2.73	3.45	3.96	2.72
Totals	43.43	44.45	38.42	45.50	47.48	35.28	43.88	46.60	39.85

There is also a wide variation from the annual mean precipitation for individual years. The annual precipitati n for 63 years at Amherst, 60 years at Williamstown and 23 years at Taunton is shown in Tables (7,8,9) at Amherst ranged from 30.7 inches to 59.0 inches. At Williamstown it ranged from 26.2 to 48.1 inches, and at Taunton from 33.8 to 53.3 inches.

The difference in precipitation between the hot dry year selected with special consideration to the growing season, in comparison with a wet year selected by the same standard, indicates that additional water is needed in dry years, especially during the months of June, July and August.

Variations in Precipitation between a Selected Wet Year and Selected Dry Year for the months of June, July and August

Month	Amherst mean of 60 years	Amherst Wet 1903	Amherst Dry 1947	Williamstown mean of 60 years	Williamstown Wet 1938	Williamstown Dry 1929	Taunton Mean 23 yrs.	Taunton Wet 1931	Taunton Dry 1944
	in.	in.	in.	in.	in.	in.	in.	in.	in.
June	3.75	7.79	3.22	3.55	5.69	3.74	3.75	7.15	2.94
July	4.02	4.64	2.73	4.11	7.20	1.33	3.52	4.73	1.84
August	3.88	4.92	1.69	3.86	4.03	1.12	3.98	5.51	1.14
Totals	11.65	17.35	7.64	11.51	16.92	6.30	11.25	17.39	5.92

The table indicates clearly that there is a wide difference between total mean rainfall for these summer months during a selected dry year. If the rainfall pattern each year approximated yearly monthly means, the need for supplemental irrigation would be limited but it is obvious from the above data that such is decidedly not the case.

B. Air Temperature

The water available to plants from the rainfall is influenced by differences in air temperature. Air temperature is important because water losses both by transpiration and evaporation are strongly affected by it. High temperatures accelerate these losses, low temperatures retard them. In places where evaporation and transpiration are high, a given amount of rainfall is less effective in plant growth than in places where the evaporation and transpiration are less. Thornthwaite[33] has attempted to combine the losses from transpiration and evaporation into one value or expression which he has called "evapotranspiration". By this means he measured the influence of air temperature. Using Thornthwaite's procedure, seven evapotranspiration curves were prepared. A general curve for each station was drawn using long time mean monthly temperature data. These curves are shown in Figure 6. In addition to these general curves, two more curves were prepared for each station, one curve for a selected dry-growing season and one for a selected wet one. These curves are shown in Figures 7,8,9.

In brief, the Thornthwaite's procedure is as follows:

1. Monthly mean temperature figures are converted from Fahrenheit to Centigrade values.

2. Using a specially devised table, these temperature values are used to determine what are called monthly heat

index values. The accumulation or total index value for the year is its value used.

3. Using 2 cycle x 3 cycle logarithmic graph paper, a point A. is located by means of a predetermined X value of P.E. = 13.5 Cm^3 and a predetermined y value of t = 26.5. Point A is called the conversion point.

4. The calculated yearly temperature index value is then located (point B) and a straight line drawn from A through B to the X axis. This line gives the direct relationship between temperature values (y axis) and evapotranspiration values (x axis), this is shown in the figures 3,4,5.

5. From another specially devised table a correction factor is applied to each evapotranspiration value obtained in step 4. This correction factor adjusts monthly for differences in day length and for differences in latitude.

6. The corrected evapotranspiration values are converted from centimeters to inches and then used for constructing annual evapotranspiration curves. The evapotranspiration data both from Table 11 and the curves in Figure 6 to 9 show that variations in evapotranspiration values are slight, not only between the three stations studied but also between wet years and dry years at each individual station. It would appear that water losses through evaporation and transpiration were approximately constant from season to season and from one location within the state to another.

Some seasonal temperature differences are indicated.

Air temperature in April and May at Taunton are cooler than at Williamstown or Amherst. On the other hand, air temperature at Williamstown in September and October are cooler than they are at Amherst or Taunton.

C. Influence of temperature is relatively constant as shown by evapotranspiration values, the principal climatic factor to be considered is precipitation. Therefore, whether or not there is an excess or a deficiency of moisture for any one month depends almost entirely on the precipitation for the month. On the average, for all three stations, a moisture deficiency (rainfall less than evapotranspiration) exists for the months of June, July and August. However, during certain wet years there may be a surplus of water. The magnitude of this is shown in Table 12, together with the magnitude of the moisture deficiency for a selected dry year and also the long-time average.

Table 11. Evapotranspiration Values Based on Long Time Mean Monthly Temperatures and Monthly Temperature for a Selected Wet Year and Selected Dry Year

Month	Amherst			Williamstown			Taunton		
	63 years Av.	Wet 1903	Dry 1947	60 years Av.	Wet 1938	Dry 1929	23 years Av.	Wet 1931	Dry 1944
	IN.	in.	in.	in.	in.	in.	in.	in.	in.
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	0.19	0.87	0.12	0	0.32	0.41	0.33	0.46	0.19
April	1.41	1.76	1.24	1.20	1.70	1.54	0.73	1.32	1.37
May	3.22	3.60	3.03	3.28	2.90	3.07	2.90	3.42	3.89
June	4.55	3.70	4.21	4.40	4.54	4.62	4.30	4.50	4.70
July	5.06	5.06	5.07	5.05	5.07	5.05	5.06	5.09	5.56
August	4.75	3.84	4.71	4.03	4.71	4.15	4.69	4.71	5.16
September	3.19	3.28	3.22	3.07	2.62	3.29	3.19	3.56	3.60
OctOber	1.72	1.80	2.32	1.67	1.81	1.42	1.76	2.09	1.44
November	0.47	0.20	0	0.44	.57	.46	0.65	1.13	0.74
December	0	0	0	0	0	0	0	0	0
	24.56	24.11	23.94	23.14	24.24	24.01	23.61	25.52	26.05

Table 12. Evapotranspiration and Rainfall with Surplus and Deficiency during Three Summer Months as Long-time Average in Dry and Wet Year

Month	Amherst Average 60 yrs.	Amherst Wet 1903	Amherst Dry 1947	Williamstown Average 60 yrs.	Williamstown Wet 1920	Williamstown Dry 1936	Taunton Average 23 yrs.	Taunton Wet 1931	Taunton Dry 1944
	in.	in.	in.	in.	in.	in.	in.	in.	in.
June	4.55	3.70	4.21	4.40	4.54	4.62	4.30	4.50	4.70
July	5.06	5.06	5.07	5.05	5.07	5.05	5.06	5.09	5.56
August	4.75	3.84	4.71	4.03	4.71	4.15	4.69	4.71	5.10
E. P.	14.36	12.60	13.99	13.48	14.32	13.82	14.05	14.30	15.36
Rainfall	11.63	17.35	7.64	11.51	16.92	6.90	11.23	17.39	5.92
Difference	-2.73	4.75	-6.35	-1.97	2.60	-6.92	-2.82	3.09	-9.44

The figures from the above table indicate that there is almost 2 inches or more deficiency of water on the average for this period at each station. For selected wet years, there was a surplus of precipitation of 2.6 to 4.75 inches, while for a selected dry year the water deficiency ranged from 6.35 to 9.44 inches. The harmful effects of drought are great when a large amount of water is needed. If the influence of climate is combined with that of the soil on the soil water relationships, it is obvious that Bridgewater and Marion are in an unfavorable position. Not only do they experience large moisture deficiency (-2.82 to 9.44), but due to the sandy nature of the soil in this locality, the reservoir capacity of the soil for holding moisture is low.

D. The Relative Frequency of Dry Years.

Assuming that the same climatic conditions will prevail in Massachusetts in the future as they have in the past, a statistical study of the frequency of the dry years can be useful.

Tables 13,14 show the number of years for each station in which potential evapotranspiration losses were greater than the natural rainfall.

Table 13. The Number of Years in which the Evapotranspiration Values for the Summer Months Exceeds Actual Rainfall

Month	Amherst 60 yrs.		Williamstown 60 yrs.		Taunton 23 yrs.	
	No. of Dry yrs.	%	No. of Dry yrs.	%	No. of Dry yrs.	%
June	38	63.3	43	71.6	16	69.5
July	51	85.0	45	75.0	20	87.0
August	42	70.0	49	81.6	14	61.0

From the table, it seems generally that the precipitation in more than 60% of the years was below the potential evapotranspiration for the three months. This high percentage shows that water may be a problem in crop production 6 to 8 years out of ten.

Table 14. Volume Weight and Specific Gravity of Five Soils in Mass.

Location of the Area Sampled		Volume Wt.	Specific Gravity
Williamstown	Cultivated	1.23	2.2
	Under Grass	1.19	2.3
Northampton	Cultivated	1.39	2.54
	Under Grass	1.30	2.55
Amherst	Cultivated	1.39	2.54
	Under Grass	1.30	2.56
Bridgewater	Cultivated	1.39	2.42
	Under Grass	1.26	2.47
Marion	Cultivated	1.40	2.52
	Under Grass	1.31	2.59

III. The Use of Potential Evapotranspiration Values and Soil Moisture Constant Values for Calculating the Need for Supplemental Irrigation

If values for the moisture equivalent, the volume weight and the permanent wilting percentage for a soil are known, it is then possible to determine the actual water-holding or reservoir capacity of that soil. For example, the value for the volume weight of the Amherst soil is 1.4. A cubic foot would therefore weigh 87.5 pounds. If a nine-inch plow layer is considered to be the principal root zone for absorbing water which observations indicate that it is, then an acre of soil will weigh approximately 2,858,000 pounds. Now, from the values for moisture equivalent of 17 per cent and permanent wilting percentage of 4.5, a value of 12.5 per cent available water is obtained. If near optimum growth can be maintained with at least 50 per cent of the available moisture as reported by Israelson(12), Blair(5) and Wadleigh(40), then 6.25 % of the top nine inches of an acre of soil will represent the weight of the readily usable water which can be stored in an acre of soil. In this case it is approximately 180,000 pounds of water or the equivalent of approximately 0.73 inches of rain. Using the same procedure with the four other soils studied, the corresponding <u>storage capacity</u>, or quantity of readily available water, is as follows: Williamstown, 1.16 inches; Northampton meadows, 0.78 inches; Bridgewater, 0.75 inches; and Marion, 0.46 inches.

The second step involves the use of daily evapotranspiration values. Beginning at the start of the growing season, a running or accumulative total of daily potential evapotranspiration values is kept from this total the amount of water from each rain is subtracted from the total. When a negative value (potential evapotranspiration exceeds rainfall) is reached equal to the readily available supply of water stored in the soil, then supplemental moisture is needed.

Using this procedure, the irrigation requirement for the Amherst soil was determined for 1947 which had a dry growing season. To increase the accuracy of daily evapotranspiration values, weekly averages were calculated instead of monthly averages but it is doubtful if this operation is necessary.

Approximately three-quarters to an inch of water should have been applied on the following days: June 30, July 7, July 30, August 5, August 11, August 21, and September 8. The total potential evapotranspiration amounts to 13.99 inches for June, July, and August while the total rainfall for this period was 7.64 inches, leaving a deficit of 6.35 inches. It is interesting to note that the eight applications of water called for in the above calculations amounts to approximately the same value as the indicated deficit of 6.35 inches.

If this relationship holds for other years as well as for other localities in Massachusetts, it is a relatively simple matter to calculate the irrigation requirements for the other soils studied. By referring to rainfall deficit values (Table 12) and by using the water storage capacity values given above, the approximate number of irrigations required for a given season can be quickly determined. To determine the actual dates, this irrigation would have been necessary requires the longer "plus and minus system" of accumulating or adding daily evapotranspiration and subtracting actual rainfall values until a deficiency equal to the soil's capacity to hold readily available water is reached.

Table 14 Frequency of Monthly Rainfall Classes Using One-half Inch Intervals for Three Weather Stations in Mass.

Class Ranges in Inches Per Month	Frequency at Amherst in 60 Years			Frequency at Williamstown in 60 Years			Frequency at Taunton in 23 Years		
	June	July	August	June	July	August	June	July	August
.01 - .49			1		0	7			
.5 - .98	5	1	1	1	3	5	1	1	1
.99 - 1.47	2	1	1	0	6	4	0	1	2
1.48 - 1.96	0	6	6	6	6	3	3	3	2
1.97 - 2.45	6	4	5	8	3	5	5	3	3
2.46 - 2.94	8	7	7	8	4	7	2	2	1
2.95 - 3.43	10	7	3	9	5	6	1	2	2
3.44 - 3.92	7	8	9	11	8	8	3	1	3
3.93 - 4.41	4	7	9	2	4	4	1	3	2
4.42 - 4.90	4	7	3	4	6	2	1	1	1
4.91 - 5.39	3	3	4	5	9	3	1	3	0
5.40 - 5.88	3	-	0	4	0	1	2	2	2
5.89 - 6.37	2	3	2	0	1	3	0	1	1
6,38 - 6,86	1	1	6	2	1	1	0	-	0
6.87 - 7.35	1	2	1	1	0	0	2	-	1
736- 7.84	2	2	0	0	1	1	0	-	-
7.85 - 8.33	0	0	0	0	0		0		
8.34 - 8.82	1	0	2	0	0		0		
8.83 - 9.31	0	1		1	2		1		
9.32 - 9.80	1				0				
9.81 -10.29					1				
10.30 -10.78									

Table 16. Irrigation Requirements for Five Soils in Massachusetts for Average and For Dry Growing Seasons

Source of Soil	Readily Available Soil Water Inch per Acre	Moisture Deficit		Number of Irrigations	
		Average	Driest Year	Average	Driest Year
Williams-town	1.16	1.97	6.92	2	6
North-ampton	0.78	2.73	6.35	3	8
Amherst	0.73	2.73	6.35	3	8
Bridge-water	0.75	2.82	9.44	4	12
Marion	0.46	2.82	9.44	6	20

It is obvious from table 16., that the most critical factor in soil-water relationships is the water-holding capacity of the soil. It not only determines the efficiency of water storage-the quantity of water from a simple rain or irrigation operation which can be held by the soil-but also the number of days that an adequate supply of moisture can be maintained for the crop after a substantial rain.

SUMMARY AND CONCLUSIONS

A study was made of the factors which influence the need for supplemental irrigation for crops in Massachusetts. These factors were grouped under three general headings 1) soil, 2) cultural practices and 3) climate.

Soil samples were collected from five localities in the state. Williamstown represented the western uplands; Northampton meadows represented the alluvial soils in the Connecticut Valley and eastern uplands; and Bridgewater and Marion represented the light sandy soils of the southeastern section of the state.

The following soil properties were studied, - texture, structure, organic matter content, moisture equivalent values, and permanent wilting p rcentage. The most important soil property as far as water relationships are concerned is texture because soil texture is directly associated with a soil capacity to hol or store water. The Williamstown soil with a substantial content of clay and silt had relatively high storage capacity or moisture equivalent value whereas the light sandy soil from Marion had a low storage capacity or moistureequivalent value. Consequently the Marion soil had a much greater and more frequent need for supplemental irrigation than did the Williamstown soil. The soils from Northampton, Amherst, and Bridgewater were intermediate.

Cultural practices were shown to be important, particularly as they affected the organic matter content of a soil and also soil structure. Samples were taken from a cultivated and sodded area at each location. With the exception of Northampton meadow soil, the grassland soils were superior to the cultivated soils. The fact is that the structure of the Northampton soil was not improved because that grass was grown only for a short period of time.

Cultivated soils, high in silt, such as those from Northampton and Amherst, had low infiltration values. Probably the most important change in cultural practices would be to introduce a sod crop into the cropping system periodically in order to increase the value of water infiltration rates.

The effect of air temperature was shown to be relatively constant. Precipitation, on the other hand, was shown to be quite variable from year to year and even between different localities within the state. Rainfall, particularly in dry years, is by far the most important factor in determining the need of soils or the crops which are growing on them for supplemental irrigation.

A procedure was developed for determining the dates for applying irrigation water and also the amount of water which is required.

APPENDIX

Figure 1.

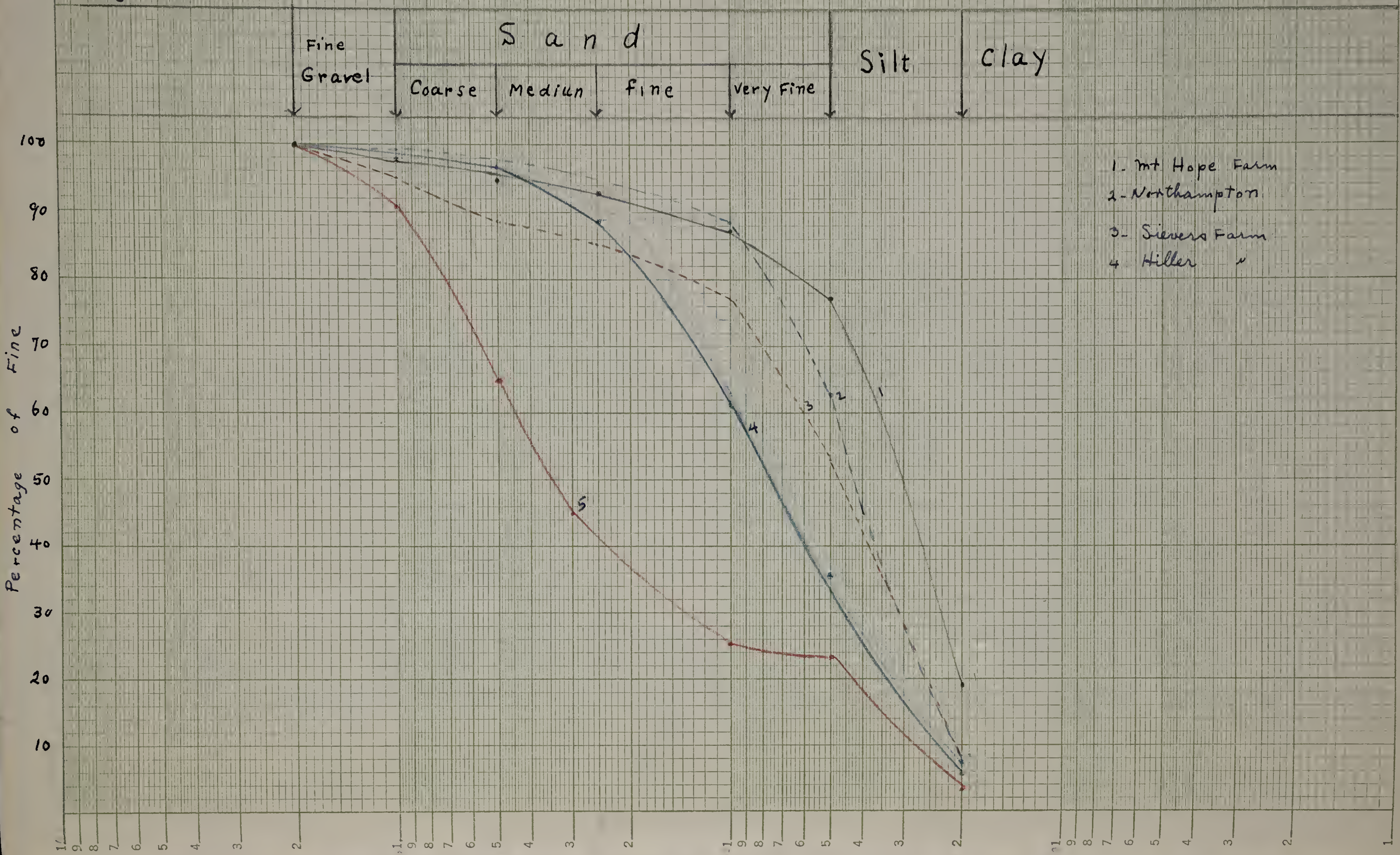

Fine Gravel
Sand
Coarse
Medium
fine
Very Fine
Silt
Clay
Percentage of Fine
1. Mt Hope Farm
2. Northampton
3. Sievers Farm
4 Hiller "
5

Figure 2. Moisture Extraction Curves for five Soils

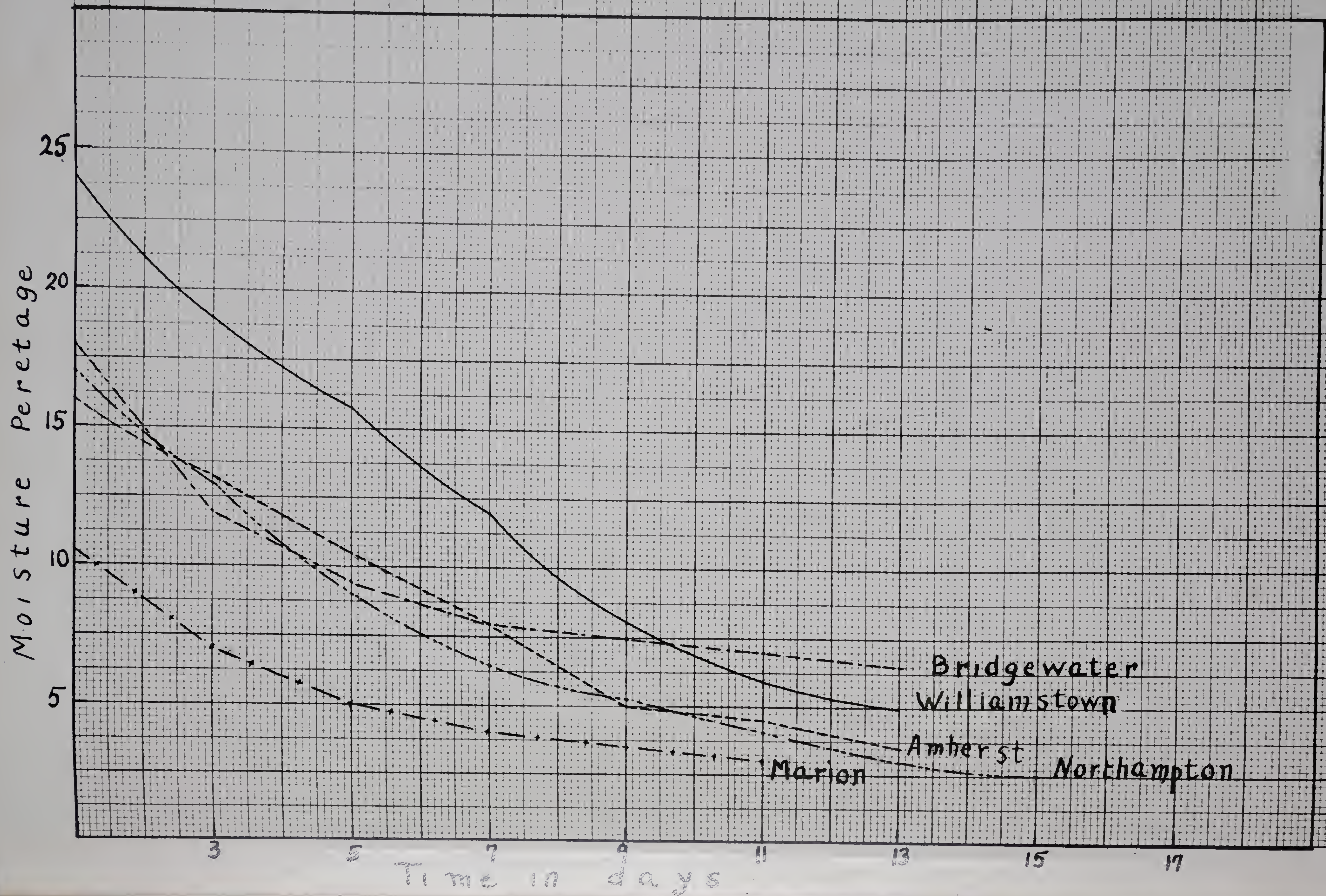
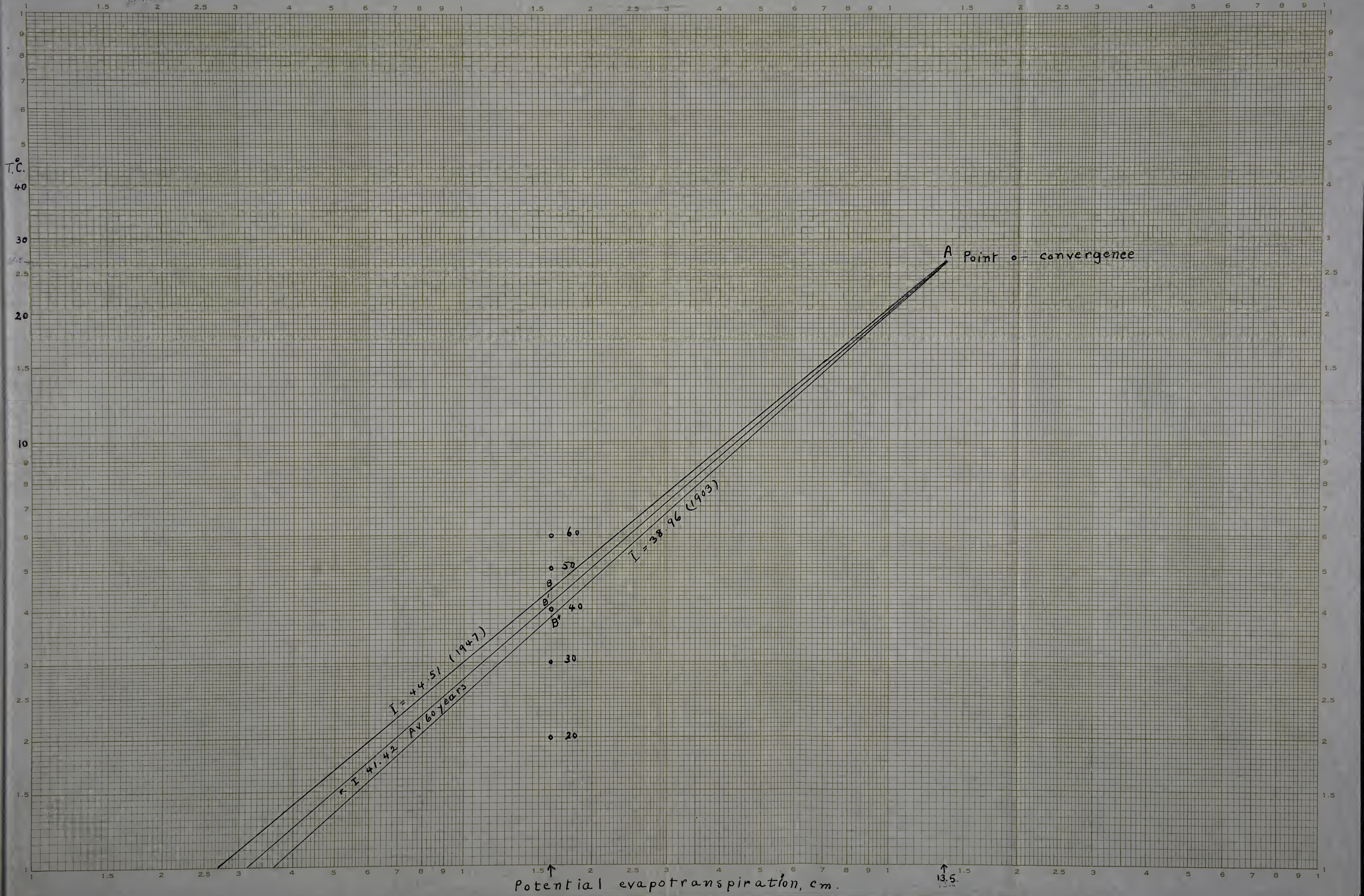
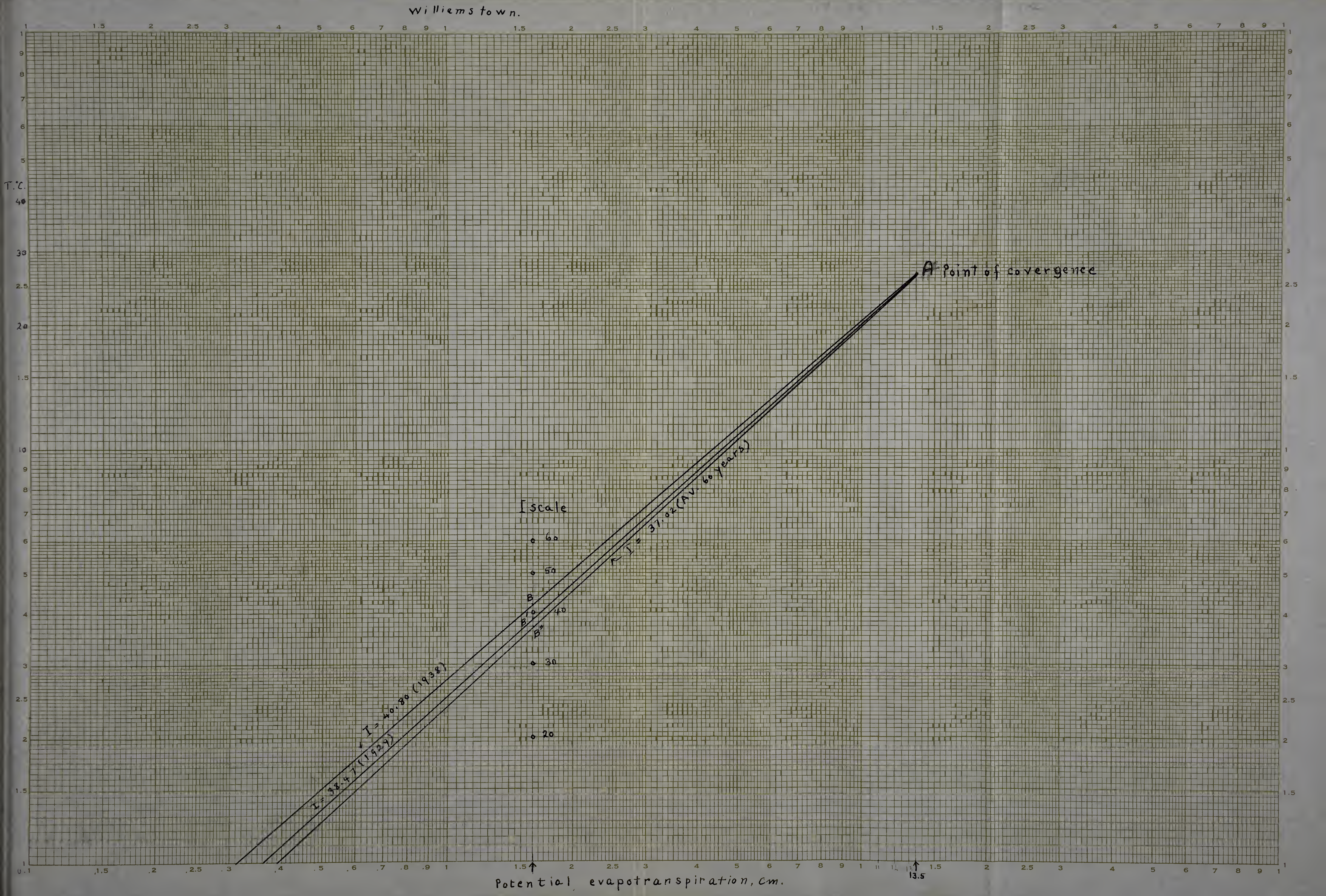
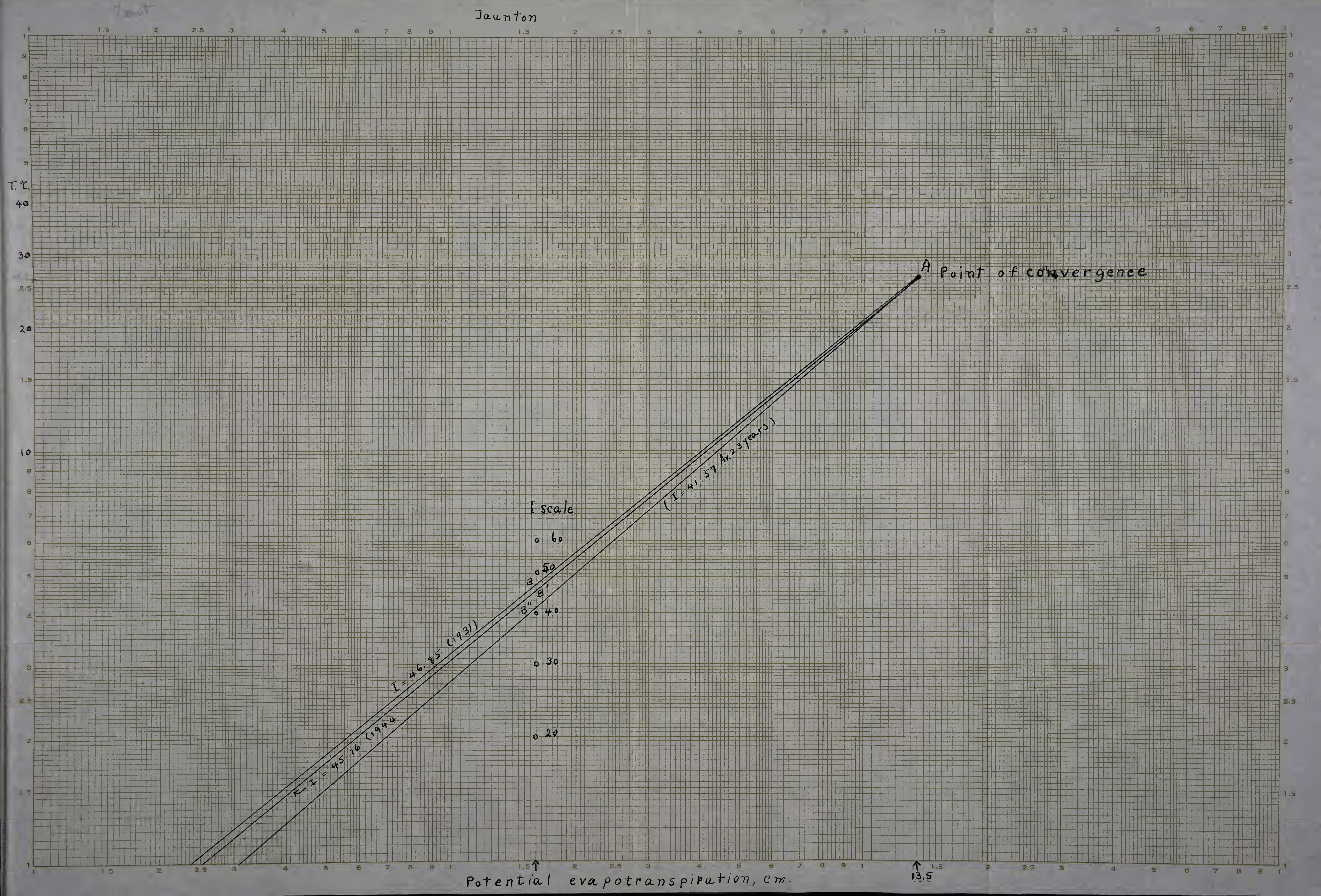


Figure 3. Amherst




Williems town.
T. °C.
A Point of covergence
I scale
60
50
40
30
20
B
B'
B"
I = 40.80 (1938)
I = 38.47 (1929)
I = 37.02 (AV. 60 Years)
13.5
Potential evapotranspiration, cm.



Jaunton
T. °C.
A Point of convergence
(I = 41.57 Av. 23 years)
I scale
60
50
40
30
20
B
B'
B"
I = 46.85 (1931)
I = 45.76 (1944
13.5
Potential evapotranspiration, cm.

Figure 6. Monthly Precipitation and Potential Evapotranspiration At Three station In Mass.

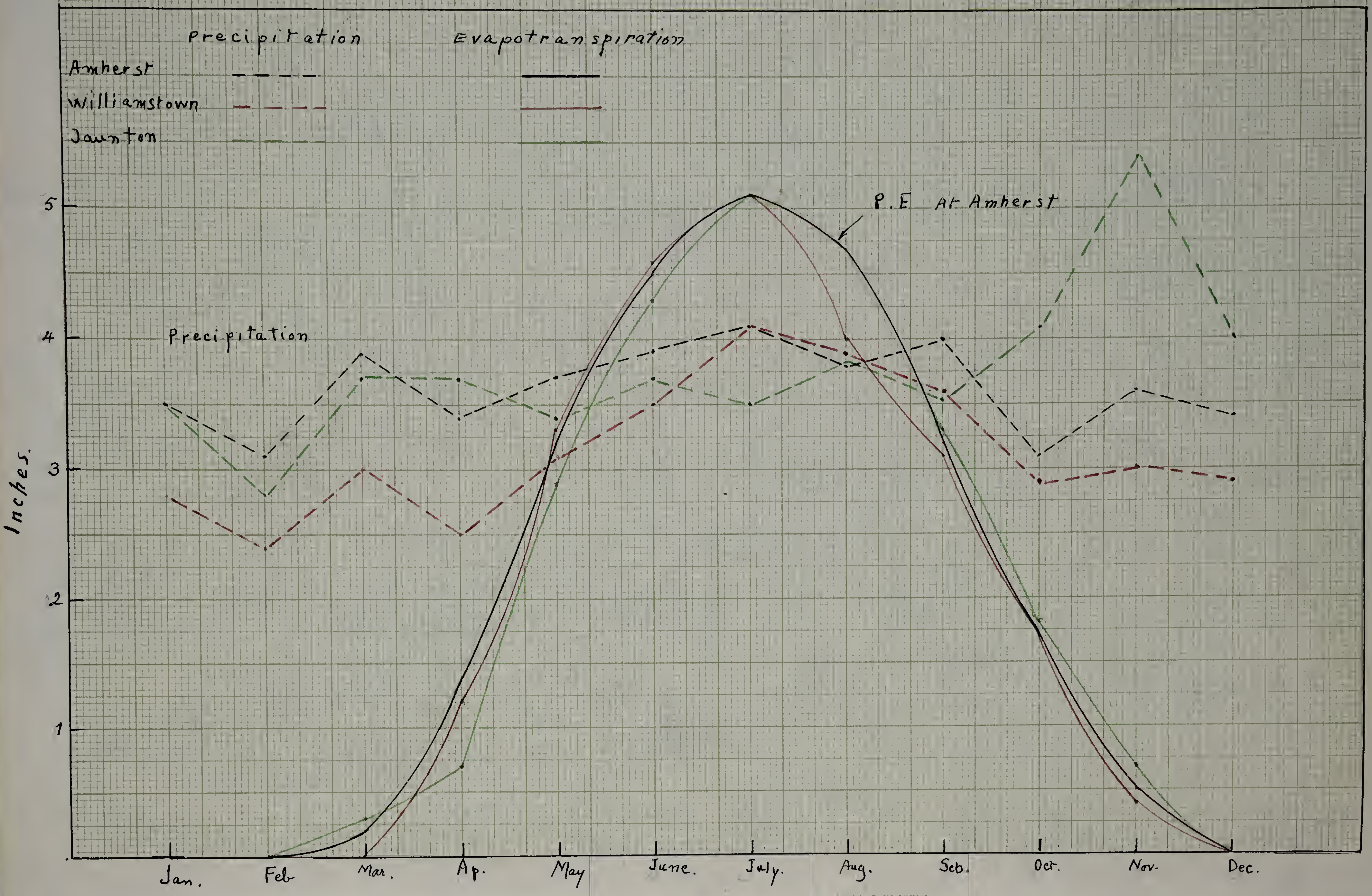
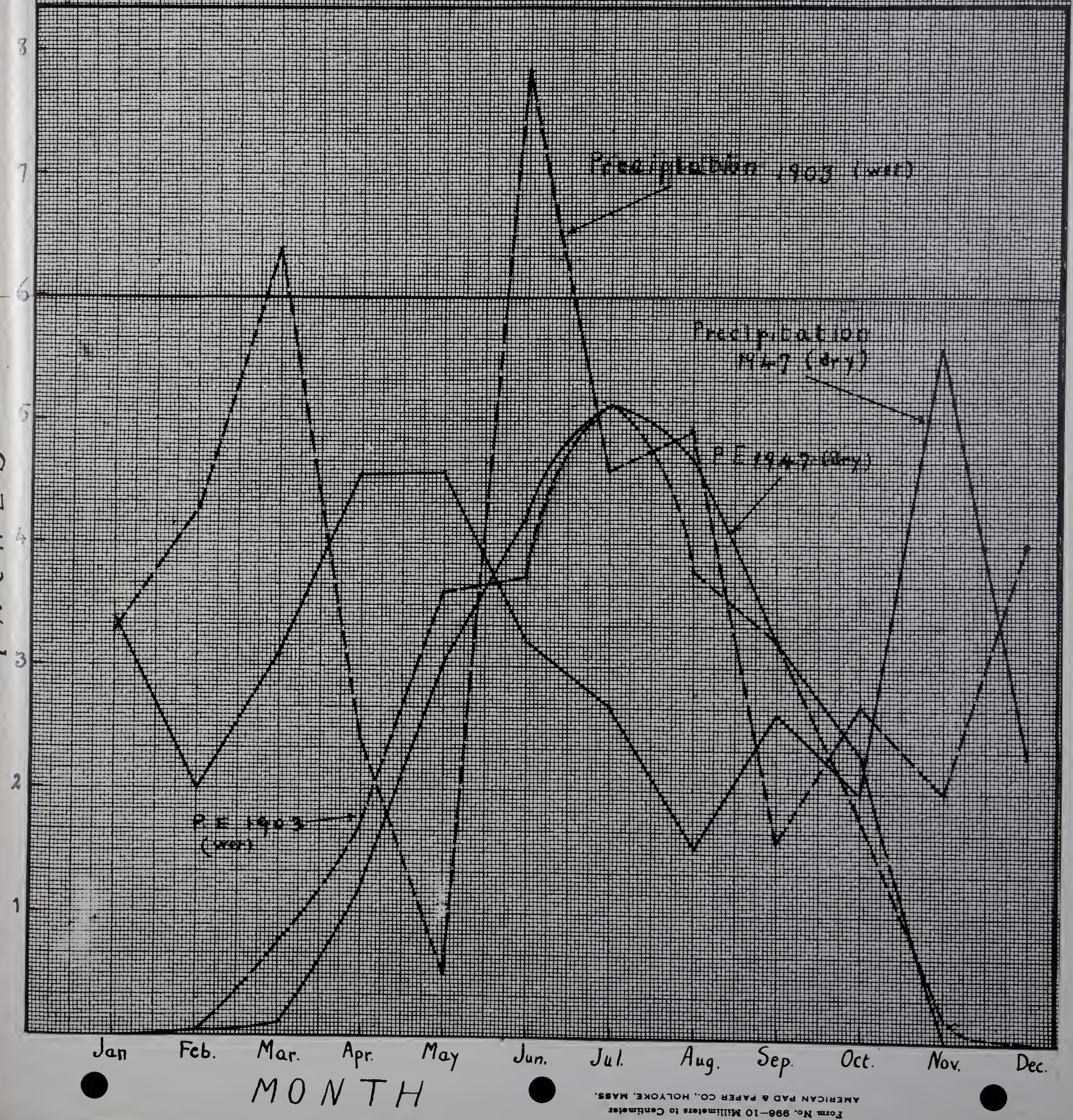


Figure 7. Precipitation and Potential Evapotranspiration in Wet year and Dry year at Amherst



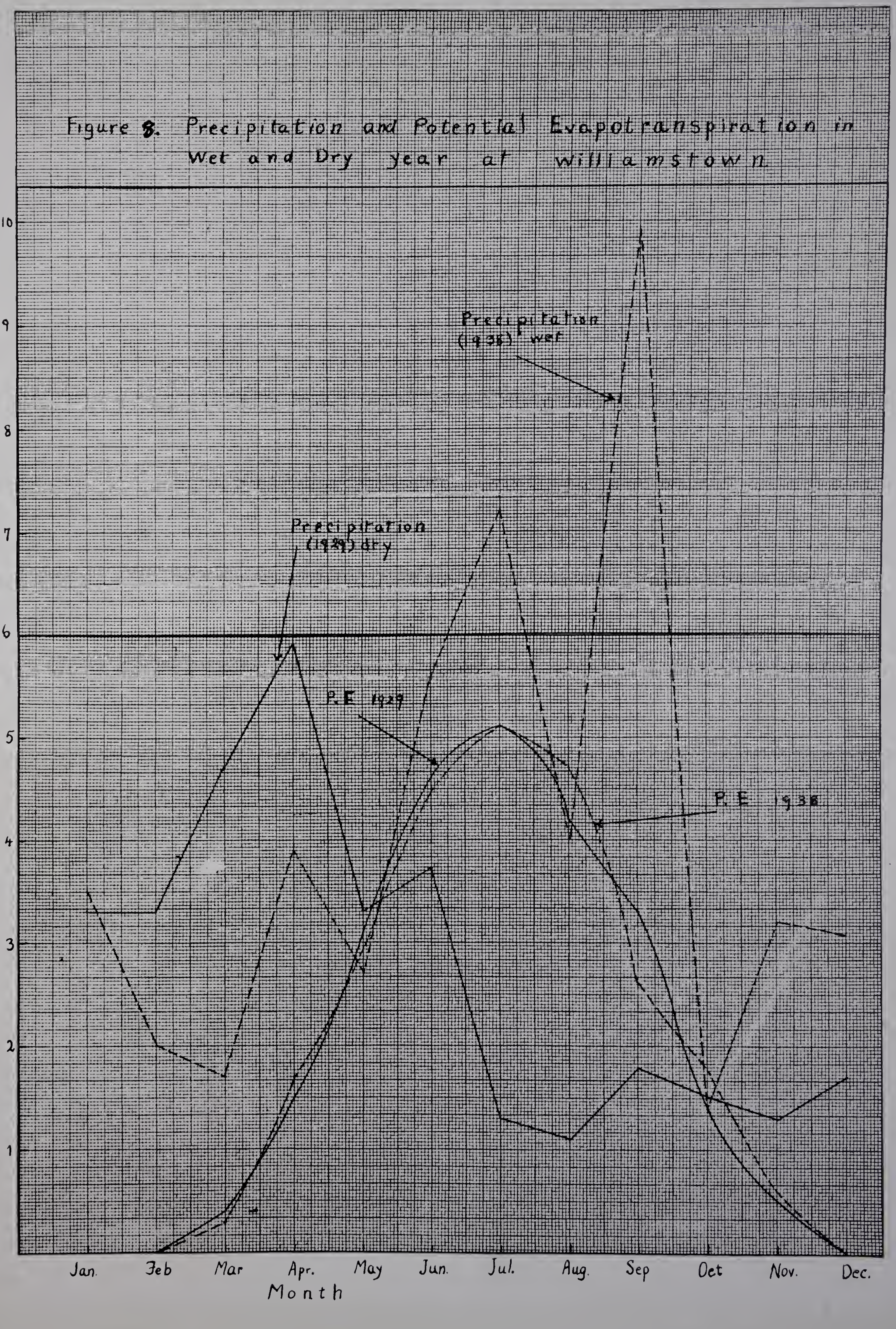
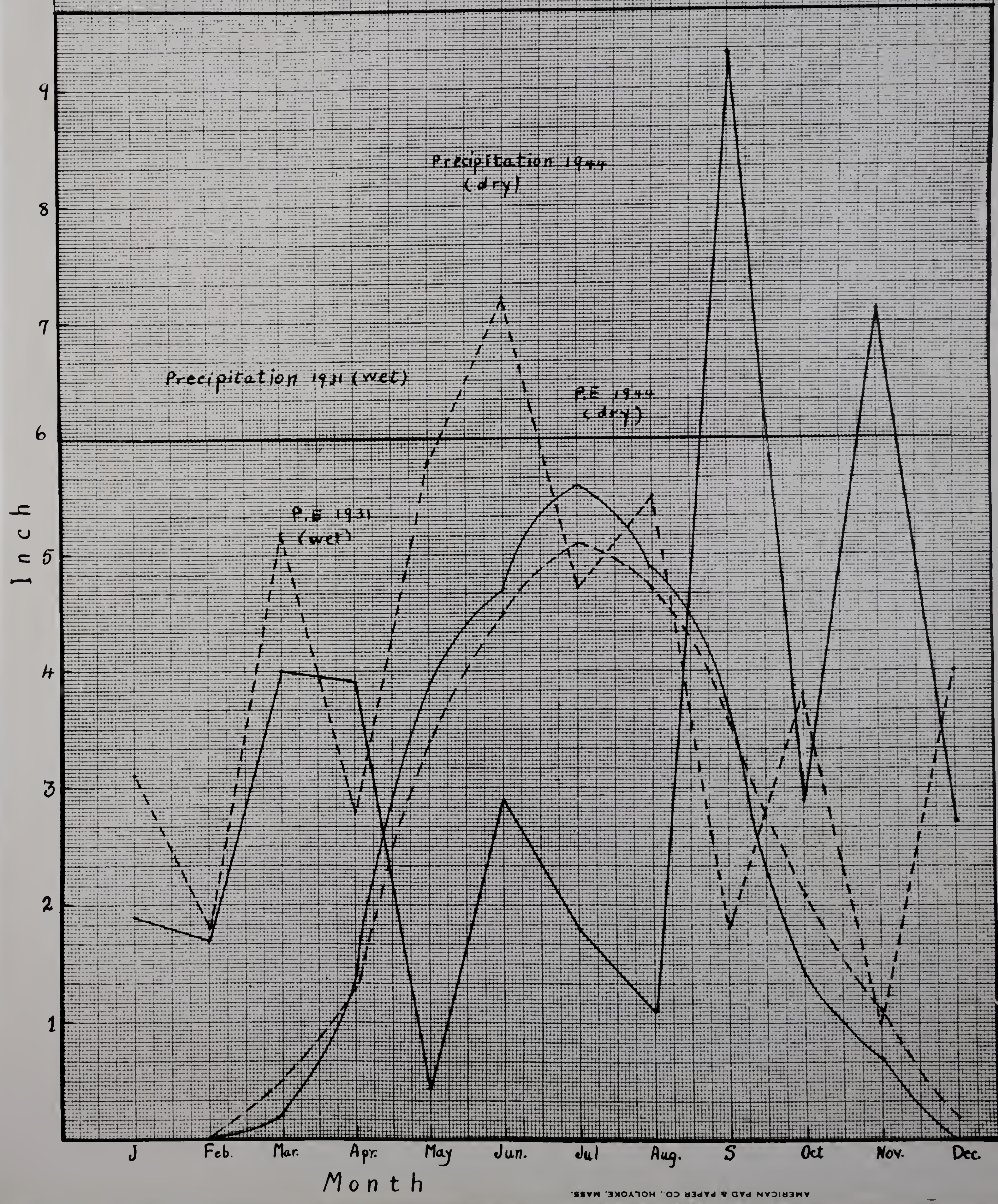


Figure 8. Precipitation and Potential Evapotranspiration in Wet and Dry year at williamstown
Precipitation (1938) wet
Precipitation (1929) dry
P. E 1929
P. E 1938
10
9
8
7
6
5
4
3
2
1
Jan.
Feb
Mar
Apr.
May
Jun.
Jul.
Aug.
Sep
Oct
Nov.
Dec.
Month

Figure 9. Precipitation and Potential Evapotranspiration in wet year and dry year at Taunton.



Average and Mean Monthly and Yearly ~~Precipitation~~ Temperature in Inches at Amherst

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Annual
1889	32.9	22.9	37.9	51.1	61.2	67.8	69.5	65.9	62.1	46.4	41.4	34.5	49.5
1890	31.0	32.6	31.9	45.8	56.3	65.2	63.4	67.2	60.4	43.2	36.9	21.8	46.8
1891	26.4	27.6	32.7	47.5	55.6	65.2	66.3	69.0	64.9	48.7	38.1	36.9	48.2
1892	23.6	26.1	31.4	45.2	54.4	69.3	69.3	68.9	59.3	48.6	37.8	26.3	46.7
1893	16.1	22.9	30.4	43.0	55.8	66.9	68.1	69.1	55.8	52.6	38.2	25.5	48.2
1894	26.4	21.5	39.6	46.7	57.3	67.8	72.9	67.9	65.4	51.6	34.8	26.9	48.2
1895	21.5	19.5	31.1	45.6	59.7	69.1	67.5	69.7	64.1	45.6	40.6	30.4	47.0
1896	20.7	25.0	29.2	48.3	61.0	64.0	71.3	68.8	59.5	47.1	42.2	25.6	47.0
1897	24.7	25.4	33.1	47.0	56.7	62.0	71.6	66.8	60.1	49.8	36.2	28.3	46.8
1898	21.8	26.0	39.7	42.4	55.3	66.1	70.9	70.2	63.6	51.1	37.5	25.8	47.5
1899	22.9	21.3	33.6	45.8	57.6	67.8	69.8	68.6	59.4	51.9	37.3	31.0	47.2
1900	24.8	24.6	29.1	45.8	55.1	67.1	71.5	70.6	64.5	55.4	40.8	28.4	48.1
1901	23.6	19.2	32.5	46.4	55.8	66.7	73.3	70.4	62.7	50.7	33.6	26.7	46.8
1902	22.2	25.3	40.5	47.2	56.6	63.1	68.3	66.2	60.9	50.3	42.4	23.7	47.2
1903	24.2	27.2	42.9	47.1	59.8	60.3	69.3	62.4	61.9	51.4	35.1	22.1	47.0
1904	14.3	17.3	30.8	43.2	60.3	65.3	70.4	66.9	60.2	46.0	34.0	19.4	44.0
1905	20.6	17.6	32.8	46.1	57.0	64.3	71.8	66.2	59.8	50.0	36.5	30.1	46.1
1906	30.2	24.1	28.0	45.9	56.9	66.1	71.1	71.2	63.8	51.4	38.7	24.1	47.6
1907	22.1	16.1	35.2	41.7	51.7	63.7	70.4	66.5	62.0	45.7	38.6	31.2	45.4
1908	25.8	20.6	34.8	45.9	59.9	67.2	72.8	67.0	64.0	52.3	38.5	27.6	48.0
1909	25.4	29.3	33.2	45.1	55.7	66.1	68.9	66.8	60.7	48.7	42.0	25.5	47.3
1910	26.2	23.6	40.2	50.4	57.0	63.7	72.2	67.1	61.7	52.3	37.1	21.9	47.8
1911	27.5	22.8	31.7	43.5	62.5	64.4	74.6	68.5	60.4	49.0	37.2	33.5	48.0
1912	14.7	21.4	30.9	46.2	58.8	64.9	71.9	66.4	61.6	53.3	40.5	33.1	46.9
1913	34.2	22.7	38.3	48.0	55.5	66.0	71.6	69.9	60.0	55.5	41.8	32.0	49.6
1914	22.4	17.9	33.7	42.6	58.9	64.6	68.6	69.7	61.0	54.2	37.6	24.7	46.3
1915	27.1	28.9	32.8	51.1	53.8	64.5	69.9	67.0	66.0	52.4	40.8	27.0	48.4
1916	27.7	20.1	26.8	44.6	56.2	61.3	72.5	70.5	61.3	51.7	38.1	26.5	46.4
1917	23.5	19.9	33.4	42.1	49.5	66.3	72.5	72.3	58.4	47.4	34.6	17.1	44.8
1918	13.9	19.6	35.4	46.2	62.2	63.0	71.1	71.6	58.0	53.1	40.0	29.3	46.9
1919	28.7	28.7	38.5	45.7	57.4	68.3	71.8	65.8	61.9	51.6	40.1	23.2	48.5
1920	15.2	21.3	34.3	43.2	54.5	64.7	68.7	71.8	64.1	56.4	36.9	31.0	46.8
1921	26.8	27.5	42.5	52.0	59.0	66.4	74.7	67.2	66.6	50.9	37.9	25.8	49.8
1922	20.1	25.8	35.3	45.8	60.0	67.4	70.8	68.2	64.0	51.7	39.5	25.1	47.8
1923	19.7	17.9	28.6	45.9	56.4	67.9	68.5	67.6	63.9	51.1	39.8	34.8	46.8
1924	25.8	20.7	34.4	44.2	53.2	64.3	71.4	70.3	59.2	51.3	40.5	25.6	46.7
1925	21.1	32.1	39.1	47.5	54.0	69.2	69.1	68.0	61.0	43.5	38.0	29.0	47.6
1926	25.5	22.6	29.4	41.2	55.5	61.6	70.3	69.0	59.8	47.8	39.8	20.1	45.2
1927	22.7	28.7	38.5	45.0	53.9	61.9	70.6	64.9	61.5	54.0	43.9	29.7	47.9
1928	27.3	25.5	33.1	43.3	55.1	63.6	70.3	72.0	59.0	51.8	40.0	32.4	47.8
1929	22.8	25.5	37.8	45.2	56.6	67.1	70.1	66.5	63.1	49.0	39.6	28.1	47.6
1930	26.0	29.2	35.0	44.1	59.1	70.6	69.9	67.8	64.0	48.9	40.2	28.1	48.4
1931	22.9	25.4	36.3	46.7	58.1	66.7	73.1	69.6	64.8	53.6	44.1	31.6	49.4
1932	33.5	26.3	31.9	44.4	57.9	62.9	68.9	70.5	62.5	52.4	36.5	30.2	48.2
1933	32.6	28.6	32.9	45.3	60.5	68.3	72.3	69.3	62.7	49.0	34.5	22.3	48.2
1934	24.0	11.6	30.9	46.2	59.3	67.6	72.4	65.0	64.6	47.7	42.8	26.4	46.7
1935	19.0	24.0	35.8	45.0	54.4	65.6	73.2	69.4	59.1	50.4	43.4	24.9	47.1
1936	23.8	18.1	40.9	43.4	59.4	67.0	70.8	69.7	62.3	50.6	35.7	31.8	47.9
1937	31.7	30.0	31.5	45.0	59.3	66.9	71.6	73.3	60.0	49.6	39.9	27.6	49.0
1938	21.6	28.8	37.4	49.2	55.6	67.1	71.7	72.4	59.4	55.2	41.5	29.7	49.2
1939	24.9	27.8	30.9	42.5	59.7	66.7	71.2	73.5	61.4	50.2	36.8	28.9	48.0
1940	18.5	26.7	30.1	42.1	57.2	64.6	70.6	66.9	60.1	46.7	39.4	29.4	46.1
1941	21.2	25.8	39.3	52.1	57.9	67.2	71.2	67.0	62.5	52.5	42.8	31.1	48.5
1942	24.1	24.0	39.4	49.7	61.4	67.5	70.5	68.9	62.7	52.7	38.8	24.8	48.8
1943	21.4	25.1	32.9	41.0	57.8	71.1	71.8	68.9	61.1	51.4	38.7	24.9	47.3
1944	26.7	25.9	32.0	42.9	63.4	66.3	72.9	73.4	63.0	50.0	39.0	25.3	48.4
1945	17.8	25.7	44.4	51.8	54.1	66.1	70.6	68.3	64.1	50.5	40.3	22.3	47.9
1946	23.2	22.6	44.5	45.0	55.8	65.0	70.2	66.1	63.9	54.7	43.2	29.9	48.7
1947	27.7	24.0	34.0	44.7	56.1	64.6	73.2	73.0	62.9	57.4	30.0	25.6	48.4
1948	18.0	21.4	34.9	47.2	57.3	64.7	72.3	71.4	63.7	51.3	46.3	32.4	48.4
1949	31.6	30.5	38.2	50.1	60.0	71.9	75.9	68.6	61.4	57.6	40.4	29.9	51.7
1950	32.8	24.8	31.2	45.1	57.5	66.6	71.0	68.9	59.2	54.0	43.0	30.0	43.4
1951	27.4	29.6	36.5	48.5	58.9	65.9	72.3	68.3	61.4	54.8	32.2	29.8	48.8
	24.2	24.1	34.7	45.8	57.3	65.9	71.0	68.8	61.8	50.9	39.0	27.6	33.6

Reference: Meteorological Records of the Agricultural Experiment Station U. of Mass.

Average and Mean Monthly and Yearly Temperature in Degrees F.° at Williamstown

Year.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1881	14.8	21.0	31.6	39.5	59.8	60.0	70.6	67.6	65.3	49.4	38.1	32.3	45.8
1882	21.6	25.4	32.5	40.4	49.6	63.2	66.9	66.0	59.0	50.6	34.3	23.9	44.4
1883	17.8	23.2	24.3	41.6	54.2	66.0	66.3	63.5	56.1	45.9	38.7	25.2	43.6
1884	18.3	27.8	29.2	42.1	54.5	66.6	64.9	66.8	61.4	48.4	37.1	27.9	45.4
1885	19.6	13.6	20.6	43.8	55.0	64.6	67.8	63.4	56.1	47.0	39.0	28.0	43.2
1886	19.7	21.1	30.2	48.2	56.7	61.6	68.0	66.2	57.5	49.3	38.8	22.1	45.0
1887	20.1	25.1	24.4	39.0	63.5	63.9	72.5	63.5	55.0	47.3	35.0	25.5	44.6
1888	12.8	21.0	24.5	39.6	52.7	64.8	68.5	66.4	57.3	42.4	38.4	29.4	43.1
1889	26.1	19.3	34.0	47.2	59.1	64.9	67.9	63.6	59.7	43.7	39.6	33.2	46.5
1892	23.2	25.2	28.0	43.4	53.8	67.7	68.8	66.9	58.4	48.3	36.6	23.4	45.3
1893	13.2	21.6	30.1	40.7	54.9	68.0	67.4	67.7	55.7	50.4	36.2	26.9	44.4
1894	26.1	22.5	37.2	46.5	57.0	66.2	68.2	62.2	61.0	50.0	33.2	27.1	47.5
1895	20.9	16.8	28.2	43.4	58.2	68.2	67.1	67.6	61.7	43.6	38.7	29.9	45.4
1896	21.1	24.2	26.0	47.1	59.3	63.8	70.9	67.6	58.8	48.4	42.2	24.9	46.2
1897	23.4	24.2	33.0	45.0	55.6	61.5	70.4	63.9	57.2	49.3	36.7	27.5	45.6
1898	21.8	24.8	37.7	41.5	55.0	65.1	69.0	66.6	60.1	50.8	35.8	26.6	46.2
1899	20.7	19.6	28.3	43.8	55.8	66.1	68.0	66.2	57.5	50.4	36.3	33.2	45.5
1900	25.0	23.9	26.7	44.6	55.3	66.6	70.1	68.8	63.2	53.0	39.8	25.6	46.9
1901	22.0	16.2	30.6	45.8	55.6	66.0	70.2	69.0	60.0	48.8	31.4	25.2	45.1
1902	21.2	21.6	38.2	46.0	54.7	61.6	66.6	63.8	59.4	49.0	42.2	22.5	45.6
1903	24.2	27.0	41.6	45.2	58.4	59.6	67.2	60.4	59.2	49.7	33.4	21.6	45.6
1904	14.7	16.0	30.0	40.7	59.6	64.8	66.8	62.2	57.3	47.2	32.0	19.7	42.5
1905	18.0	15.5	30.8	44.4	56.1	62.9	69.6	63.9	58.2	49.0	35.2	29.2	44.4
1906	29.6	22.2	26.3	43.6	55.4	65.0	68.6	68.5	61.2	49.9	36.0	23.8	45.8
1907	22.5	15.2	34.2	40.1	50.8	62.1	68.7	64.0	60.2	44.2	37.1	30.8	44.2
1908	24.8	19.1	33.4	43.7	58.2	64.7	70.5	65.1	61.8	50.8	38.5	26.9	46.5
1909	25.1	27.7	30.3	43.8	54.9	64.7	66.8	64.7	58.9	46.5	41.0	23.3	45.6
1910	24.7	21.0	39.0	49.2	55.0	62.2	70.2	65.4	59.6	51.0	34.6	19.9	46.0
1911	26.6	24.1	29.7	42.2	62.8	62.8	71.9	67.4	58.5	47.7	35.3	32.8	46.8
1912	14.8	18.5	28.2	44.6	57.5	62.2	69.5	64.2	59.4	50.3	39.1	32.5	45.1
1913	33.8	21.3	37.8	46.9	54.5	64.8	69.0	66.9	57.7	53.4	41.7	29.8	48.1
1914	21.9	14.9	31.0	41.5	57.7	63.6	67.5	67.1	57.8	52.7	35.4	24.7	44.7
1915	26.1	27.8	28.9	49.5	52.2	63.7	68.3	64.8	63.2	50.3	38.7	26.2	46.6
1916	25.8	19.3	22.3	43.7	56.0	61.0	71.3	68.9	59.4	49.5	36.8	25.8	45.0
1917	23.2	18.8	31.6	42.7	47.7	64.3	70.0	70.1	55.8	45.8	32.6	16.5	43.3
1918	11.5	20.1	32.7	44.1	61.8	61.2	68.7	68.6	56.5	51.4	39.8	30.5	45.6
1919	27.1	26.4	36.2	43.0	56.2	68.1	68.2	64.8	60.3	50.9	37.2	20.4	46.6
1920	13.4	20.2	32.3	41.1	53.0	62.8	66.8	68.9	61.0	54.4	35.8	29.2	44.9
1921	25.6	26.4	42.0	50.7	57.6	64.4	72.5	62.3	62.1	49.6	37.5	23.5	47.8
1922	18.6	25.6	33.8	43.6	58.2	67.0	69.2	66.4	60.9	48.4	37.8	26.2	46.3
1923	19.2	16.4	27.3	44.1	53.4	66.0	66.1	65.3	61.0	48.3	37.9	34.7	44.9
1924	25.2	16.9	32.1	42.0	51.8	63.4	68.7	66.5	56.7	47.5	38.7	23.7	44.4
1925	17.5	30.4	37.1	45.8	50.7	67.7	66.7	66.6	60.0	42.6	37.6	27.2	45.8
1926	23.8	20.7	26.1	39.0	54.2	60.6	68.8	68.1	58.8	46.2	38.3	20.0	43.7
1927	20.6	28.4	35.4	43.5	52.5	61.0	69.0	63.3	57.2	52.1	42.3	27.3	46.0
1928	25.4	23.4	31.1	41.9	54.3	62.5	71.4	70.0	57.1	50.4	39.1	31.1	46.5
1929	22.1	22.3	36.4	44.5	56.1	66.3	68.7	64.9	62.0	47.1	38.1	27.0	46.3
1930	25.3	26.3	32.9	42.9	58.2	69.5	68.8	66.8	62.5	47.4	38.9	27.9	47.3
1931	21.1	22.3	33.9	45.7	57.6	65.7	72.8	67.6	62.8	51.5	44.7	31.0	48.1
1932	34.1	26.9	28.3	42.5	57.4	64.8	67.6	67.2	59.8	51.9	36.1	30.3	47.2
1933	31.6	26.4	29.9	45.5	59.6	67.2	71.4	67.7	61.4	47.9	32.8	23.5	47.1
1934	24.4	9.8	30.1	45.6	58.7	67.8	70.9	64.5	63.5	46.3	41.4	24.5	45.6
1935	18.4	21.8	34.5	43.2	52.0	65.4	71.6	67.4	46.9	49.2	42.1	21.8	45.4
1936	21.0	17.4	40.1	42.3	60.0	66.2	69.4	67.6	60.8	49.1	33.8	30.9	46.6
1937	31.5	27.4	27.9	43.7	58.0	66.4	71.1	72.3	57.9	43.2	38.5	25.3	47.4
1938	21.3	27.1	36.1	48.3	55.1	66.4	70.9	70.8	57.3	51.6	40.5	28.8	47.8
1939	22.3	27.2	28.8	41.2	59.5	66.7	70.1	70.7	60.8	49.5	34.4	27.1	46.5
1940	14.4	22.5	27.2	40.6	57.9	64.8	69.3	65.4	57.8	44.4	38.3	29.4	44.3
1941	18.9	22.8	27.4	50.9	57.6	67.0	71.0	65.5	60.8	50.8	42.8	30.7	47.2
1942	22.7	20.1	37.3	49.2	60.6	66.6	69.1	66.4	60.6	50.4	38.1	20.6	46.8
	22.0	22.0	31.3	43.9	56.1	64.7	69.1	62.8	59.5	48.8	37.6	26.6	45.5

Reference: Milham W., Meteorology and Meteorological Observations in Williams College

Average and Mean Monthly and Yearly Temperature in Degrees F.° at Tauton

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1926	27.8	23.8	32.1	42.6	54.2	61.0	67.4	67.8	57.8	48.8	41.7	23.2	45.7
1927	27.1	30.7	38.9	44.9	53.2	61.7	70.0	64.7	59.1	53.6	45.7	32.8	48.6
1928	28.8	26.9	34.4	44.5	53.8	63.0	70.9	71.6	58.8	62.4	40.6	32.4	48.2
1929	25.8	27.8	39.8	46.2	56.8	66.0	69.2	66.0	62.0	49.6	40.0	29.4	48.2
1930	27.0	31.7	35.4	42.0	55.0	69.0	69.7	66.5	65.6	48.6	39.6	29.0	48.3
1931	26.3	28.6	36.8	47.0	58.4	65.6	72.2	70.0	65.0	54.9	46.1	35.6	50.5
1932	37.3	30.0	33.4	45.4	56.9	65.0	69.2	69.8	61.8	54.2	41.1	34.4	49.9
1933	35.8	31.8	35.1	45.8	59.6	66.9	69.2	69.8	63.7	50.8	36.1	26.6	49.3
1934	30.0	16.2	34.4	47.3	59.2	67.2	72.2	66.5	65.0	48.8	44.4	29.6	48.4
1935	23.4	26.6	38.6	45.1	54.6	64.7	72.3	68.5	61.2	50.3	45.0	25.0	47.9
1936	25.7	21.8	43.0	44.4	59.2	65.7	69.2	69.3	63.6	52.2	37.8	35.2	48.1
1937	37.0	33.9	33.0	44.3	58.2	65.8	70.7	73.6	60.4	49.7	40.8	28.4	49.4
1938	26.2	31.3	38.3	48.1	54.8	64.7	71.4	71.8	60.9	54.0	43.8	32.8	49.1
1939	26.8	32.0	33.8	43.7	36.3	64.3	69.5	72.5	61.6	51.8	37.8	31.8	48.5
1940	20.0	28.0	32.2	42.2	55.6	64.2	69.9	65.9	60.3	47.0	40.8	33.0	46.6
1941	24.6	27.4	32.1	49.5	57.4	66.3	70.5	67.8	63.0	53.0	44.5	34.7	49.2
1942	25.9	27.4	40.2	48.3	61.2	66.2	70.4	68.8	63.8	52.7	41.4	27.4	49.4
1943	25.7	30.2	36.2	43.0	57.9	69.9	71.6	68.8	61.8	53.0	40.6	27.2	48.8
1944	29.1	28.2	34.2	44.2	61.6	66.2	72.3	72.4	63.9	51.4	41.6	29.4	49.5
1945	23.0	27.8	45.2	52.2	55.3	65.8	71.4	68.4	66.3	50.1	44.0	25.5	49.6
1946	28.2	27.5	44.1	44.5	56.2	65.3	69.9	66.9	63.8	55.1	45.4	33.2	50.0
1947	32.3	29.2	36.0	45.6	56.4	63.2	73.0	71.6	63.0	57.4	38.4	28.4	49.5
1948	21.4	23.7	37.2	46.4	55.2	62.2	71.2	71.5	61.8	50.8	47.4	33.3	48.6
Average	28.1	27.8	36.7	40.3	56.8	65.2	70.6	69.2	62.4	52.2	41.9	30.3	48.8

Reference: U.S. Department of Agriculture Weather Bureau

Table III

Average and Mean Monthly and Yearly Precipitation in Inches at Amherst

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1889	3.29	1.45	1.46	2.42	4.71	5.01	10.5	2.72	3.17	4.58	6.04	3.57	48.9
1890	2.61	4.19	5.37	1.73	5.39	1.53	5.63	4.88	5.85	7.13	1.32	2.86	48.5
1891	6.75	4.23	2.99	2.66	1.97	4.75	5.28	4.18	2.66	2.94	2.99	5.40	46.8
1892	5.85	1.90	2.40	0.76	6.28	3.46	4.41	6.47	2.16	0.66	4.98	1.01	40.3
1893	3.33	5.75	3.66	4.41	5.02	3.32	2.59	3.49	2.82	4.88	2.81	4.86	46.9
1894	2.16	1.74	1.77	1.83	4.00	3.13	1.55	0.31	4.63	4.85	3.14	3.53	32.6
1895	3.87	1.05	2.71	5.56	2.07	2.76	3.87	3.46	5.04	4.77	5.36	3.94	44.5
1896	1.07	4.67	6.11	1.32	2.58	2.57	4.96	3.84	5.41	3.23	3.03	0.87	39.7
1897	3.00	2.52	3.53	2.42	4.38	6.65	4.51	4.29	1.94	0.73	5.85	7.23	57.0
1898	7.15	3.80	1.63	3.73	5.61	3.69	4.09	6.85	3.65	6.27	5.48	2.30	54.2
1899	2.80	3.56	7.13	1.79	1.28	4.13	4.89	2.00	7.90	1.84	2.17	2.00	41.5
1900	4.08	8.12	5.76	1.85	3.78	3.65	4.67	4.11	3.67	3.72	5.87	2.40	51.7
1901	1.81	0.62	5.66	5.95	6.91	0.87	3.86	6.14	4.17	3.88	2.08	7.77	49.7
1902	1.72	3.54	5.29	3.31	2.32	4.54	4.66	4.65	5.83	5.59	1.27	4.27	47.0
1903	3.28	4.27	6.40	2.30	0.48	7.79	4.64	4.92	1.66	2.72	2.04	3.95	44.4
1904	4.74	2.45	4.48	5.73	4.55	5.35	2.62	4.09	5.45	1.74	1.35	2.75	45.3
1905	3.90	1.70	3.66	2.56	1.28	2.86	2.63	6.47	6.26	2.27	2.06	3.15	38.8
1906	2.18	2.73	4.90	3.25	4.95	2.82	3.45	6.42	2.59	5.69	1.98	4.49	45.4
1907	2.73	1.92	1.82	1.98	4.02	2.61	3.87	1.44	8.74	5.00	4.50	3.89	42.5
1908	2.25	3.53	2.86	1.97	4.35	0.76	3.28	4.27	1.73	1.57	1.06	3.05	30.7
1909	3.56	5.16	3.01	5.53	3.36	2.24	2.24	3.79	4.99	1.23	1.06	2.95	39.1
1910	6.14	5.08	1.37	3.07	2.67	2.65	1.90	4.03	2.86	0.93	3.69	1.72	36.1
1911	2.36	2.18	3.80	1.87	1.37	2.02	4.21	5.92	3.41	8.81	3.84	4.42	44.2
1912	2.18	3.16	5.70	3.92	4.34	0.77	2.61	3.22	2.52	2.07	4.03	4.04	38.6
1913	3.98	2.94	6.38	3.30	4.94	0.90	1.59	2.26	2.56	5.16	2.11	3.38	39.5
1914	3.72	3.36	5.52	6.59	3.56	2.32	3.53	5.11	0.52	2.09	2.62	2.89	41.8
1915	6.52	7.02	0.12	3.99	1.20	3.00	9.13	8.28	1.37	2.89	2.20	5.86	51.6
1916	2.56	5.27	3.97	3.69	3.21	5.34	6.85	2.49	5.08	1.01	3.29	2.85	45.6
1917	3.64	1.98	4.08	1.83	4.13	5.27	3.36	7.06	2.42	6.60	0.63	2.56	43.6
1918	4.11	2.99	2.91	2.78	2.47	4.01	1.84	2.22	7.00	1.32	2.87	2.95	37.5
1919	2.02	2.80	4.22	2.37	6.20	1.09	4.17	4.81	4.45	1.81	6.20	1.48	41.6
1920	2.74	4.45	3.63	4.71	3.65	6.26	2.06	3.62	6.74	1.54	5.62	6.02	51.0
1921	2.00	2.38	3.57	6.47	4.56	3.87	6.00	2.35	1.84	1.08	6.20	1.90	42.2
1922	1.56	3.02	5.34	2.81	5.47	9.68	4.28	4.25	2.27	2.55	1.56	3.15	45.9
1923	6.02	1.81	1.98	3.19	3.26	2.24	1.77	2.55	1.89	5.50	5.05	4.23	39.5
1924	3.85	2.56	1.05	4.54	2.21	1.28	1.75	3.11	5.87	0.01	2.57	2.16	31.0
1925	3.42	3.64	4.12	3.10	2.55	4.28	6.97	1.93	3.09	4.74	3.23	3.56	44.6
1926	3.23	5.01	3.95	3.62	1.19	2.03	3.24	3.97	1.50	5.02	5.38	2.78	40.9
1927	2.50	2.62	1.96	1.60	4.83	3.37	3.40	5.01	2.79	4.59	8.64	5.65	47.0
1928	2.19	2.90	1.17	4.16	3.25	6.97	6.23	8.40	3.07	0.87	1.88	0.97	42.1
1929	4.33	3.92	3.20	6.89	4.17	3.06	0.70	1.54	3.62	2.75	2.73	4.05	41.0
1930	2.57	1.39	3.95	1.41	3.34	4.47	4.50	1.82	2.08	2.24	3.42	1.63	32.8
1931	3.58	1.80	3.79	2.95	7.44	4.24	3.87	6.57	2.50	3.06	1.55	3.83	45.2
1932	3.67	2.70	4.24	2.33	1.67	2.62	3.83	2.67	3.96	3.69	6.05	1.99	39.4
1933	2.44	3.58	4.79	5.03	1.69	3.68	2.25	6.63	12.3	3.90	1.19	2.81	50.3
1934	3.50	2.82	3.60	4.44	3.42	4.67	1.73	3.02	9.54	2.35	3.46	2.99	45.5
1935	4.96	2.50	1.48	2.54	2.17	5.50	3.10	0.82	4.67	0.88	4.41	1.05	34.1
1936	6.47	2.64	7.04	4.07	1.76	3.28	1.45	4.85	3.80	4.90	2.02	5.96	48.2
1937	5.38	2.23	3.38	4.03	6.09	5.72	2.88	4.91	3.24	4.33	4.86	2.44	49.5
1938	6.60	1.77	2.00	3.07	3.81	8.45	7.45	2.04	14.6	2.49	2.82	3.95	59.0
1939	2.21	2.62	4.49	4.56	2.15	3.21	2.30	3.89	2.97	4.55	0.98	3.89	38.8
1940	2.63	2.72	5.58	6.37	5.67	2.46	4.69	1.56	1.53	1.04	6.31	3.01	43.6
1941	2.21	1.59	4.63	0.55	2.87	2.46	4.04	1.79	2.88	2.13	4.29	3.82	33.9
1942	3.54	1.66	7.89	0.96	2.98	3.63	4.95	2.93	3.94	3.27	6.07	6.03	47.8
1943	2.92	1.63	3.07	3.66	5.62	2.38	6.18	2.49	2.40	3.88	4.64	0.58	39.4
1944	1.24	2.34	4.36	3.66	1.35	4.70	3.88	4.33	5.71	1.74	4.21	2.18	39.3
1945	3.07	3.33	2.16	5.43	6.45	7.67	7.36	2.79	3.57	2.18	4.21	3.91	51.5
1946	2.72	3.52	1.60	2.16	5.41	3.30	5.30	4.00	4.88	1.51	0.70	3.51	38.6
1947	3.37	1.96	3.29	4.59	4.63	3.22	2.73	1.69	2.84	2.04	5.63	2.33	38.3
1948	2.63	2.45	2.92	2.87	5.83	5.67	2.95	3.56	1.91	1.13	5.22	2.87	40.0
1949	4.52	2.47	1.03	2.70	4.76	0.72	3.41	3.64	3.55	2.58	1.79	2.44	33.6
1950	4.33	3.99	2.67	3.64	2.77	3.65	2.83	2.94	2.34	1.87	6.60	4.64	42.3
1951	3.28	4.61	5.13	3.63	2.96	3.04	4.16	3.56	2.63	4.66	6.39	4.30	48.3
Average	3.48	3.09	3.87	3.37	3.70	3.76	4.12	3.85	4.02	3.13	3.62	3.38	43.4

Meteorological Records Massachusetts Agricultural Experiment Station

Average and Mean Monthly and Yearly Precipitation in Inches at Williamstown

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1880	3.39	2.60	1.46	4.77	2.58	1.55	4.36	3.59	3.09	2.46	1.51	2.39	33.8
1881	1.88	6.19	2.28	-	3.53	2.08	5.16	1.02	2.26	2.28	3.33	5.04	-
1882	2.23	-	2.35	1.72	4.26	3.85	2.42	3.26	7.04	0.32	1.18	0.96	-
1883	-	2.64	0.87	1.98	3.81	3.19	4.59	2.92	2.64	3.32	1.65	-	-
1884	1.75	3.76	3.89	1.83	2.51	1.65	-	-	0.58	2.98	2.92	3.72	-
1885	6.63	3.56	0.96	3.18	2.00	1.48	2.87	6.66	1.65	3.12	3.97	3.43	39.5
1886	3.92	2.61	5.01	1.56	4.77	2.72	4.20	1.56	4.31	2.60	5.80	4.04	43.1
1887	6.29	4.50	5.15	3.23	1.31	4.33	10.3	7.03	2.30	1.13	3.77	4.30	54.2
1888	-	2.18	7.89	2.80	3.64	3.90	1.23	4.48	4.21	5.06	4.12	3.38	-
1889	2.96	1.22	1.10	2.31	1.78	5.08	5.81	2.94	2.39	2.95	4.20	3.30	36.0
1892	2.68	1.13	1.75	0.40	5.43	2.07	4.22	4.58	1.68	1.57	2.99	5.46	34.0
1893	2.72	3.72	1.39	2.43	2.75	2.08	1.46	5.84	4.46	2.26	1.22	5.94	36.3
1894	2.54	2.29	1.13	1.82	3.16	2.99	3.39	1.46	4.58	4.91	-	1.75	-
1895	1.87	1.70	2.10	3.90	2.10	3.62	2.37	3.25	2.22	3.74	4.12	3.11	34.1
1896	0.71	2.29	3.10	0.79	2.22	2.55	3.89	3.06	4.83	2.94	2.98	1.46	30.8
1897	2.62	1.37	2.93	3.50	4.21	6.61	9.74	3.40	2.12	0.86	6.46	4.61	48.4
1898	5.25	2.15	2.47	3.60	4.10	3.01	1.48	8.51	3.22	6.99	3.25	2.42	46.4
1899	1.61	2.31	4.05	1.58	1.06	3.66	5.03	1.60	5.31	1.11	1.30	2.29	30.9
1900	3.61	3.46	3.14	1.17	2.43	4.94	5.56	5.91	1.21	3.52	3.59	1.54	40.1
1901	1.69	0.48	4.58	5.76	4.98	1.80	5.78	7.14	1.98	1.91	2.43	4.63	43.2
1902	1.24	2.45	3.56	3.70	3.30	4.83	4.64	5.14	4.01	3.66	0.97	4.41	41.9
1903	2.68	3.55	4.67	1.37	0.63	9.07	3.49	7.51	1.36	4.46	1.92	2.19	42.9
1904	1.96	0.94	1.51	2.22	3.24	5.29	1.60	4.34	5.39	2.56	1.68	1.39	32.1
1905	1.91	0.56	2.74	1.89	1.19	5.74	5.35	4.55	3.24	2.05	1.95	2.13	33.3
1906	1.36	1.89	2.33	2.93	5.40	3.55	5.50	2.77	1.63	3.18	2.45	3.09	36.1
1907	2.24	1.52	1.56	2.88	2.22	3.86	3.96	1.25	6.06	6.50	3.42	2.17	37.6
1908	0.95	2.29	2.03	2.85	5.19	3.24	4.98	3.91	0.38	1.74	0.83	2.09	30.5
1909	3.69	4.46	2.96	3.20	2.84	3.54	1.51	5.37	4.27	1.33	1.49	1.70	36.4
1910	3.90	3.14	1.02	2.53	5.06	3.03	2.61	2.01	5.68	2.03	3.61	2.32	36.9
1911	2.38	0.75	2.49	1.12	1.62	3.85	2.30	4.41	4.21	5.08	1.93	1.82	32.0
1912	2.00	1.23	3.28	4.12	4.83	1.62	2.69	3.64	2.35	4.55	2.44	3.59	36.3
1913	2.99	2.32	6.08	1.76	2.89	0.87	3.88	1.26	2.92	3.91	1.63	2.33	32.8
1914	2.31	1.94	3.90	5.65	1.94	2.21	4.33	5.10	0.53	1.72	2.14	1.94	33.7
1915	3.47	4.14	0.41	2.12	1.46	1.73	9.37	4.47	3.44	2.71	2.03	5.63	40.4
1916	2.05	1.53	3.51	2.48	3.52	3.62	5.30	2.45	5.20	1.79	4.24	4.28	40.0
1917	2.84	2.17	2.54	2.54	3.20	3.52	2.11	4.11	1.67	5.05	0.82	1.85	32.4
1918	1.89	1.86	2.37	2.45	4.04	3.04	1.78	2.31	6.44	2.75	1.83	3.42	34.2
1919	2.68	1.29	7.39	3.18	5.81	2.23	3.03	4.51	6.43	3.32	5.05	1.55	46.5
1920	1.54	3.99	3.30	4.72	1.85	4.15	3.89	4.96	4.91	2.22	4.17	4.45	44.2
1921	1.13	4.22	4.17	2.86	2.41	2.94	6.51	3.59	2.41	1.58	4.58	1.51	37.9
1922	1.56	1.52	3.87	2.63	3.27	6.60	2.05	5.91	1.60	1.42	1.19	2.50	34.1
1923	4.97	1.94	2.41	2.62	2.01	3.39	3.20	3.48	4.08	4.07	4.77	3.20	40.1
1924	3.15	2.40	0.72	5.20	3.28	2.10	4.47	4.44	4.34	0.07	2.16	1.66	34.0
1925	2.05	2.17	2.93	2.58	2.69	4.58	3.14	3.79	6.24	3.13	3.00	1.92	38.2
1926	1.97	4.19	2.43	2.39	1.18	2.52	3.84	3.30	3.15	6.61	3.25	2.32	37.2
1927	2.94	1.81	2.53	0.87	4.04	3.11	5.68	4.26	1.52	5.72	9.39	3.09	45.0
1928	1.45	3.21	1.72	3.51	2.90	5.85	5.28	5.78	2.73	1.27	2.22	0.94	36.9
1929	3.34	3.28	4.68	5.98	3.32	3.74	1.33	1.12	1.89	1.53	2.29	2.79	35.3
1930	2.82	1.63	3.67	1.45	2.52	2.80	4.23	1.40	2.27	1.69	3.24	1.33	29.1
1931	2.79	1.25	2.24	2.71	4.53	5.42	5.45	3.53	4.41	2.08	1.83	3.51	39.8
1932	4.33	2.40	3.33	2.02	2.46	2.34	4.78	4.16	1.96	3.38	4.03	2.62	37.8
1933	2.26	2.82	3.20	5.14	1.68	2.58	1.95	6.28	6.97	2.96	1.41	3.35	40.6
1934	3.03	3.06	2.64	4.33	3.21	7.30	2.45	2.01	3.97	2.30	4.46	2.53	41.3
1935	5.02	2.50	2.52	2.26	2.30	4.45	5.77	1.47	3.64	1.16	5.28	1.29	37.7
1936	4.41	1.89	7.90	3.72	3.21	3.05	1.90	6.89	1.97	3.50	2.78	4.24	45.5
1937	4.28	2.16	2.90	2.84	5.09	4.86	2.99	1.80	7.83	4.77	3.57	1.75	44.8
1938	3.40	2.03	1.68	3.19	2.69	5.59	7.20	4.03	9.97	1.43	3.22	3.08	47.5
1939	2.46	2.84	2.97	4.45	1.29	2.19	2.91	4.63	2.81	4.90	1.92	2.14	35.5
1940	1.88	2.08	3.67	5.04	4.42	2.94	4.31	1.42	6.35	1.14	4.84	3.65	41.8
1941	1.29	1.92	0.98	0.21	2.55	2.52	5.80	1.62	2.81	2.38	1.69	2.42	26.2
Average	2.76	2.43	2.97	2.85	3.06	3.55	4.11	3.85	3.59	2.90	2.99	2.85	38.00

Reference: Milham W., Meteorology and Meteorological Observation in William College

Average and Mean Monthly and Yearly Precipitation in Inches at Taunton

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1926	2.89	3.89	2.97	2.15	3.17	2.83	6.17	2.23	1.70	6.32	5.93	2.79	43.1
1927	2.44	2.68	1.43	2.05	3.01	2.94	4.56	10.1	3.29	4.33	4.81	5.38	47.0
1928	2.52	3.26	2.37	5.36	2.29	5.11	4.09	1.58	5.37	5.05	2.37	2.62	42.6
1929	3.38	3.53	4.24	7.60	3.89	0.92	2.51	3.12	3.82	3.45	3.54	4.42	44.4
1930	3.04	3.05	2.88	1.68	3.00	1.80	2.33	3.64	0.37	5.62	3.58	2.06	33.8
1931	3.13	1.77	5.16	2.84	5.78	7.15	4.73	5.51	1.75	3.81	1.01	3.96	46.0
1932	6.12	1.81	5.62	1.54	2.69	2.10	3.16	6.23	6.80	7.63	6.58	1.67	52.0
1933	2.09	3.02	6.07	7.61	3.19	1.65	3.18	3.36	11.6	3.27	1.64	3.24	49.0
1934	4.06	3.18	3.85	5.03	3.05	4.48	1.76	2.29	3.83	3.96	4.66	3.29	43.5
1935	5.25	2.72	1.85	5.45	1.79	6.97	3.66	2.30	3.34	1.07	5.42	1.25	41.1
1936	6.07	2.32	6.60	4.44	1.10	2.18	1.62	4.25	7.42	2.21	1.17	9.31	48.7
1937	4.01	1.14	4.02	5.68	2.30	3.91	0.96	7.20	3.30	4.04	5.60	3.97	46.1
1938	3.68	2.22	2.34	2.78	4.51	8.89	5.88	1.89	6.74	3.91	3.25	3.53	49.6
1939	2.69	4.06	5.47	4.85	1.06	3.95	2.11	5.73	3.02	5.90	1.60	2.47	42.9
1940	2.40	4.79	3.92	7.12	4.71	2.00	4.37	0.97	4.17	2.23	8.11	2.72	47.5
1941	3.68	2.32	2.15	2.45	2.01	5.40	5.12	3.67	0.02	2.26	2.96	2.93	35.0
1942	2.97	3.96	7.18	0.85	1.77	2.41	5.20	4.04	2.04	4.74	5.65	3.96	44.8
1943	3.30	1.82	3.02	2.99	4.90	2.03	4.33	2.95	1.02	3.38	3.21	1.07	34.0
1944	1.91	1.69	3.97	3.90	0.42	2.94	1.84	1.14	9.29	2.90	7.13	2.72	39.8
1945	3.55	4.09	1.92	1.69	3.88	3.51	2.29	2.74	1.61	2.71	8.39	7.06	43.4
1946	3.49	2.89	1.68	2.79	4.68	3.91	1.01	10.7	2.81	6.00	1.23	3.55	39.3
1947	2.65	0.84	2.77	4.08	5.59	5.44	5.84	1.45	2.95	2.05	4.79	3.30	41.8
1948	5.71	2.09	4.07	3.45	10.39	3.26	5.20	4.57	1.73	6.23	5.28	1.33	53.3
Average	3.52	2.75	3.68	3.86	3.44	3.73	3.52	3.98	3.83	4.05	5.26	3.45	43.9

Reference: Climatological data U. S. Department of Agriculture Weather Bureau

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