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CROP PRODUCTION IN RELATION TO PHYSICAL FACTORS.

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A THESIS

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CROP PRODUCTION IN RELATION TO PHYSICAL FACTORS.

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I N T R O D U C T I O N .

As the title would indicate, the object sought in this paper is to correlate, if possible, the facts determined by a physical study of the soils of several plots, cropped under different conditions, with the information gained by a close study of the crops grown on the respective plots. Among progressive thinkers in the agricultural field, the impression is daily growing stronger that the subject of soil physics is fundamental in crop production. A score of Experiment Stations have carried on investigations in this connection which will be duly accredited further on. However, like any movement in its beginnings, the work has been, with several notable exceptions, rather fragmentary and unrelated to crop yields. In passing, it might be pertinent to observe the work of the Department of Agriculture in studying the relation between crops and soil texture. Tobacco soils of Connecticut and Georgia of like texture produced crops of nearly identical quality; it was learned in addition that a certain per cent of clay favorably influenced the quality of vegetables grown there. A mass of data has been accumulated on the moisture requirements of the several field crops. Many series of moisture determinations have been published, together with the crop yields in a few instances. Several Stations, notably Wyoming, have made studies upon the relation between minimum and maximum water content and yield. Minnesota, North Dakota, Utah have made moisture determinations under different tillage, rotation, and irrigation systems. New Mexico Station has done some excellent work in combining mechanical analysis with complete physical study of several plot soils; altho similar to our work, this did not include a crop study. On the other hand, considerable work has been done in associating different types of natural vegetation with certain types of soil and degrees of soil fertility. So successful has this been that a "Use Survey" of State lands, upon this basis, has been urged. Briefly then, the studies of cropping results in relation to those physical soil factors that surround them are few and scattered compared with chemical studies in the same field.

In the development of the title, a three-fold view point will be utilized. Part one deals with the purely physical study such as specific gravity, tenacity and pore space. Part two, dealing with the whole question of soil moisture, normally follows at this point. Part three, dealing with the crop, comes last, since it is directly dependent upon the two factors, mechanical condition and soil moisture, which precede it. Such phases as score card study, weed content and yield will be elaborated here. To summarize the objects of this paper: Part One deals with plot soil study; Part Two deals with plot moisture study; Part Three deals with plot crop study.

This experimental work was carried out upon a nearly level stretch of land located upon the northeast portion of University Farm. This is known as Field C. This field is further sub-divided into four series (I. - IV.) of plots, running lengthwise of the field. Each series is composed of eleven plots, each one-tenth acre in size. These plots were laid out in the spring of 1894 and designed as a study of rotations. Plots one, six, eleven, in each series, were designated as check plots and are cropped according to the five year standard rotation: wheat, grass, grass, oats, corn. The others range from a two year to a seven year rotation with a number of continuously cropped plots in addition. After a thorough examination, it was decided that only typical plots should be studied. Here is the list.

Plot 4 Series I - 4 year rotation: wheat, clover, oats, corn. Wheat in 1911.

Plot 5 Series I - 5 year rotation: wheat, grass, grass, oats, millet. Wheat in 1911.

Plot 6 Series II - Standard 5 year rotation: wheat, grass, grass, oats, corn. Wheat in 1911.

Plot 7 Series II - Continuous corn.

Plot 8 Series II - Continuous potatoes.

Plot 10 Series II - Continuous peas.

Plot 1 Series III - Standard 5 year rotation: wheat, grass, grass, oats, corn. Wheat in 1911.

Plot 2 Series III - Continuous wheat.

Plot 3 Series III - Continuous wheat together with six-tenths pounds of clover sown annually.

Plot 4 Series III - 2 year rotation: wheat and clover. Oats and peas substituted in 1911.

Plot 7 Series III - Continuous pasture.

Plot 4 Series IV - 6 year rotation: grain, pasture 3 years, corn, peas. Pasture in 1911.

Plot 10 Series IV - 2 year rotation: wheat and timothy. Wheat in 1911.

Scanning the tables briefly, we find one 4 year rotation, one 6 year rotation, two 2 year rotations, three 5 year rotations, six continuously cropped plots. This gives us a very helpful check all along the line and, with the variation present, gives us a fund of facts touching upon a wider field. However, it is noticeable that the prevailing crop is wheat. This is due to the fact that all rotations started the same year. The dry season of 1910 prevented a catch, necessitating a re-seeding throughout. Plot 4 Series III, however, was put into peas and oats and cut for hay since no clover catch was obtained in 1910.

PART I.

PHYSICAL STUDY OF SOILS OF THE SEVERAL PLOTS.

In this section of this thesis, which embraces about one-third of the whole, I propose to elaborate my findings along the line of purely physical studies of the several plots as fundamental to what follows. The comparative features of this and other available work will be shown and the whole will center, in a measure, about the factor of loss on ignition. The several features will be covered in this order: Loss on Ignition, Apparent Specific Gravity, Real Specific Gravity, Field Weight, Tenacity, Breaking Strength, Pore Space. This last factor comes as introductory to the problem of soil moisture. Any available data, bearing on the same topics, will be used to amplify, explain or support our findings.

A. Loss on Ignition.

The presence of organic matter in any or all stages of decay is one modifying factor that affects everyone of the physical factors that we study. Whether it be a question of soil weight or soil moisture, this influence is felt. But the determination of humus (the product of decaying organic matter) is a chemical problem and in this paper we are concerned, primarily, with the question of soil physics. However, by a series of ignition tests, we acquire a body of results that indicate, relatively, the amount of organic matter present. Such a series of tests, carried on in duplicate, was made by igniting soil for fifteen minutes, cooling and weighing. After allowing for hygroscopic moisture, we secured the following results:

Table I.

Loss on Ignition.

PLOT	LOSS ON IGNITION.
Plot 4 Series I	8.30 %
Plot 5 Series I	7.80 %
Plot 6 Series II	7.25 %
Plot 7 Series II	5.99 %
Plot 8 Series II	6.55 %
Plot 10 Series II	6.19 %
Plot 1 Series III	7.49 %
Plot 2 Series III	7.69 %
Plot 3 Series III	8.14 %

PLOT	LOSS ON IGNITION
Plot 4 Series III	8.36 %
Plot 7 Series III	8.08 %
Plot 4 Series IV	7.78 %
Plot 10 Series IV	7.72 %

In this connection, we will give the results of ignition tests at Rothamsted. However, these plots had been cropped for forty years, which explains the outstanding differences:

Unmanured plots	4.2 % loss
Manured plots	6.7 % loss.

The outstanding feature of Table I. is, of course, a comparison of continuous and rotation cropping. Observe that seven per cent loss occurs in all but three cases - the continuously cropped plots of cultivated type. The highest content of all is recorded in those plots where clover is grown annually or biennially. However, it is worthy of note that the continuous pasture also ranks high. On the other hand, Plot 6, Series II, (rotation) ranks lower than any other with the exception of continuously cropped plots. As a check upon these figures, the work of Professor Snyder (Minnesota Bulletin No. 109) has been referred to. In general his nitrogen determinations seem to bear out our results above, if one is justified in saying there is any relation between nitrogen content and loss on ignition. We would point out two further facts: while Snyder finds the continuous wheat plots standing at the head of the continuous series from the chemist's viewpoint, but yet inferior to the rotation plots, our findings in experimental soil physics have been uniformly favorable to this plot. Snyder found further, that Plot 6 Series II contained the smallest amount of nitrogen of any rotation plots. We find it occupies the same position in regard to ignition loss except that continuous wheat is also somewhat higher. It is also noteworthy that Plot 1 Series III (5 year rotation) also ranked rather low in comparison with other plots. Can this mean that the heavy yields produced combined with more rapid oxidation and frequent cultivation have caused a more rapid conversion of organic matter into soluble humus than the grass crop and application of organic matter, combined, could return? The greater loss in plots three, four, seven, Series III is readily understood when we recall that clover is grown so much and the soil disturbed so little. Much the same applies to the plots in Series IV where grass forms fifty to sixty-six per cent of the rotation. A brief quotation from "Lawes and Gilbert" is appropriate here and may explain some of the phenomena observed on these plots. "Continuous cropping without manure soon reduces such materials in the soil to a low ebb below which they do not fall appreciably in succeeding years. The crop production becomes very near stationary and is accompanied by very small reduction (of organic matter) even if there are not compensating influences at work maintaining the store at a constant low level. Similarly, when very large amounts of organic matter are added every year ----- after a time there is but little increase in the proportions of carbon and nitrogen present in the soil because the bacterial agencies ------ are so stimulated by abundant food supply as to keep pace with the annual additions." In the light of these facts, our findings of small differences in yield under different cropping systems can be more readily understood.

B. Specific Gravity.

1. Apparent.

As any student of elementary physics knows, the specific gravity of matter means the weight of a given volume in relation to the weight of the same volume of water. But some forms of matter, soil for example, may have more than one kind of specific gravity. This is readily explained. Soil is not the compact mass of matter it appears to be on first sight. Its solid particles are not in absolute and complete contact but are more or less permeated by air spaces (pore space). This gives rise, then, to the terms "Apparent" and "Real" Specific Gravity. By the former, we understand the comparative weights of equal volumes of soil and water under natural conditions of the latter, i.e. with due recognition of pore space. By the latter, we understand the comparative weights of equal volumes of water and soil, the latter based on absolute weight of solid matter, the solid particles in complete contact, and all pore space eliminated. We will first discuss apparant specific gravity.

This topic was studied from two viewpoints, laboratory and field conditions. In the former case, brass vessels of equal size (300 cc.) were used. The soils, sifted to 2 mm. diameter, were poured into the respective vessels and subjected to the same pressure by dropping a weight of five hundred grams a uniform number of times from the same height. With the field study, the results were determined from field weight. A core of soil was extracted by driving the cylinder, three inches in diameter, to a depth of six inches into the soil. The volume was then determined, and from this the apparent specific gravity by comparison with an equal volume of water. There will be some variations between the two methods for the reason that compaction was uniform in all cases with laboratory testings, but unequal in field tests. Some plots were in grain, some in cultivated crops, and still others in pasture. Naturally, the mechanical effects of cattle tramping over soil or tilling it at the surface will materially affect the field weight of equal volumes increasing it in the first case and decreasing it in the second.

Table II.

Apparent Specific Gravity of Soils.

PLOT	LABORATORY RESULTS	FIELD RESULTS
Plot 4 Series I	1.117	1.193
Plot 5 Series I	1.123	1.274
Plot 6 Series II	1.136	1.252
Plot 7 Series II	1.164	1.382
Plot 8 Series II	1.233	1.404
Plot 10 Series II	1.195	1.271
Plot 1 Series III	1.165	1.213
Plot 2 Series III	1.135	1.208

PLOT	LABORATORY RESULTS	FIELD RESULTS
Plot 3 Series III	1.123	1.136
Plot 4 Series III	1.149	1.245
Plot 7 Series III	1.167	1.408
Plot 4 Series IV	1.154	1.343
Plot 10 Series IV	1.343	1.108

It is apparent that laboratory and field studies have given much the same results. Plot 6 Series II is a trifle heavier than Plot 5 Series I in field study and the reverse in laboratory work. The daily moisture determinations constantly indicated a higher percentage in the latter. Hence, in extracting the core, the soil particles would cling together better and the soil completely intact would be extracted. With a drier soil the work could not be done so neatly, fragments would drop off and the soil being somewhat looser, as great a mass would not be removed in a given volume, thus reducing weight. On the other hand, the drier soil indicating less organic matter present would naturally weigh a trifle heavier under equal pressure as laboratory findings indicated. Observe the small variations in Plots 4 and 10 Series IV. The former is in pasture this year. Hence it contains a greater mass of soil within a given volume, due to compression, while the last plot was very loose and dry, the most so of all plots studied. The explanation above applies with still greater force here.

Apparent specific gravity is of greater importance, economically, than real specific gravity, for it is based on natural soil conditions. In a measure, it may indicate the quantity of organic matter present - the larger the quantity of the latter, the lighter the soil. Hall in "The Soil" page 163, proves this by actual measurement.

Table III.

From Hall's "The Soil."

Apparent Specific Gravity.

Soil Type	Apparent Specific Gravity.
Sandy clay	1.279
Ligh sand	1.266
Sandy loam	1.225
Light loam	1.222
Sandy subsoil	1.18
Light loam subsoil	1.144

Soil Type	Apparent Specific Gravity
Heavy clay	1.062
Sandy peat	0.782

Similar data is furnished by O'Connell.

Table IV.

From O'Connell's "Soils, their Nature and Management."

Apparent Specific Gravity.

Soil Type	Apparent Specific Gravity
Sandy soil	1.28
Loam	1.22
Clay	1.06
Peat	.78

B. Specific Gravity.

2. Real.

The tables on real specific gravity will be given in connection with those on apparent specific gravity and loss on ignition so as to trace through a comparison if such exists. The picnometer method was used and the tests were often repeated a third time to insure accuracy.

Table V.

Comparison of Loss on Ignition and Specific

Gravity, Real and Apparent.

Plot	Specific Gravity Apparent Field	Specific Gravity Apparent Laboratory	Specific Gravity Real	Loss on Ignition.
Plot 4 Series I	1.193	1.117	2.526	8.30 %
Plot 5 Series I	1.274	1.123	2.537	7.80 %
Plot 6 Series II	1.252	1.136	2.577	7.25 %
Plot 7 Series II	1.382	1.164	2.613	5.99 %
Plot 8 Series II	1.404	1.233	2.659	6.55 %
Plot 10 Series II	1.271	1.195	2.63	6.19 %
Plot 1 Series III	1.213	1.156	2.596	7.49 %
Plot 2 Series III	1.208	1.135	2.593	7.69 %
Plot 3 Series III	1.136	1.123	2.59	8.14 %
Plot 4 Series III	1.245	1.149	2.59	8.36 %
Plot 7 Series III	1.408	1.167	2.595	8.08 %
Plot 4 Series IV	1.343	1.154	2.59	7.78 %
Plot 10 Series IV	1.108	1.168	2.599	7.72 %

Observe how the laboratory and field study of apparent specific gravity agrees in absolute uniformity with real specific gravity with the two exceptions already noted. Upon further comparison of this data with loss on ignition, we find as a whole the same relationship still exists. While the three continuously cropped plots do not indicate exact proportion between organic content and real specific gravity, the results are still striking.

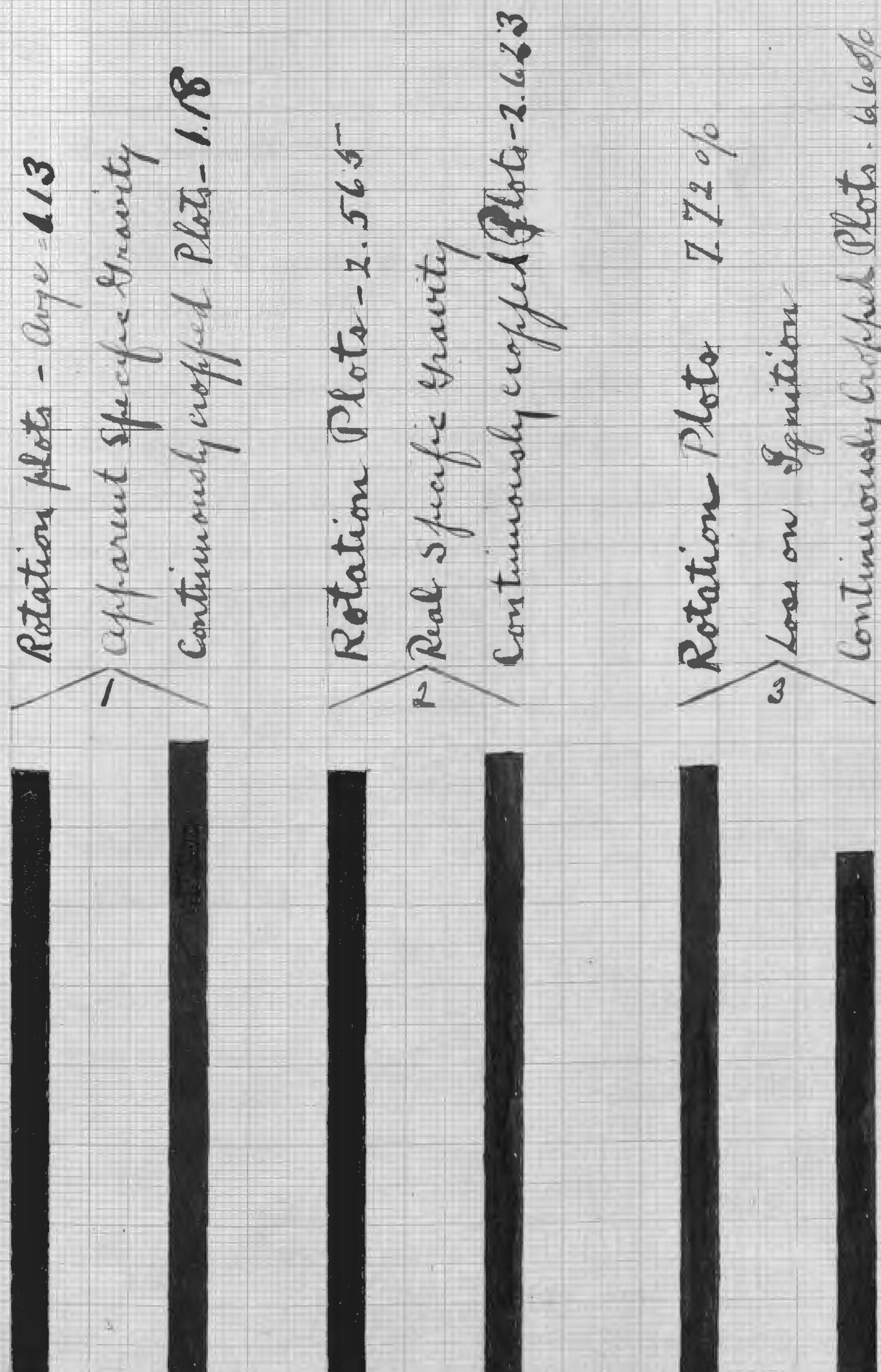
Table VI.

Condensed Comparison of Data in Table V.

Plot		Apparent Specific Gravity	Real Specific Gravity	Loss on Ignition.
Plot 4 Series I	Rotation Plots.	1.137	2.565	7.72 %
Plot 5 Series I				
Plot 6 Series II				
Plot 1 Series III				
Plot 4 Series IV				

Plate I Table VI

Comparison of Apparent and Real Specific Gravity and Loss on Ignition



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Plot		Apparent Specific Gravity	Real Specific Gravity	Loss on Ignition.
Plot 7 Series II Plot 8 Series II Plot 10 Series II Plot 2 Series III	Continuously cropped plots.	1.182	2.623	6.60 %

These rotation plots represent a fair average of the soil conditions under systematic cropping on Field C to which the continuous method of cropping affords a marked contrast. The showing of the latter would be much poorer were it not for the good conditions of the wheat plots.

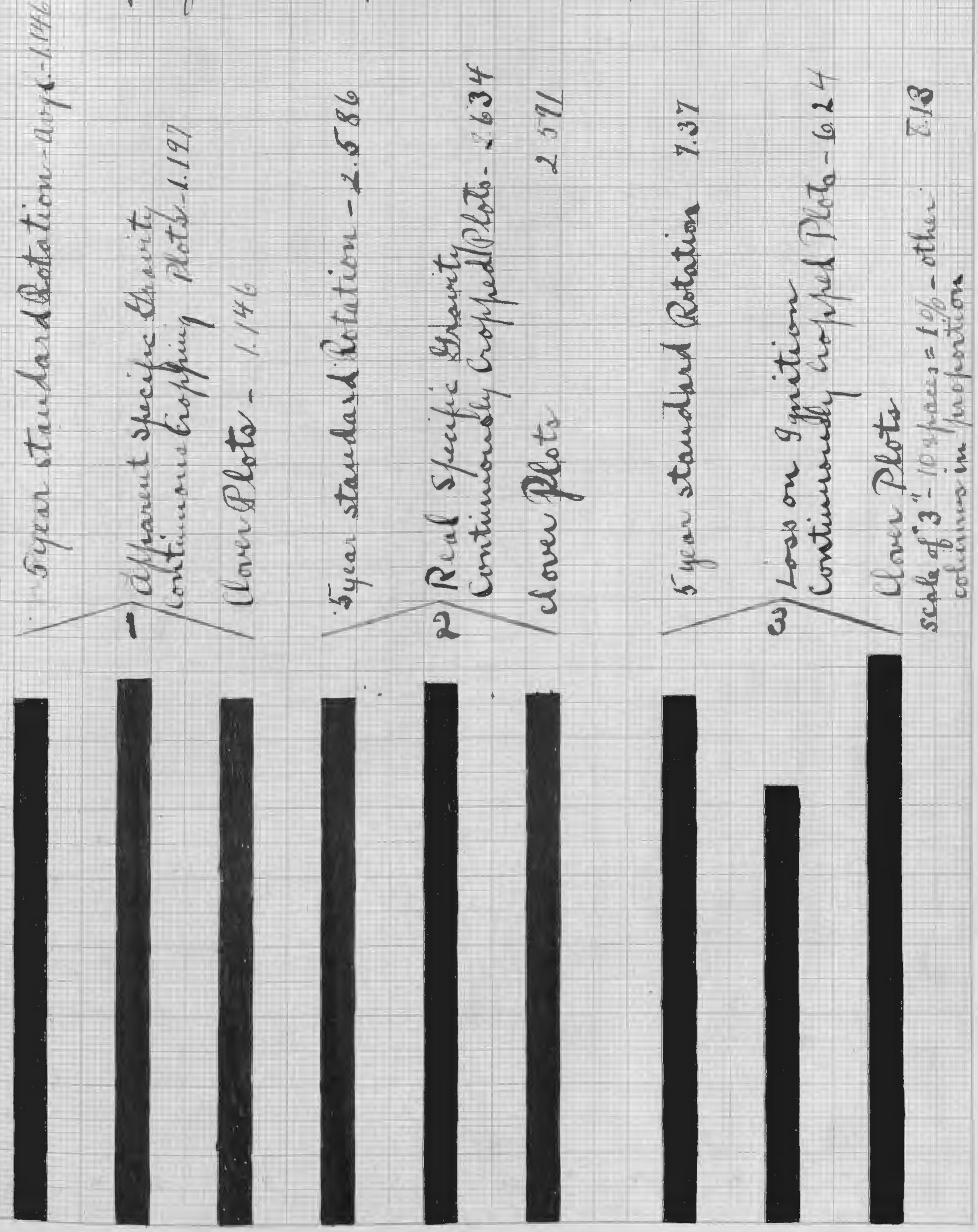
Table VII.

Another Condensed Form of Table V.

Plot		Apparent Specific Gravity.	Real Specific Gravity	Loss on Ignition.
Plot 6 Series II Plot 1 Series III	Standard 5 year rotation.	1.146	2.586	7.37 %
Plot 7 Series II Plot 8 Series II Plot 10 Series II	continuous cropping plots.	1.197	2.634	6.24 %

Plate II Table VII

A further comparison of Apparent and Real Specific Gravity and Loss on Ignition.



Plot	Apparent Specific Gravity	Real Specific Gravity	Loss on Ignition.
Plot 3 Series III) clover plots and continuous pasture. Plot 4 Series III) Plot 7 Series III)	1.146	2.591	8.13 %

Note effect of omission of wheat from list of continuously cropped plots. The marked difference in loss on ignition in the last two cases is out standing. The excellent showing of Plot 2 Series III (continuous wheat) in all work thus far is worthy of comment. Naturally, the plot in continuous grass, showed up well in organic content. Note further that only in those cases where ignition loss falls below seven per cent does real specific gravity rise above 2.6. The high ignition loss in the clover plots, over eight per cent, is significant when compared to the five year rotation loss, seven per cent plus. Lyon and Fippin in "Soils" page 96 have constructed the following table:

Table VIII.

From Lyon and Fippin's "Soils."

Real Specific Gravity of Soils.

Soils.	Specific Gravity.
Clay	2.837
Silt	2.698
Very fine sand	2.68
Coarse sand	2.655
Fine sand	2.659
Medium sand	2.648
Fine gravel	2.647

The New Mexico Station has done some interesting work in specific gravity determinations. The soils tested were of a clay loam character and showed variation ranging from 2.6 to 2.72. In general, we find that real specific gravity is independent of the fineness of particles and is determined by the organic or inorganic source of the material. Thus pure clay might have a slightly higher real specific gravity than sand, yet it will always have a lower apparent specific gravity because of greater pore space. In our determinations the variations will naturally not be very great and I feel we can very safely assume, from a review of the figures above, that it is largely dependent upon the organic matter present.

Soil Weight.

Following closely upon a study of specific gravity comes the subject of soil weight. We plan to show this data upon basis of real and apparent specific gravity and field weight. The latter is, of course the most important since the two former are merely empirical calculations. The method of taking field samples with cylinder has already been given.

Table IX.

Field Weight, Calculated on three Bases and Contrasted with Loss on Ignition.

Weight per cubic foot.

Plots	Apparent Specific Gravity	Real Specific Gravity	actual Field Weight	Loss on Ignition.
Plot 4 Series I	69.81#	157.87#	74.35#	8.3 %
Plot 5 Series I	70.187#	158.56#	79.63#	7.9 %
Plot 6 Series II	71.00#	161.06#	78.00#	7.25 %

Plots	Apparent Specific Gravity	Real Specific Gracity	Field Weight	Loss on Ignition.
Plot 7 Series II	72.25#	163.31#	86.14#	5.99 %
Plot 8 Series II	76.06#	166.18#	87.50#	6.55 %
Plot 10 Series II	74.68#	164.37#	79.62#	6.19 %
Plot 1 Series III	72.25#	162.25#	75.53#	7.49 %
Plot 2 Series III	70.93#	162.06#	75.09#	7.69 %
Plot 3 Series III	69.18#	161.87#	72.08#	8.14 %
Plot 4 Series III	71.81#	161.87#	77.56#	8.36 %
Plot 7 Series III	72.83#	162.187#	87.41#	8.08 %
Plot 4 Series IV	72.12#	161.87#	82.48#	7.78 %
Plot 10 Series IV	72.90#	162.43#	69.86#	7.72 %

Table X.

Weight of Acre Foot of Soil (based on first six inches) Contrasted with Loss on Ignition.

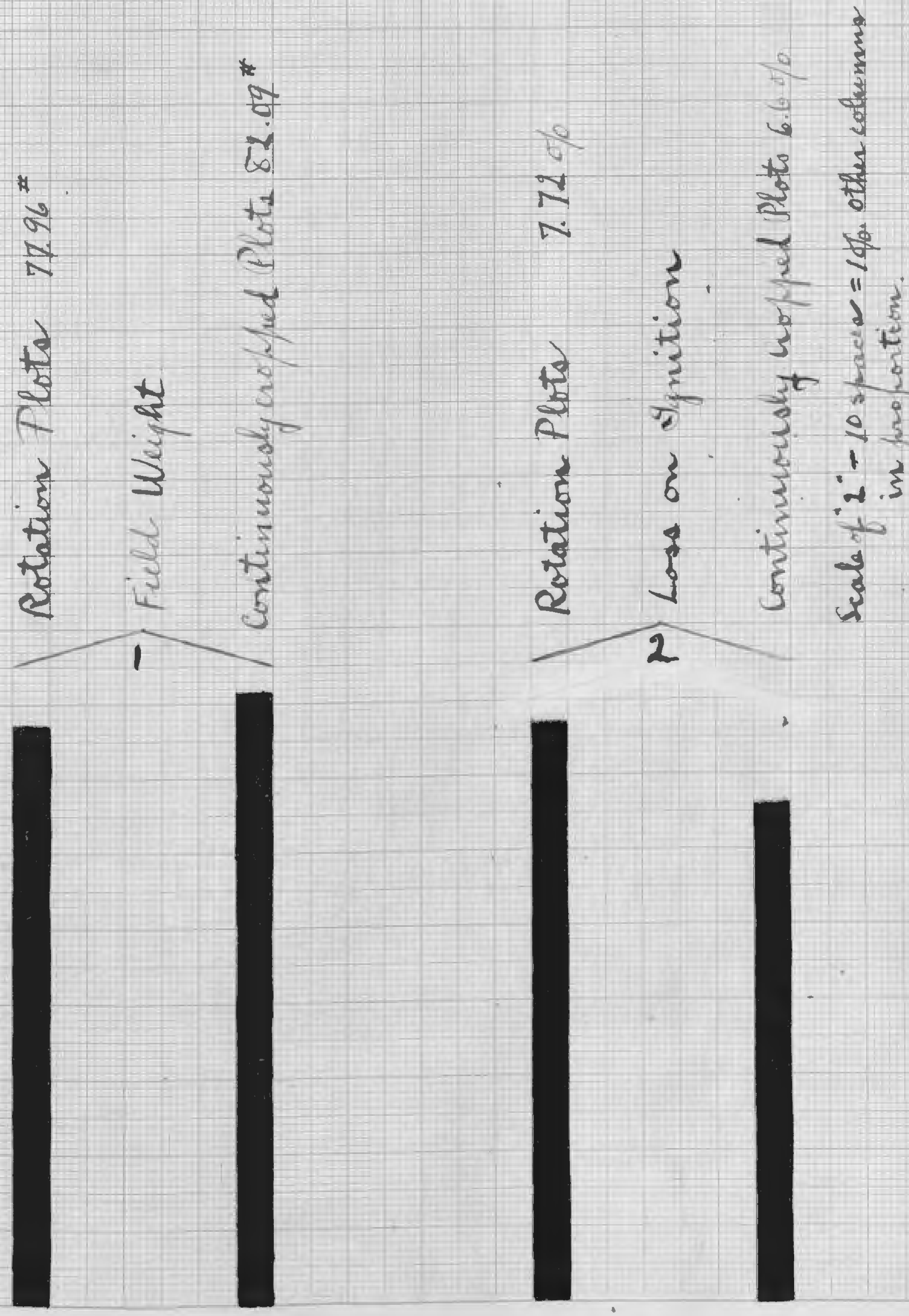
Plot	Weight	Loss on Ignition.
Plot 4 Series I	3,238,000#	8.30 %
Plot 5 Series I	3,468,000#	7.90 %
Plot 6 Series II	3,397,000#	7.25 %
Plot 7 Series II	3,754,000#	5.99 %

Plot	Weight	Loss on Ignition.
Plot 8 Series II	3,811,000#	6.55 %
Plot 10 Series II	3,468,000#	6.19 %
Plot 1 Series III	3,288,000#	7.49 %
Plot 2 Series III	3,267,000#	7.69 %
Plot 3 Series III	3,136,000#	8.14 %
Plot 4 Series III	3,375,000#	8.36 %
Plot 7 Series III	3,807,000#	8.08 %
Plot 4 Series IV	3,593,000#	7.78 %
Plot 10 Series IV	3,105,000#	7.72 %

In the discussion of "Field Weight" we shall follow our outline taking up first "Weight per cubic foot" and later "Weight per Acre foot." The weight per cubic foot is a common expression we use when speaking of soils. For it is concrete and more readily understood than the rather abstract terms of specific gravity. The weights per unit volume vary from 69.06 pounds in one extreme to 87.5 pounds on the other. It is noticeable that there is some variation in the actual field weight and the laboratory estimates based on apparent specific gravity. This is natural, for these field soils have had different treatment. Thus

Plate III - Table XI

A comparison of Field Weight and Loss on Ignition



the continuous pea plot, Plot 10 Series II, was extremely loose and dry which explains its behavior when compared with continuous corn which throughout the latter part of the season maintained a very high moisture content. Likewise Plot 10 Series IV was very loose and dry throughout the season. Plot 7 Series III being in continuous posture for ten years quite naturally would leave the soil somewhat compressed and show a greater relative weight for a given volume not withstanding its high content of organic matter. The same explanation largely holds true for the next plot in pasture, Plot 4 Series IV. Turning now to "Loss on Ignition" with these general facts in mind, the general relationship between field weight and organic content is indicated, which was pointed out in the determinations of apparent specific gravity.

Table XI.

Condensed Form of Table IX.

Plots		Field Weight	Loss on Ignition.
Plot 4 Series I Plot 5 Series I Plot 6 Series II Plot 1 Series III Plot 4 Series IV	Rotation Plots	77.96#	7.72 %

Plots		Field Weight	Loss on Ignition.
Plot 7 Series II Plot 8 Series II Plot 10 Series II Plot 2 Series III	Continuously Cropped Plots	82.09#	6.6 %

These figures are quite expressive. Using the same tabular arrangement and making the necessary changes we have

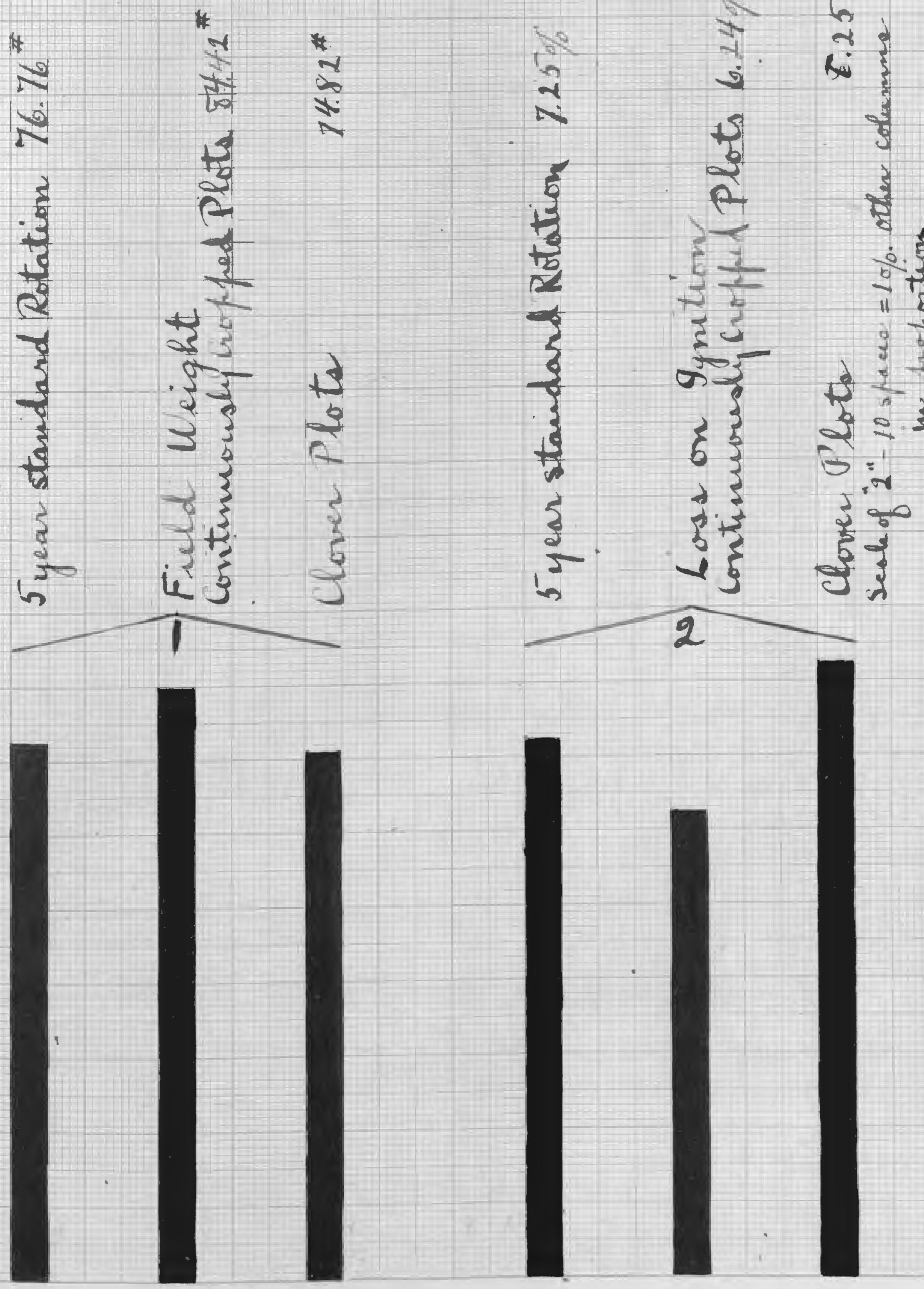
Table XII.

Another Condensed Form of Table X.

Plots		Field Weight	Loss on Ignition.
Plot 6 Series II Plot 1 Series III	5 year standard rotation.	76.36#	7.25 %
Plot 7 Series II Plot 8 Series II Plot 10 Series II	Continuously Cropped Plots.	84.42#	6.24 %
Plot 3 Series III Plot 4 Series III	Clover Plots	74.82#	8.25 %

Plate IV - Table XII

A further comparison of Field Weight and Loss on Ignition



Note here increase of weight upon omission of continuous wheat plot. Before passing on to consider the weight per acre foot of soil let us briefly survey some other work of this type. McConnell, in "Soils, their Nature and Management" says that "A medium good arable soil is taken at 75# per cubic foot as a standard and gives a variation in weight from 49# (peat) to 80# (sandy soil)." We will quote further from two other authorities. From A. D. Hall's work we take the following:

Table XIII.

Soil Weight From "Soils" - A. D. Hall.

Soil	Weight per Cubic Foot.
Sandy Peat	49#
Heavy Clay	66.4#
Light Loam	76.4#
Sandy Loam	76.7#
Light Sand	79.2#
Sandy Clay	80#

King, of Wisconsin, working under conditions comparable to ours made these findings:

Table XIV.

Soil Weight From "Soils" - F. H. King.

Soil	Weight per Cubic Foot.
Peat	30# - 50#
Garden Mold (rich)	70#
Heavy Clay	75#
Common Arable Land	80# - 90#
1/2 Sand, 1/2 Clay	96#
Dry, Calcarous, Siliceous Soil	110#

Apparently then according to King, our soil, on a scale of weight, would range from a garden mold to common arable land. Our five year standard rotation would fit very nicely into Hall's tabulation as a sandy loam while the clover plots would range between a garden loam and a heavy clay.

Our determinations on the weight of an acre foot of soil show a variation of about 706,000# or more than 22 per cent. The same explanations apply here as have preceded. The last and lowest weight occurred where the soil was very loose while the heaviest weight comes in the potato soil where the sponge like action of organic matter is so largely lacking. Mechanical factors cause the heavy weight found in pasture plots while continuous growth of clover probably explains the low weight in Plot 3 Series III.

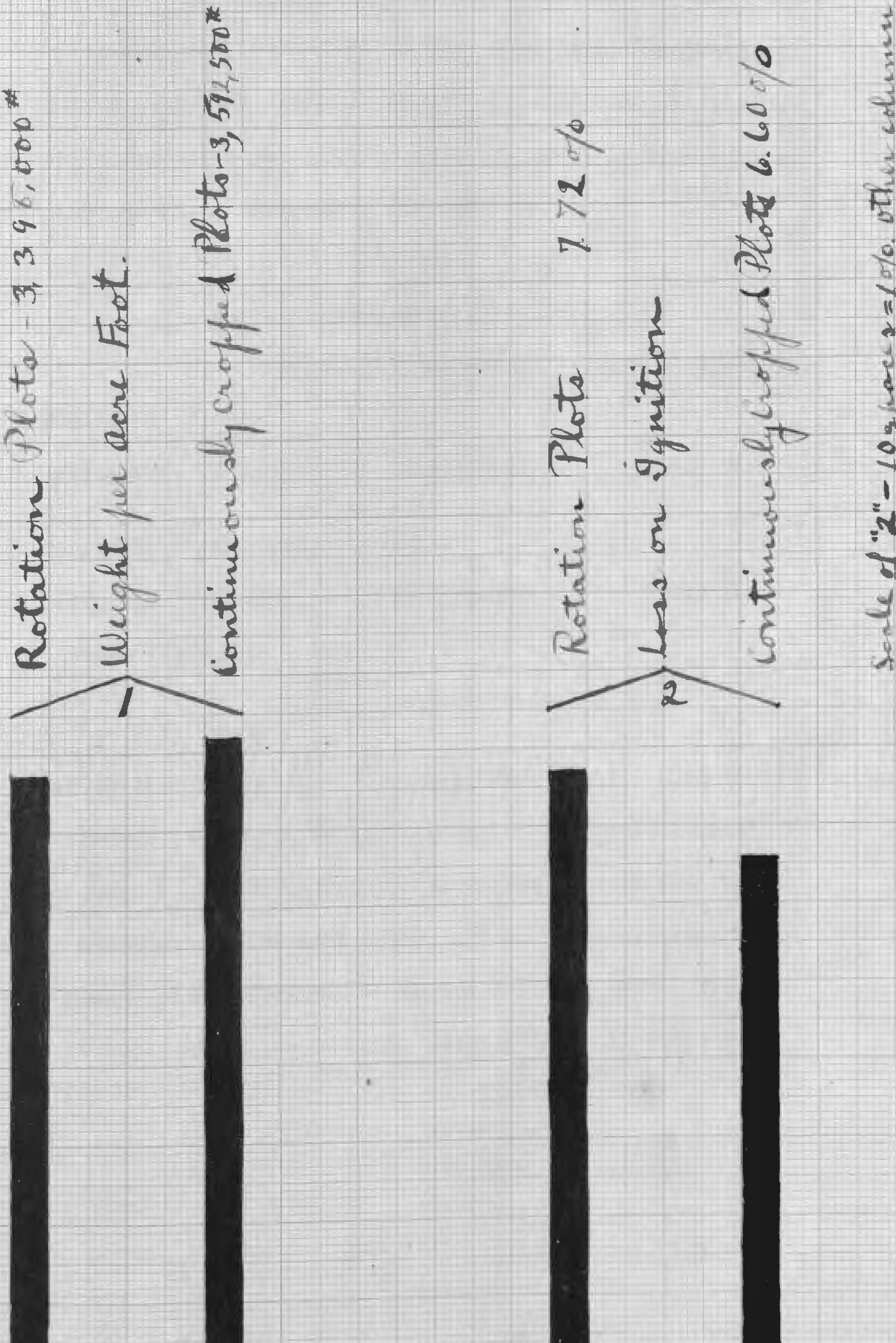
Table XV.

Condensed Form of Table X.

Plot		Weight per Acre Foot.	Loss on Ignition.
Plot 4 Series I Plot 5 Series I Plot 6 Series II Plot 1 Series III Plot 4 Series IV	Rotation Plots.	3,398,000#	7.72 %
Plot 7 Series II Plot 8 Series II Plot 10 Series II Plot 2 Series III	Continuously Cropped Plots.	3,592,500#	6.60 %

Plate V - Table XV

Comparison of Weight per Acre Foot and Loss on Ignition



Considered on the basis of the plots under cultivation, corn, potatoes and peas, omitting wheat, the weight of continuously cropped plots per acre foot run fully 80,000# in excess of the figures just given. See next table.

Table XVI.

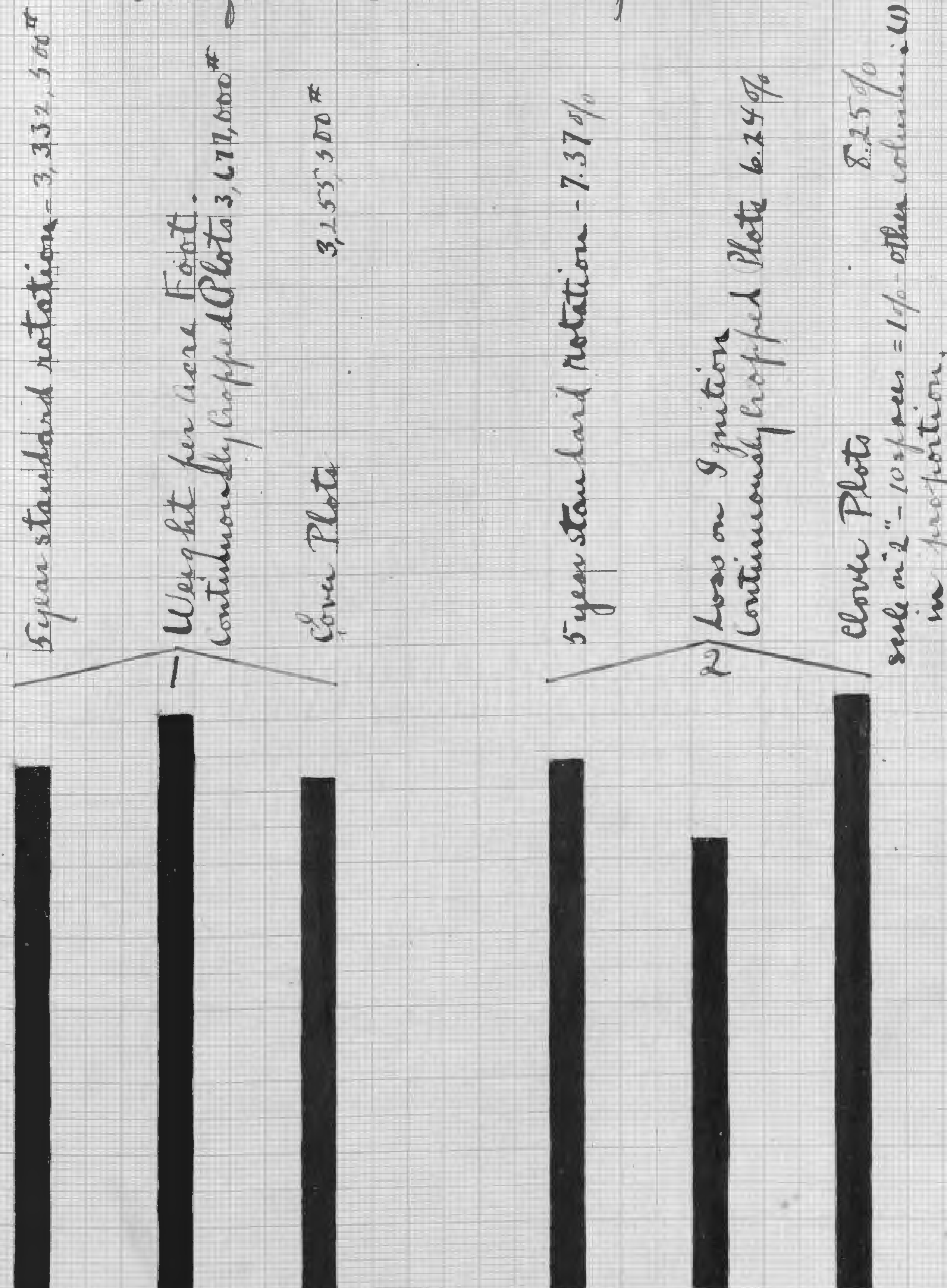
Another Condensed Form of Table X.

Plot		Weight per Acre Foot.	Loss on Ignition.
Plot 6 Series II) Plot 1 Series III)	5 Year Standard Rotation.	3,332,500#	7.37 %
Plot 7 Series II) Plot 8 Series II) Plot 10 Series II)	Continuous Cropping Plots.	3,677,000#	6.24 %
Plot 3 Series III) Plot 4 Series III)	Clover Plots.	3,255,500#	8.25 %

Before passing on to the subject of Tenacity, Breaking Strength, etc., it may be well to briefly observe some additional data. McConnell states that every inch of depth of soil over one acre weighs about 120 tons. In our soils it varies from 138 tons to 150 tons on the average, altho individual plots run

Plate VI - Table XVI

A further Comparison of Weight per acre foot and Loss on Ignition



above and below. King places the weight of the first acre foot of soil at 2,740,000# dry soil. This is below any of our findings. Hilgard has gathered the following data:

Table XVII.

From Hilgard's "Soils."

Soil	Weight per Cubic Foot.
Swamp and Peat Land	2,250,000#
Garden and Woodland	3,000,000#
Loams	3,500,000#
Sandy Lands	4,000,000#

Hall's figures, altho based on foreign conditions are worthy of quotation.

Table XVIII.

From A. D. Hall's "Soils."

Soil	Weight per Cubic Foot.
Sandy Peat	2,106,664#
Heavy Clay	2,866,664#
Light Loam	3,306,664#
Sandy Loam	3,320,000#
Light Sand	3,413,332#

Soil	Weight per Cubic Foot.
Sandy Clay	3,466,664#

The Rothamsted Station has compiled some interesting data in this connection. The work was carried on at three different fields, samples being taken to a depth of nine inches.

Table XIX.

From Hall's "Book of Rothamsted Experiments."

Soil	Weight per Acre Foot.	Per Cent Moisture
a. Arable Land	3,892,920#	12.6 %
b. Arable Land	4,209,928#	21.4 %

The letter (a) refers to Rothamsted loam with clay subsoil, while (b) refers to Woburn sandy soil, clay subsoil. Apparently, the Rothamsted data runs both above and below our findings. This may be due to a variety of causes, the methods of handling the lands, and the mechanical composition being important. Stones formed as much as ten per cent of the total weight in some cases above while in our soils they are practically absent. Based upon King's data, our soils would range between sandy and clay loam.

Using Hall's data, our five year rotation soil would be classed as a sandy loam, with the remaining plots running higher. The clover plots compare very closely to Hilgard's estimate for clay lands.

The phenomena of Soil Tenacity or Stickiness is one of considerable importance from an economic viewpoint and some work was done in this direction. The plan followed, was to take a uniform weight of soil and moisten it with a uniform quantity of water. The soil was then fitted into a mould which had been guaged to hold this quantity of moist soil. To reduce friction, glass surfaces worked over each other. The mould was in this form 

A cord, attached at (b) worked over a pulley with weight attached. The other half of the mould was fastened at (c). Thus, the break occurs at (a) when the weight becomes strong enough to overcome friction and separate the soil. The area of cross section was (3/4 x 3/4) inches. The average weight necessary to cause a separation, less the friction (which averaged around 200 grams) follow:-

Table XX.

Tenacity of Moist Soil Contrasted

with Loss on Ignition.

Plot	Tenacity - Grams needed to break.	Loss on Ignition.
Plot 4 Series I	290	8.3 %
Plot 5 Series I	298	7.90 %
Plot 6 Series II	203	7.25 %
Plot 7 Series II	130	5.99 %
Plot 8 Series II	121	6.55 %
Plot 10 Series II	121	6.19 %
Plot 1 Series III	223	7.49 %
Plot 2 Series III	239	7.69 %
Plot 3 Series III	553	8.14 %
Plot 4 Series III	374	8.36 %
Plot 7 Series III	341	8.00 %
Plot 4 Series IV	230	7.78 %
Plot 10 Series IV	231	7.72 %

This determination was extremely interesting as it gave results I had not anticipated. In reviewing the tables, it will be found that the greater the Loss on Ignition the greater is the apparent tenacity. In other words, the tenacity of soils was greater as the quantity of vegetable matter increased. In only three cases did the weight required to break the soil fall below 200 grams and these occurred with the continuous corn, pea, potato plots. The behavior of the soils when equal weights of soil were mixed with equal quantities of water was very interesting. The soil from the three plots just mentioned became very muddy and slushy but as the amount of vegetable matter increased they became much drier and assumed more of a crumbling structure. One explanation that occurs is that the presence of organic matter tends to bind the particles together in moist soil and resist disintegration. We may further assume that the quantity of water used was just that which would place our rotation soils in the highest adhesive state, and while the same quantity would reduce continuously cropped soils to flowing mud. We might argue further that as vegetable mould increased the same degree of tenacity is attained with less moisture. The rotation soils have a greater moisture capacity and by the time the point of saturation is reached here it has already been passed in the continuously cropped soils and given way to a fluid state. Generally speaking tenacity or stickiness is dependent upon texture, the finer grained soils being the stickier. Sand has its greatest cohesive when moist and clay, on the other hand, exhibits better sticking qualities when dry.

To view this matter from another angle, these same soils were studied in the dry state. A mould was made 3.5 inches long with a cross section 3/4 inches square. The soils were thoroughly moistened and a number of sticks of each were made in this mold and completely dried. To test its breaking power, a stick would be suspended at either end and a vessel attached at the middle. Sand was poured into this until breaking occurred. Thus the breaking strength of air dry soil was studied.

Table XXI.

Breaking Strength of Air Dry Soil Contrasted With Tenacity of Moist Soil and Loss on Ignition.

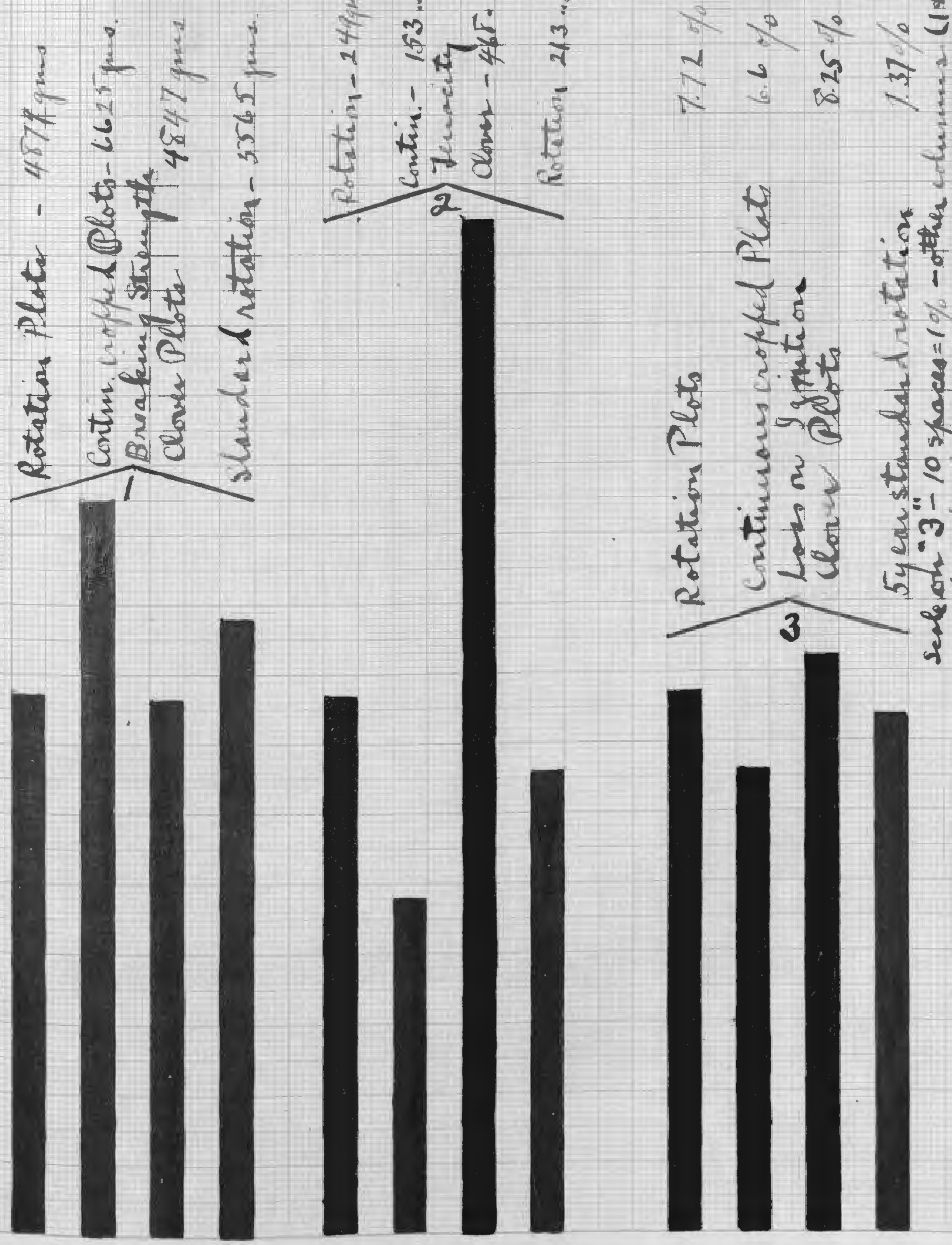
Plot	Breaking Strength	Tenacity of Moist Soil	Loss on Ignition.
Plot 4 Series I	3419 Grams	290 Grams	8.3 %
Plot 5 Series I	4736 "	298 "	7.9 %
Plot 6 Series II	5218 "	203 "	7.25 %
Plot 7 Series II	6234 "	130 "	5.99 %
Plot 8 Series II	7404 "	121 "	6.55 %
Plot 10 Series II	7137 "	121 "	6.19 %

Plot	Breaking Strength	Tenacity of Moist Soil	Loss on Ignition
Plot 1 Series III	5912 Grams	223 Grams	7.49 %
Plot 2 Series III	5703 "	239 "	7.69 %
Plot 3 Series III	4991 "	553 "	8.14 %
Plot 4 Series III	4693 "	374 "	8.36 %
Plot 7 Series III	4820 "	341 "	8.08 %
Plot 4 Series IV	5712 "	230 "	7.78 %
Plot 10 Series IV	5552 "	231 "	7.72 %

This table makes an interesting comparison with the last. Directly as the grams measuring tenacity of moist soils tends to decrease, so the loss on ignition and the breaking strength of dry soils tend to increase. No less than three sticks are represented in last average of breaking test. The same soils, that in soft, liquid state moved so easily with lateral pressure, when the moisture had departed offer the greatest resistance to pressure operated in a vertical direction. As a measure of resistance to the plow, we feel this is a better test. For here all soils are equally dry. Altho equal quantities of water were applied in the previous test, all soils were not equally wet for the saturation

Plate VII - Table XXI

Comparison of Breaking Strength (dry soil), Tenacity (moist soil), and Loss on Ignition



point was not the same. The difficulty of obtaining this made the method used about the only fair test possible. To conclude, then, we see that when equal quantities of water are added to equal quantities of soil, the continuously cropped soils show the least tenacity. But when like portions of these same soils are thoroughly dried and subjected to vertical pressure, the continuously cropped soil requires greater pressure to break it. The following table makes these results more graphic.

Table XXII.

Condensed Form of Table XXI.

Plot		Breaking Strength Dry Soil	Tenacity Moist Soil	Loss on Ignition.
Plot 4 Series I Plot 5 Series I Plot 6 Series II Plot 1 Series III Plot 4 Series IV	Rotation Plots	4879 Grams	249 Grams	7.72 %

Plot		Breaking Strength Dry Soil	Tenacity Moist Soil	Loss on Ignition
Plot 7 Series II	Contin-			
Plot 8 Series II	uously			
Plot 10 Series II	Cropped	6625 Grams	153 Grams	6.6 %
Plot 2 Series III	Plots			
Plot 3 Series III	Clover			
Plot 4 Series III	Plots	4847 Grams	468 Grams	8.25 %
Plot 6 Series II	5 Year Standard			
Plot 1 Series III	Rotation	5565 Grams	213 Grams	7.37 %

But two subjects, Pore Space and Soil Aeration, remain to be considered in Part 1. They will be covered in the order given as Soil Aeration is naturally dependent upon the quantity of pore space. The data on pore space properly comes at this stage as introductory to the general subject of soil moisture.

Table XXIII.

Pore Space Contrasted with other

Physical Factors.

Plot	Laboratory Findings	Field Findings	Average	Loss on Ignition
Plot 4 Series I	55.71 %	52.78 %	54.28 %	8.3 %
Plot 5 Series I	55.74 %	49.79 %	52.76 %	7.9 %
Plot 6 Series II	55.93 %	51.49 %	53.69 %	7.25 %
Plot 7 Series II	55.49 %	47.12 %	51.29 %	5.99 %
Plot 8 Series II	53.71 %	47.2 %	50.45 %	6.55 %
Plot 10 Series II	54.25 %	51.67 %	53.19 %	6.19 %
Plot 1 Series III	55.47 %	53.28 %	54.37 %	7.49 %
Plot 2 Series III	56.24 %	53.46 %	54.83 %	7.69 %
Plot 3 Series III	56.64 %	56.14 %	56.39 %	8.14 %
Plot 4 Series III	55.64 %	51.93 %	53.78 %	8.36 %
Plot 7 Series III	55.03 %	45.75 %	50.90 %	8.08 %
Plot 4 Series IV	55.38 %	48.15 %	51.76 %	7.78 %
Plot 10 Series IV	55.16 %	57.23 %	56.69 %	7.72 %

The pore space is determined by learning what per cent apparent specific gravity is of real, and subtracting the result from 100 per cent. This data was determined on both laboratory and field findings for apparent specific gravity. Both are given, together with their average, and compared with loss on ignition. We observe the results in all three columns appear to maintain a good balance. Laboratory results disclose the lowest pore space existing in the continuous potato plot, the highest in continuous wheat and clover plot. The field studies again disclose the minimum pore space as almost identical in continuous corn and potato plots and highest in the last plot (Plot 10 Series IV). This is readily understood by ony who has worked with this soil and observed its very loose texture which explained its very low field weight and a pore space much beyond what laboratory study would indicate. The column of average results very nearly duplicates the last except that potatoes again ran below the corn plot. The low pore space of the two pasture plots in third column is easily explained by their high field weight which, for mechanical reasons, is not proportional to real specific gravity.

Despite its greater loss on ignition the continuous pasture plot shows less pore space than the rotation plot since the latter has been under pasture but two years. There is a general relation between pore space and organic content. In Part II moisture retention will be studied in relation to pore space. The next table presents the material in brief form.

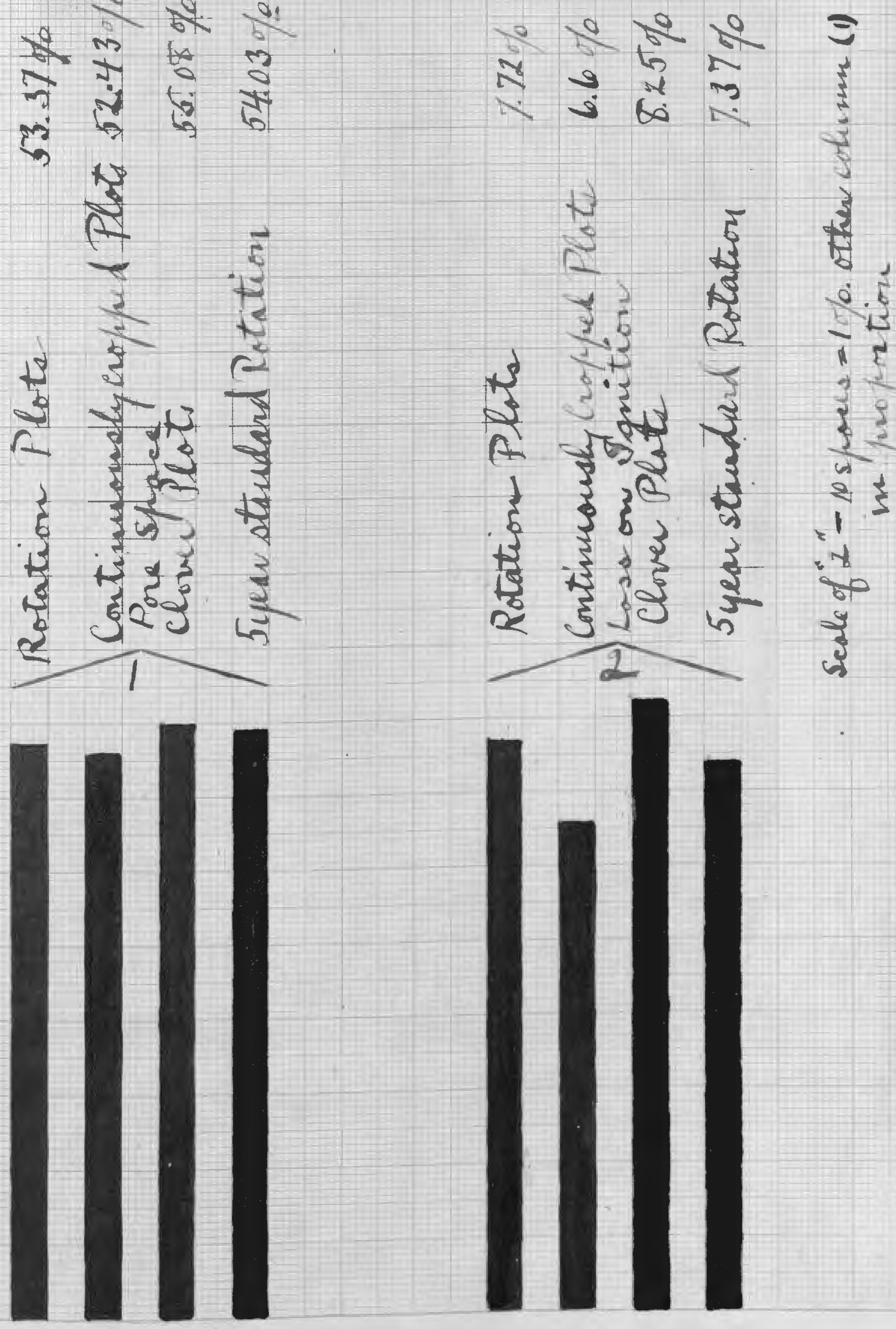
Table XXIV.

Condensed Form of Table XXIII.

Plot		Pore Space (Laboratory Data)	Loss on Ignition.
Plot 4 Series I Plot 5 Series I Plot 6 Series II Plot 1 Series III Plot 4 Series IV	Rotation Plots	53.37 %	7.72 %
Plot 7 Series II Plot 8 Series II Plot 10 Series II Plot 2 Series III	Continuous Cropping Plots	52.43 %	6.6 %

Plate VIII - Table XXIV

Comparison of Pore Space and Loss on Ignition.



Plot		Pore Space (Laboratory Data)	Loss on Ignition.
Plot 3 Series III)) Plot 4 Series III)	Clover Plots.	55.08 %	8.25 %
Plot 6 Series II)) Plot 1 Series III)	5 Year Standard Rotation.	54.03 %	7.37 %

Considerable material is available on the subject of pore space. King states that pore space varies from 52.23 % (first foot) to 32.85 % 6th foot. The weights at corresponding depths varied from 79# to 111# per cubic foot. He estimates further that in finer soils and loose mulches it may vary from 45.17 % to 72.58 %. Lyon and Fippin in "Soils" page 97 give the following:

Table XXV.

From Lyon & Fippin "Soils."

Soil	Pore Space (By Volume).
Clean Sand	33.5 %
Coarse Sand	40.00 %
Medium Sand	41.8 %
Fine Sand	44.1 %
Sandy Loam	51.0 %

Soil	Pore Space (By Volume).
Fine Sandy Loam	50.0 %
Silt Loam	53.0 %
Clay Loam	51.0 %
Clay	56.0 %
Gumbo	58.46 %
Heavy Clay (Puddled)	47.19 %
Very Heavy Clay	65.2 %

This data clearly defines the fact that, under natural conditions, the porosity increases with fineness of texture; since the presence of vegetable mold has this effect, we may assume that the different quantities of this substance explain the variations that we observed. Put into the terminology above, our continuously cropped soils have a porosity approximating sandy loam, our rotation soils would range between clay and silt loam while the clover plots approach more nearly in weight to clay proper.

Observations on soil aeration or ventilation which is closely related to pore space form the closing chapter of Part I. It is to be regretted that complete data cannot be given here, yet the several plots tested gave good responses. The work, necessarily, was started in autumn after the crops were removed but when well under way heavy rains interfered. When weather and soil conditions were again right, several of the plots had been plowed, which of course, prevented further work. The data was gathered in this matter. A tube, twelve inches long, two inches in diameter, was driven into the soil, upside down, to a depth of six inches. A rubber tube, attached to a small opening, at the top, established connection with an inflated rubber bag in metallic case. The air was thus forced thru rubber tubing into the metallic tube, thence thru the soil, escaping round about on all sides. The number of cubic centimeters escaping per minute was the unit of comparison.

Table XXVI.

Soil Aeration Contrasted with other Physical Factors.

Plot	Water Content	Soil Aeration (No. cc. escaping per min.)	Loss on Ignition	Pore Space
Plot 4 Series I	25.13 %	90.59 cc.	8.30 %	54.28 %
Plot 6 Series II	26.32 %	63.71 cc.	7.25 %	53.69 %
Plot 7 Series II	21.25 %	69.44 cc.	5.99 %	51.29 %
Plot 8 Series II	25.13 %	56.43 cc.	6.19 %	50.45 %

The water content figures represent the average for two preceding months. This data shows an interesting relation between pore space, loss on Ignition, soil aeration, water content. The volume of air passing thru the soil in one minute responds directly to the pore space and organic matter content, governed, however, by the amount of moisture present. The moisture determinations for the two preseding months were taken and averaged with results as tabulated. The four year rotation plot and continuous potatoes responded with almost equal amounts. This factor, eliminated or neutralized, we see that aeration responds directly to pore space and quantity of Loss on Ignition. On the other hand, our five year standard rotation plot shows much more loss on ignition and also more pore space than the continuous corn but less soil aeration per minute. When we observe a difference of 5.07 inches or 23.8 per cent we can readily understand why air should penetrate with slightly greater rapidity thru the corn soil though greatly devoid of vegetable matter. Bulletin 25, Department of Soils states "Aeration is dependent much more on porosity than on texture and structure of soil;" furthermore, "when the porosity of the soil is reduced by compacting, the case with which air flows thru it under the driving influence of a difference of pressure is greatly reduced, varying as the sixth or seventh power of the porosity." Applying these statements to our results, they become much clearer. For pore space, water logged, loses its efficiency though potentially greater than the total of another plot.

Table XXVII.

(See next Page).

Resume on Soil Physics Tables.

Plot	Apparent Specific Gravity (Laboratory)	Apparent Specific Gravity (Field)	Real Specific Gravity	Tenacity	Breaking Strength
Plot 4 Series I	1.17	1.193	2.526	290 Gms.	3719 Gms.
Plot 5 Series I	1.123	1.274	2.537	298 "	4736 "
Plot 6 Series II	1.136	1.252	2.577	203 "	5218 "
Plot 7 Series II	1.164	1.382	2.613	130 "	6234 "
Plot 8 Series II	1.233	1.404	2.659	121 "	7404 "
Plot 10 Series II	1.195	1.271	2.63	121 "	7157 "
Plot 1 Series III	1.156	1.213	2.596	223 "	5912 "
Plot 2 Series III	1.135	1.208	2.593	239 "	5703 "
Plot 3 Series III	1.123	1.136	2.591	553 "	4991 "
Plot 4 Series III	1.149	1.245	2.59	374 "	4693 "
Plot 7 Series III	1.167	1.408	2.595	341 "	4820 "
Plot 4 Series IV	1.154	1.343	2.59	230 "	5712 "
Plot 10 Series IV	1.168	1.108	2.599	230 "	5552 "

Resume of Tables on Soil Physics.

Plot	Field Weight Weight Per cubic Foot	Weight Per acre Foot	Pore Space	Soil Aeration (Per Min.)	Loss on Ignition.
Plot 4 Series I	74.35#	3,238,000#	55.78%	90.59 cc	8.3 %
Plot 5 Series I	79.63#	3,468,000#	55.74%		7.9 %
Plot 6 Series II	78.00#	3,397,000#	55.93%	63.71 cc	7.25 %
Plot 7 Series II	86.14#	3,754,000#	55.46%	69.44 cc	5.99 %
Plot 8 Series II	87.5 #	3,811,000#	53.71%	56.43 cc	6.55 %
Plot 10 Series II	79.62#	3,468,000#	54.57%		6.19 %
Plot 1 Series III	75.53#	3,288,000#	55.47%		7.49 %
Plot 2 Series III	75.09#	3,267,000#	56.24%		7.69 %
Plot 3 Series III	72.08#	3,136,000#	56.64%		8.14 %
Plot 4 Series III	77.56#	3,575,000#	55.64%		8.36 %
Plot 7 Series III	87.41#	3,807,000#	55.03%		8.08 %
Plot 4 Series IV	82.48#	3,593,000#	55.38%		7.78 %
Plot 10 Series IV	69.06#	3,105,000#	55.16%		7.72 %

With this resume of Part I., we will take up the study of Part II., Soil Moisture.

PART II.

STUDY OF MOISTURE RELATIONSHIP OF PLOTS.

In this division of this thesis we shall aim to make a thorough study of the moisture problem and show the results of observations during the season of 1911. The meteorological records show the season to be one of the wettest in years. Starting with a dry winter and a spring rainfall considerably below normal, the precipitation for the last one-half nearly broke all records. The season of 1910, uniformly dry, would have been more desirable for doing this work. The material is arranged in order of sequence from the work already covered. The subject of moisture retention will first be elaborated, since it is so closely related to pore space. Following in order will come the discussion of hygroscopic water, percolation of ground water, capillary water, available and non-available water, daily moisture determinations in the region of the feeding roots, and finally bi-monthly determinations of surface, subsurface and subsoil moisture.

In determining the per cent of water retained in soil, the method followed was to allow the water to flow over the soils, packed into a number of uniform vessels connected by a rubber tubing, and soak thru them. When all were thoroughly saturated and dripping had ceased from the lower end, the per cent of water retained was determined upon the basis of dry weight of soil. Then, to make our comparison more adequate, we will repeat our tables on Pore Space and Loss on Ignition.

Table XXVIII

Retention of Water Contrasted with other Physical Factors.

Plot	Per Cent Water Retained.	Pore Space Lab. Findings.	Loss on Ignition.
Plot 4 Series I	44.71 %	55.78 %	8.3 %
Plot 5 Series I	44.33 %	55.74 %	7.9 %
Plot 6 Series II	43.74 %	55.93 %	7.25 %
Plot 7 Series II	38.68 %	55.46 %	6.00 %
Plot 8 Series II	37.20 %	53.71 %	6.55 %
Plot 10 Series II	40.65 %	54.57 %	6.19 %
Plot 1 Series III	42.17 %	55.47 %	7.49 %

Plot	Per Cent Water Retained.	Pore Space Lab. Findings	Loss on Ignition.
Plot 2 Series III	43.00 %	56.24 %	7.69 %
Plot 3 Series III	43.01 %	56.64 %	8.14 %
Plot 4 Series III	42.81 %	55.64 %	8.3 %
Plot 7 Series III	42.46 %	55.03 %	8.08 %
Plot 4 Series IV	41.93 %	55.38 %	7.78 %
Plot 10 Series IV	40.99 %	55.16 %	7.72 %

Scanning the table one readily observes that the retention between retention of water, pore space, loss on ignition, is very close. However, the differences in the first column are the more pronounced. Altho the differences in pore space are but fractional in the soils of continuous peas, potatoes, corn, the amount of water retained varies measurably. Taking the average of laboratory and field determinations would have shown much greater variation in pore space, but since the laboratory weights and water retention were both determined in the same vessels, we followed what seemed the fairer course. This table has greater significance in more abbreviated form.

Table XXIX.

Condensed Form of Table XXVIII.

Plot		Pounds Water Per Cubic Ft.	Acre Inches of Water	Pore Space	Per Cent Retained.
Plot 4 Series I Plot 5 Series I Plot 6 Series II Plot 1 Series III	Rotation Plots	30.92#	6.01	53.37 %	43.37%
Plot 7 Series II Plot 8 Series II Plot 10 Series II Plot 2 Series III	Continuous Cropped Plots	29.5 #	5.66	52.43 %	39.89%
Plot 3 Series III Plot 4 Series III	Clover Plots.	30.62#	5.86	53.69 %	42.94%
Plot 6 Series II Plot 1 Series III	5 Year Standard Rotation.	30.87#	5.92	54.03 %	42.95%

Plate IX Table XXIX

Comparison of Pounds water per Cu. Foot, Acre inches of Water, Pore Space and Loss on Ignition.

Scale on "2" – 10 spaces = 1 inch – other columns (3, 4, 1) in proportion

In this condensed form the data on water retention has much more meaning. The relation is carried thru with uniformity between the four 5 year rotations and remaining plots. The standard rotations were slightly above in pore space and below in moisture retention, otherwise bearing out the comparisons nicely. The general bearing of organic matter upon pore space and water capacity, disclosed in the earlier table, are here emphasized. The data on pounds per cubic foot and acre inches are merely added for explanatory or illustrative purposes. The data gained by experimental work elsewhere is deserving of brief comment and comparison with our results.

Brooks states that this factor varies from one-third, (in sand) to two-thirds (in organic matter). It runs from 15 per cent in coarse sand to 50-60 per cent in heavy loam while ordinary loam runs at about 40 per cent. Bailey states that "Saturated soils hold 4-6 acre inches of water or 20-30 pounds per cubic foot." Lloyd in "Science of Agriculture" gives us the following:

100 pounds sand will absorb 25 pounds water.

100 pounds loam will absorb 40 pounds water.

100 pounds clay loam will absorb 50 pounds water.

100 pounds clay will absorb 70 pounds water.

The three factors governing water retention are given by Lyon and Fippin as texture, structure and quantity of organic matter. To illustrate the first principle they give us this data.

Table XXX. (a)

From Lyon and Fippin's "Soils."

Soil Texture - A Factor in Water Retention.

Soil	Per Cent Clay	Per Cent Water Retained Against Force 2,940 Times Force of Gravity.
Coarse Sand	4.8 %	4.6 %
Medium Sandy Loam	7.3 %	7.0 %
Fine Sandy Loam	12.6 %	11.8 %
Silt	10.6 %	12.9 %
Silt Loam	17.7 %	26.9 %
Clay Loam	26.6 %	32.4 %
Clay	59.8 %	46.5 %

This table indicates that with finer texture, we have greater retention of water; opening up a loose, sandy soil lowers retentive power while reduction of clay has an opposite effect.

The effect of structure is illustrated in the following table:

Table XXX. (b)

Soil Structure - A Factor in Water Retention.

Soil	Structure	Dry Per Cent	Per Cent Water at Different Heights 2"	40"
Sandy Loam	Loose	50	28	6
" "	Compact	35	27	10
Clay Loam	Loose	50	42.5	26
" "	Compact	52	34	12

The third factor affecting water retention - organic matter - is illustrated by another table from the same authors:

Table XXX. (c)

Organic Matter - A Factor in Water Retention.

Soil	Per Cent Water Retained.
Ordinary Vegetable Mold	190 %
Peat	201 - 309 %
Garden Loam - 54% clay - 7% humus	96 %
Dark Illinois Prairie Soil	57 %
Muck Soil - 30# per Cubic Foot	75 %

The same authors state that the ratio of water absorbed in clean sand, sand and muck, pure muck stands in the ratio of 1:1:1.93. King of Wisconsin states that manure tends to increase the quantity of water in first three feet of soil and lower it in the second three feet. Before closing the discussion on water retention, we will present another table compiled by Lyon and Fippin relating to behavior of gravitational water.

Table XXXI.

From Lyon & Fippin's "Soils."

Behavior of Gravitational Water.

Soil	Weight Per Cubic Foot.	Per Cent Pore Space	Pounds Water Per Cubic Foot	Per Cent Water in Soil at Saturation.
Dune Sand	80#	52 %	32.5 %	40.5 %
Coarse Sand	81#	51 %	32 %	39.5 %
Fine Sandy Loam	83#	50 %	31.5 %	38.0 %
Light Silt Loam	83#	50 %	31.5 %	38.0 %
Clay	68#	59 %	37.0 %	54.5 %
Humus	15#	80 %	50.0 %	33.3 %

These tables, in application, are self evident. They indicate that our soil behave like ordinary loams except as modified by cultural methods.

We know that soil moisture is classified under three heads: hygroscopic, surface or ground, capillary moisture, and a comparative study of the question must include individual consideration of each.

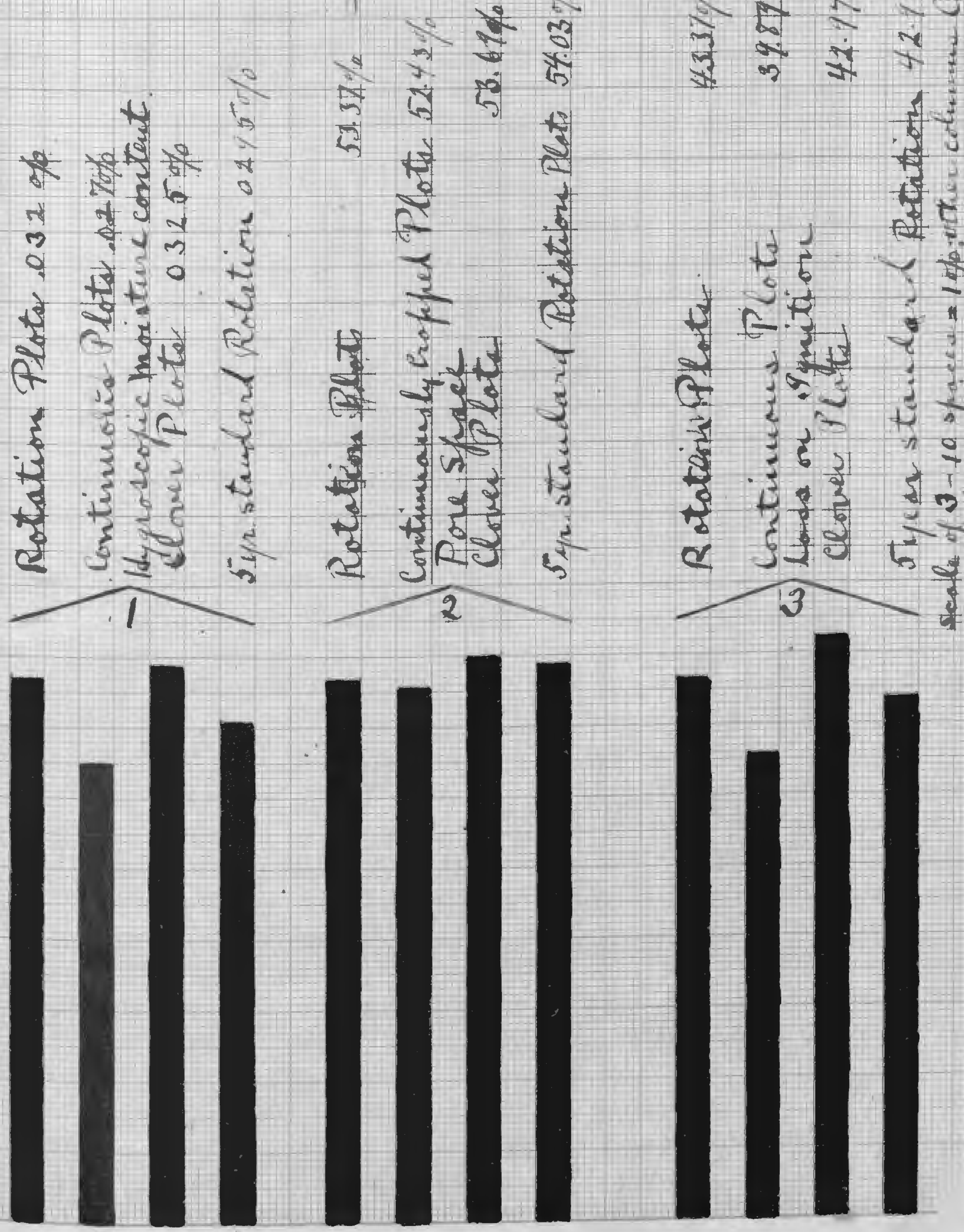
Table XXXII.

Hygroscopic Moisture Contrasted with other Physical Factors.

Plot	Hygroscopic Moisture	Pore Space	Loss on Ignition.
Plot 4 Series I	.03	55.78 %	8.3 %
Plot 5 Series I	.032	55.74 %	7.9 %
Plot 6 Series II	.029	55.93 %	7.25 %
Plot 7 Series II	.028	55.46 %	6.00 %
Plot 8 Series II	.025	53.71 %	6.55 %
Plot 10 Series II	.027	54.57 %	6.19 %
Plot 1 Series III	.03	55.47 %	7.49 %
Plot 2 Series III	.0307	56.24 %	7.69 %

Plate X Special

Digest of Table XXXI concerning hygroscopic water, Pore space and Loss on Ignition



Plot	Hygroscopic Moisture	Pore Space	Loss on Ignition.
Plot 3 Series III	.033	56.64 %	8.14 %
Plot 4 Series III	.032	55.64 %	8.36 %
Plot 7 Series III	.0307	55.03 %	8.08 %
Plot 4 Series IV	.0286	55.38 %	7.78 %
Plot 10 Series IV	.0254	55.16 %	7.72 %

Hygroscopic water remains in the soil when it is air dry. It is considered of relatively lesser importance since it is of no direct use to plants but may indirectly aid in dissolving pland food since it invests the soil particles so closely. One would naturally suppose that, with greater pore space, the quantity of hygroscopic moisture would increase as in the case of capillary water, since we have a greater number of particles, per unit volume, invested with moisture. Altho no elaborate study was made, the data we present in general supports this theory. We quote at this point from Lyon and Fippin's "Soils:" -

Light Sand contains .5 - 1 % hygroscopic water

Silt Loam contains 2 - 4 % hygroscopic water

Clay " 8 -12 % hygroscopic water.

The Massachusetts (Hatch) Station records the following data in the Report for 1899 - Page 69.

Table XXXIII.

From Massachusetts (Hatch) Report for 1899.

Study of Hygroscopic Moisture.

Soil	Per Cent Hygroscopic Moisture	Organic Matter
Montague Soil	.9 %	.9 %
Eastham Soil	2.0 %	.78 %
Bridgewater Soil	2.10 %	.66 %
Orleans Soil	2.20 %	2.1 %
Amherst Soil	2.98 %	2.82 %
Concord Soil	4.19 %	2.76 %
Attleboro Soil	7.64 %	4.2 %

As a whole, viewed from either extreme, all the data quoted tends to support the contention we made above, that a greater quantity of organic matter, creating a greater pore space, increased the amount of water remaining in air dry soil. These findings will be interesting when we come to study the matter of available and non-available moisture.

Seepage or percolation of water has to do with the behavior of surface or ground water which is the rain that falls, soaks into the ground and maintains the supply of water in wells, springs, capillary openings. The same tubes used in study of water retention were used in this case, filled in the same manner, compressing them by dropping a weight of 500 grams a uniform number of times from the same height. Rubber tubes connected the vessels, water was turned on, and after 2.5 - 3 hours, began to seep through. When all were working nicely, the amount passing thru each in thirty minutes was saved and measured. This, when repeated, formed the unit of comparison.

Table XXXIV.

Percolation of Water Contrasted with other Physical Factors.

Plot	Percolation (cc. in 30 min.)	Pore Space	Loss on Ignition.
Plot 4 Series I	8.75 cc	55.78 %	8.3 %
Plot 5 Series I	7.50 cc	55.74 %	7.9 %
Plot 6 Series II	8.12 cc	55.93 %	7.25 %
Plot 7 Series II	9.00 cc	55.46 %	5.99 %

Plot	Percolation (cc in 30 min.)	Pore Space	Loss on Ignition.
Plot 8 Series II	14.5 cc	53.71 %	6.55 %
Plot 10 Series II	8.75 cc	54.57 %	6.19 %
Plot 1 Series III	10.57 cc	55.47 %	7.49 %
Plot 2 Series III	10.00 cc	56.24 %	7.69 %
Plot 3 Series III	6.25 cc	56.64 %	8.14 %
Plot 4 Series III	6.32 cc	55.64 %	8.36 %
Plot 7 Series III	6.3 cc	55.03 %	8.08 %
Plot 4 Series IV	14.00 cc	55.38 %	7.78 %
Plot 10 Series IV	8.1 cc	55.16 %	7.72 %

Before commenting on these results, we will briefly review work of other men. A. D. Hall secured this data.

Table XXXV.

From Hall's "Soils."

Soil	Inches of Water lost in				
	30 min.	31-60 min.	24 hrs.	2-11 da.	12-21 da.
No. 20 Sand	10.25	4.68	0	0	0
No. 60 Sand	5.67	4.52	0	0	0
No. 100 Sand	1.21	.84	0	0	0
Sandy Loam	0	0	2.04	5.07	.9
Clay Loam	0	0	1.96	2.11	.49

King in "Physics of Agriculture" states these results secured on Wisconsin Soils.

Table XXXVI.

From King's "Physics of Agriculture."

Rate of Percolation thru Sandy and Clay Loams.

Time	Sandy Loam.	Clay Loam.
First 21 hours	2.64"	0
First 23 hours		1.918"
First 10 days following above	5.072"	2.111"
Second 10 days following above	.905"	.493"

These two tables tend to support the statement of Fletcher that percolation is checked by the presence of greater pore space. He further states the natural corollary to this, that the presence of clay or organic matter tends to check seepage. These facts are doubtless true, but a series of determinations on the soils of the several plots failed to show any direct relation as our tables indicate. Altho our continuous potato plot showed the greatest loss of water, it scarcely exceeds that of the six year rotation which includes three years of grass. On the other hand, our five year standard rotation (Plot 1 Series III) showed a greater loss than the continuous cropping plot of corn or peas. The soils were all equally compacted, so the difference was due to some other factor. However, it is quite noticeable that the two clover soils and also the continuous pasture responded favorably to the influence of vegetable matter present and lost but little water. To support our statements, we cite the following data:

Table XXXVII.

"From King's Physics of Agriculture."

Percolation of Water in Relation to Pore Space and Size of Particles.

Diameter of Sand	Per Cent Pore Space	Amount of Water Seepage 1st 30"	2nd 30"
.4745 mm.	38.86	10.25 cc	4.683 cc
.1848 mm.	40.07	7.549 cc	5.258 cc
.1551 mm	40.76	5.674 cc	4.522 cc
.1181 mm	40.57	1.512 cc	1.294 cc
.0826 mm	39.73	1.213 cc	.845 cc

The California Station Report for 1899 explains in detail a laboratory study of percolation of water thru soil. The test was made with loam, adobe, sand. The flow was most rapid in the order given above, contrary to expectation. Reviewing the results of both citations, we find that seepage is not always governed by the quantity of pore space present. Hilgard states further that "Were it not for the variously assorted sizes of soil particles, water would not be held long enough to afford growth." He states further that "There seems to be no direct relation between total pore space and the facility of percolation." In view of these facts, our results appear justified, as our cropping system has probably not yet been carried far enough to materially alter pore space or percolation thru it. At Rothamsted it was found that from 48-51 per cent of the water was disposed of by seepage so we are probably about right in stating that approximately 50 per cent of the rainfall of this section is removed by under ground seepage.

Following closely upon a study of gravitational and hygroscopic moisture, a brief review of capillary movements is in order. This is the water that supports plant life and moves about in the soil independent of gravity and in response to attraction by soil particles. To make these observations, a number of glass tubes were secured and filled with soil, subjecting them to an equal and uniform pressure. This was done by dropping the tube from a certain height a specified number of times. One series was firmed by means of a tamping stick. The readings were taken every hour and the table below shows the average of four tests at the close of the fourteenth hour. The water was provided below in vessels of equal capacity.

Table XXXVIII.

Capillary Rise of Water.

Plot	Rise of Water in Inches at end of Fourteenth Hour.
Plot 4 Series I	13.4 Inches.
Plot 5 Series I	13.5 "
Plot 6 Series II	15.4 "
Plot 7 Series II	15.18 "
Plot 8 Series II	12.57 "
Plot 10 Series II	14.87 "
Plot 1 Series III	14.06 "
Plot 2 Series III	14.62 "

Plot	Rise of Water in Inches at end of Fourteenth Hour.	
Plot 3 Series III	15.30	Inches
Plot 4 Series III	13.90	"
Plot 7 Series III	14.07	"
Plot 4 Series IV	13.09	"
Plot 10 Series IV	14.68	"

After air drying these soils and passing them thru a two millimeter sieve, likewise compacting each in the same measure, it was thought we might observe some effect due to the difference in content of organic matter in the different plots. But four tests failed to establish any definite conclusions. It is significant than in the continuous potato soil the water rose the smallest distance by a good margin, thereby balancing our observations on water percolation, in which case potato soil lost water most rapidly of all the plot soils. The main facts we may glean from this table are that the differences in organic content are too slight, as yet, to affect capillary action and that the differences noted are due almost entirely to a dissimilarity of texture which affects the arrangement of particles and the formation of larger or smaller capillary spaces. The potato soil nearly always assumed a coarse, granular condition which was much less noticeable in the other continuously cropped plots. This naturally reducing the facility of elevating water particles from one granule to another.

Formerly, it was stated that hygroscopic water was that portion of the soil water not available for plant growth. Later observations have proved, however, that plants wilt before this point is reached. This has given rise to a new classification of capillary water as available and non-available. This relation was here determined by the wilting test. Sunflower seeds were germinated and when about two inches high were transplanted to larger vessels containing a soil sample direct from the plot. The receptacle was then covered over and about the plant with paraffined paper. The object was to prevent evaporation and permit a longer growth. When the plant began to wilt it was assumed that the supply of available water was exhausted, and, if the plant continued to grow at its terminal end, the growth was at the expense of the water in its own tissue. The plant, vessel and soil were all weighed at this point, the loss thus far representing available water. The rest of the water was then driven off, the differencé representing the non-available water.

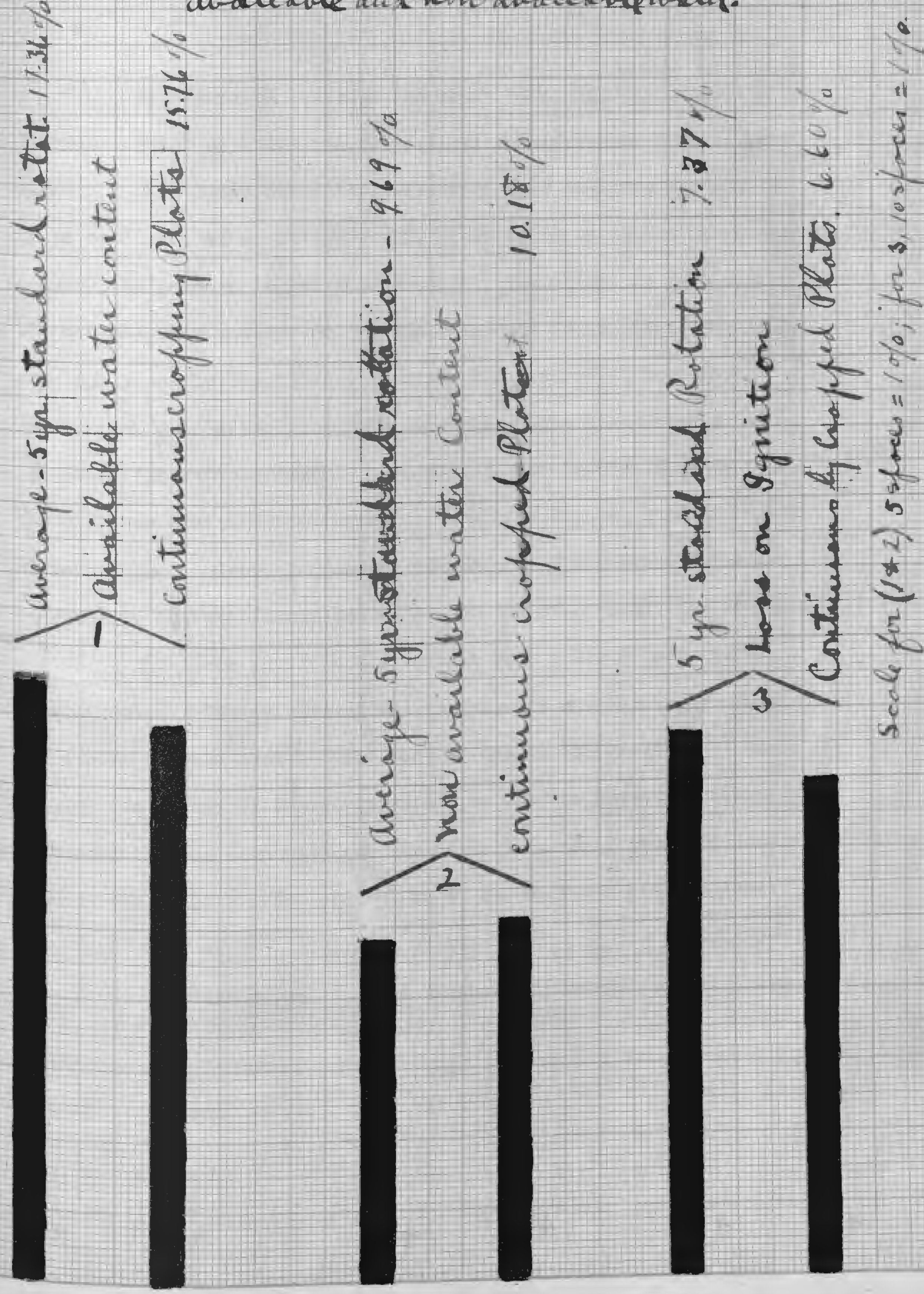
Table XXXIX.

Relative Quantities of Available and Non-available Water Present.

Plot	Per Cent Non-available Water	Per Cent Available Water
Plot 4 Series I	10.15	17.42
Plot 6 Series II	9.62	18.86
Plot 7 Series II	10.65	14.62
Plot 8 Series II	10.65	15.80
Plot 10 Series II	9.10	16.08
Plot 1 Series III	9.77	15.85
Plot 2 Series III	10.33	16.54
Plot 3 Series III	9.73	19.64
Plot 4 Series III	10.29	16.70
Plot 7 Series III	9.53	18.48
Plot 4 Series IV	10.33	14.92
Plot 10 Series IV	9.98	15.44

Plate XI Special

Digest of Table XXXIX concerning available and non available water.



the field tests. At maturity, the manured rotation wheat plots contained but 7.13% moisture and the continuous wheat retained 12.93% or over 50 per cent more unavailable water. This bore out the findings at North Dakota, where manured plots contained 5 per cent less (unavailable) moisture at harvest time. Based upon the evidence we have, we would incline to the belief that when these plots have been operated longer, further tests will indicate that the amount of non-available water will increase where continuous cropping is followed, while the introduction of organic matter would tend to neutralize this. The first two tests brought this out clearly, but the third gave less striking results.

Turning briefly, to other available material on this subject, we find the work of Lyon and Fippin covering the widest field. The following table illustrates some of their findings.

Table XL. "Lyon & Fippin's Soils."

Available Water and Wilting Point of Different Soil Types.

Soil Type	Available Water	Wilting Point
Dune Sand	7.7 %	3 %
Coarse Sand	7.6 %	3 %
Find Sandy Loam	13.0 %	5 %

Soil Type	Available Water	Wilting Point
Light Silt Loam	10.9 %	10 %
Clay	13.4 %	17 %
Muck	170 %	80 %

The same authorities have determined the relation between water capacity and available water.

Table XLI.

From Lyon and Fippin's "Soils."

Water Capacity and Available Water

Soil	Water Capacity		Available Water		
	Minimum Per Cent	Maximum Per Cent	Per Cent	Cubic Inches per cu. ft.	Inches per Acre Foot
Light Sandy Loam	3	8	5	122	3.4
Silt Loam	15	25	10	218	6.0
Clay	23	40 *	17	274	7.6

* Estimated.

These tables indicate that water capacity and amount of available water increase in the same ration. King shows, on the other hand, that the same ration exists between pore space and non-available. Thus corn drew the moisture down in sand from a maximum capacity of 18 per cent to 4.17 per cent; in clay from 26 per cent capacity, the moisture was reduced to 11.79 per cent. Another interesting fact is that different crops wilt at different stages of water content. Thus grasses wilt at 9.85 per cent and legumes at 10.95 per cent under the same soil conditions. In summarizing, then, both available and non-available moisture rises or falls in proportion to pore space present (this holds especially with sand and clay). On a loam type, such as predominates on University Farm, the pore space will doubtless be increased and more water retained. On the other hand, since soil would be more mellow, a more thorough and uniform distribution of roots would be effected which would expedite water absorption. Then as vegetable component would fall we would expect a drop in water capacity and a rise in percentage of unavailable water which is borne out by the tests made.

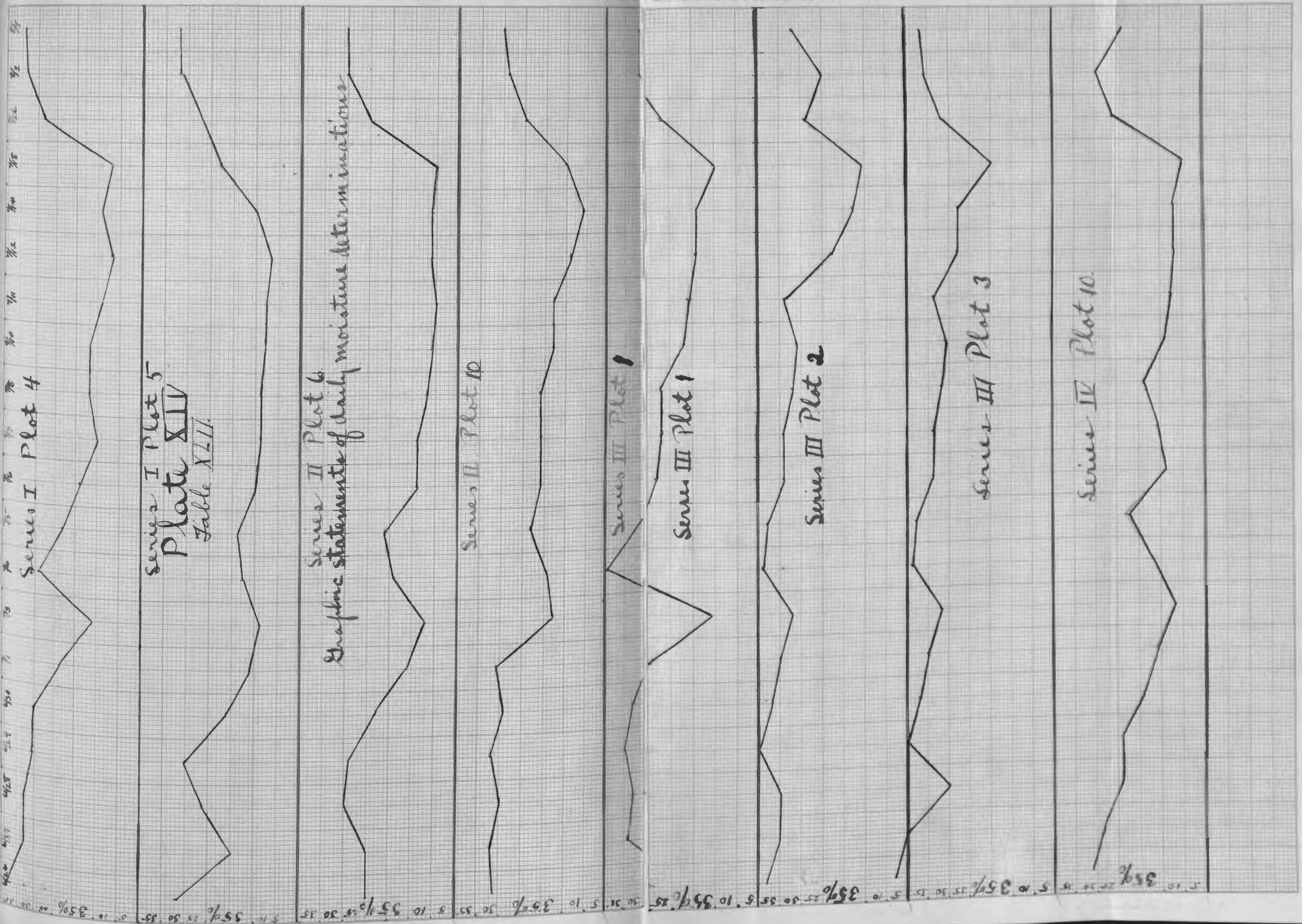
Table XLII.

* Daily Moisture Determinations in Percentage Form.

Plot	6/21	6/26	6/27	6/28	6/29	6/30	7/1	7/3	7/4	7/5	7/6
Plot 4 Series I	22.79	33.21	28.41	28.42	25.88	25.51	18.74	11.18	23.93	18.48	13.79
Plot 5 Series I	12.12	27.51	15.30	20.78	25.53	16.16	10.93	9.28	12.56	14.38	10.12
Plot 6 Series II	10.82	20.17	19.78	24.64	23.72	17.72	10.87	7.14	13.82	16.10	9.35
Plot 10 Series II	20.25	26.15	27.14	25.36	26.63	24.00	25.55	13.45	14.04	17.78	15.52
Plot 1 Series III	16.99	24.15	28.92	27.65	29.73	27.51	23.97	11.04	35.25	26.25	22.87
Plot 2 Series III	24.12	32.88	26.97	30.19	31.00	26.85	19.39	22.26	30.23	29.02	24.40
Plot 3 Series III	25.21	37.59	34.59	25.33	34.71	31.91	29.92	26.67	13.87	33.30	28.58
Plot 4 Series III	17.67	34.37	31.82	25.83	30.54	43.56	17.87	24.18			
Plot 5 Series III	20.24	35.49	33.65	32.61	33.96	30.03	27.34	16.24			
Plot 10 Series IV	12.71	26.33	23.17	19.17	18.52	14.10	11.06	7.46	12.10	18.44	8.87

Plot	7/7	7/8	7/10	7/11	7/12	7/14	7/18	7/26	8/2	8/9	8/17	8/23
Plot 4 Series I	9.93	11.91	12.10	9.25	7.13	9.48	7.29	23.31	27.96	27.37	29.15	28.23
Plot 5 Series I	9.43	8.92	8.45	7.87	7.17	10.41	4.29	22.12	26.79	27.49	28.74	28.67
Plot 6 Series II	9.21	6.95	5.99	5.45	6.48	5.94	4.71	19.82	25.40	24.80	26.92	27.74
Plot 10 Series II	15.53	16.02	12.81	12.54	8.62	6.19	10.45	20.08	24.22	24.63	16.22	24.07
Plot 1 Series III	22.01	21.88	17.10	16.46	14.09	13.80	9.59	21.69	25.60	25.96	25.63	18.90
Plot 2 Series III	25.21	6.29	21.32	29.27	18.37	13.48	11.42	24.47	19.78	27.01	28.55	19.82
Plot 3 Series III	29.09	27.32	26.05	29.49	23.21	23.22	14.82	27.44	31.00	32.00	31.75	31.05
Plot 4 Series III							14.71	25.17	28.54	29.73	30.54	28.49
Plot 5 Series III							20.40	22.92	29.58	29.01	32.10	31.59
Plot 10 Series IV	10.52	14.40	8.63	7.61	7.19	6.63	4.63	21.48	25.28	18.71	27.15	27.42

* This includes the few determinations at intervals of one week made at beginning and close of season.


Series I Plot 4
Series I Plot 5
Plate XIV
Table XLII.
Series II Plot 6
Graphic statements of daily moisture determinations
Series II Plot 10
Series III Plot 1
Series III Plot 1
Series III Plot 2
Series III Plot 3
Series IV Plot 10.

Several irregularities in the table require explanation. Plots 4 and 5, Series III, were not carried thru continuously. The crops on both were cut early for hay, thus cutting off further study. Likewise the last three determinations, at intervals of one week, seem to disagree with the findings of the season studies. Two reasons may be given. The crops were removed, thereby cutting off transpiration, and increasing evaporation, while the rainfall was so heavy it tended to keep the ground soaked at all times. Thus, different factors were operating.

These determinations were taken daily in the region of the feeding root system of the plants for a period of about three weeks. Following this, determinations were made during the autumn, after the crops were removed, until the last week in August. The samples were taken by removing the top earth, taking a small sample at desired depth, placing in metallic soil can, and drying immediately in the laboratory. The only instrument used was the trowel. The object of the work was to learn, if possible, whether any relation exists between water content and water use. This latter problem will be discussed later. We will first consider and contrast the daily average moisture content, the seasonal average and the loss on ignition to see if any relation exists between the amount of water present from day to day and the assumed moisture content of the soil.

Table XLIII.

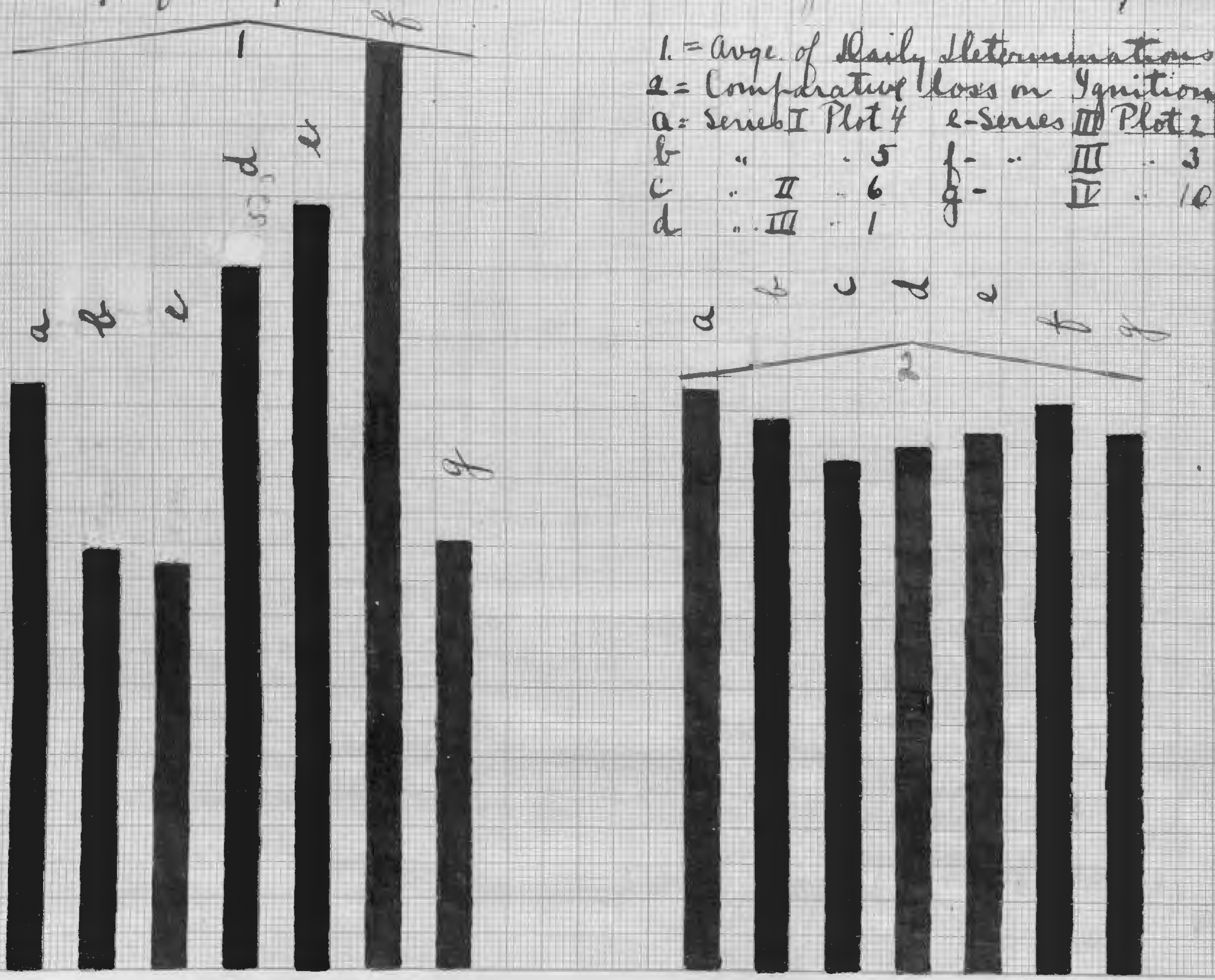
Daily Moisture Determinations Contrasted with other Physical Factors of Wheat Plots.

Plot	Daily Average	Seasonal Average	Loss on Ignition.
Plot 4 Series I	18.43 %	19.84 %	8.30 %
Plot 5 Series I	13.16 %	15.72 %	7.90 %
Plot 6 Series II	12.59 %	14.93 %	7.25 %
Plot 1 Series III	22.33 %	22.26 %	7.49 %
Plot 2 Series III	24.22 %	23.58 %	7.69 %
Plot 3 Series III	29.23 %	28.91 %	8.14 %
Plot 10 Series IV	13.46 %	15.34 %	7.72 %

What significance have these tables ? We have uniform seed, planted uniformly at the same depths, on land prepared in the same manner. Yet, as the assumed organic portion is increased or lowered, there is a corresponding rise or fall in the amount of water the plant roots have to feed upon. Many interest-

Plate XII Table XLIII

Average of Daily Moisture Determinations compared with Loss on Ignition.



ing questions arise at this point. A reference to our tabulations indicates the same general differences existing after the removal of the crops as before, but not in the same measure. We may assume then, that the differences are in part due to dissimilar organic contest which makes the soil more porous thereby providing a greater capacity for capillary water. This form of soil moisture, usually moving in opposition to gravity may be lost in two ways: evaporation and plant use. A brief test carried on for several weeks upon the most diverse soils we had studied failed to show any distinct differences in evaporation. With the factor of evaporation uniform, yet with variations existing in water content of soil at region of feeding roots, the next question is shall we find variation in the use of water by the several plants in proportion to the variation in the soil.

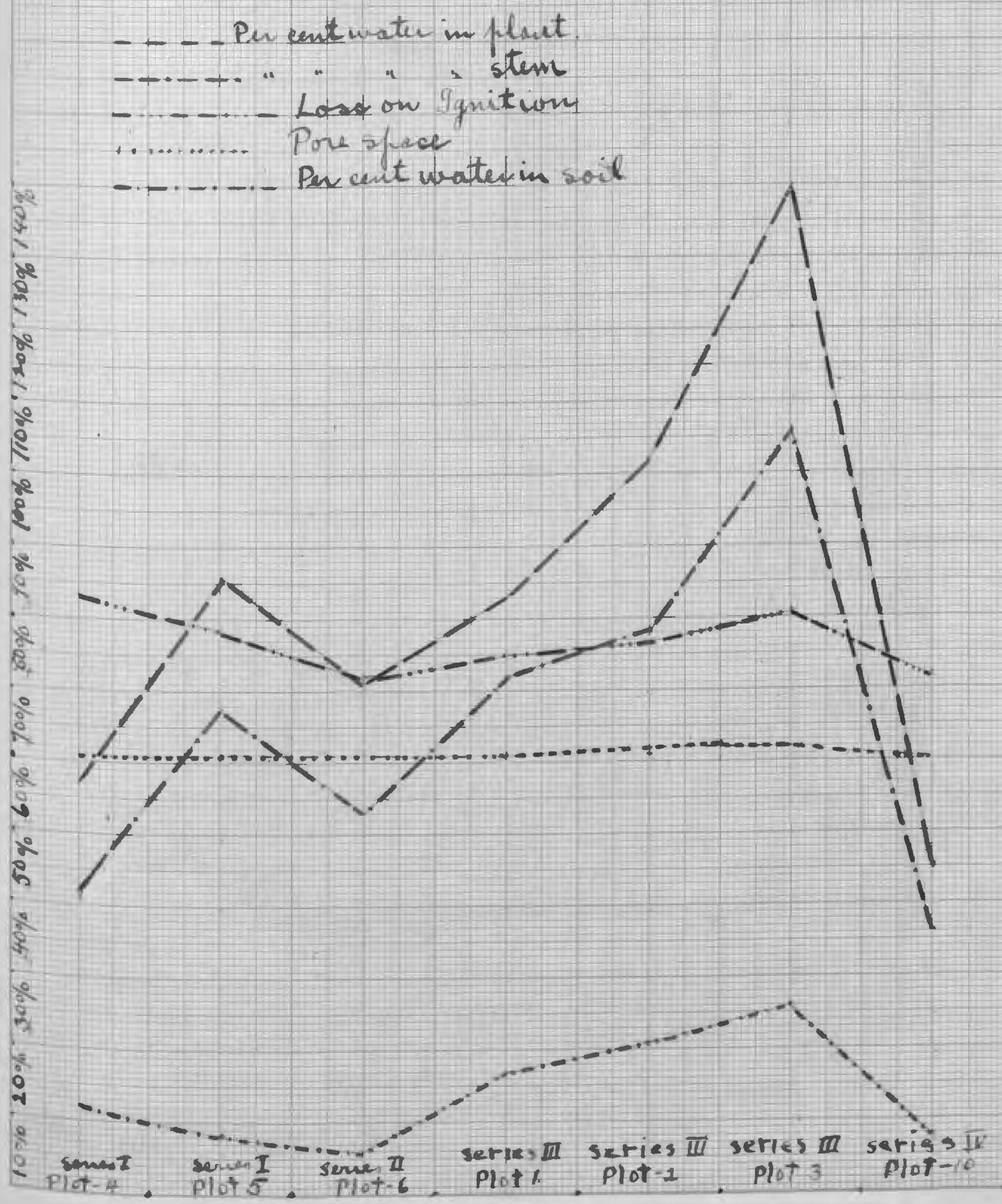
Table XLIV.

Water Usage by Wheat Plants.

Plot	Per Cent Water in Soil	Per Cent Water in Stem	Per Cent Water in Plant
Plot 4 Series I	12.10	42.3	57.29
Plot 5 Series I	8.45	67.9	85.99
Plot 6 Series II	5.99	53.72	71.66

Plate XIII - Table XLIV

A comparison of moisture in plant, stem, soil, Loss on Ignition and Pore space.



Plot	Per Cent Water in Soil	*Per Cent Water in Stem	*Per Cent Water in Plant
Plot 1 Series III	17.10	72.80	83.50
Plot 2 Series III	21.32	78.44	102.80
Plot 3 Series III	26.05	106.55	139.9
Plot 10 Series IV	8.63	36.54	45.8

* Based on dry matter present.

Excluding the first plot, we see a gradual decrease in water content in the plant as it decreases in the soil, and as the latter becomes moister, the same conditions obtain in the plant. Finally the figures drop back again in Plot 10 Series IV. We have traced a general relationship between the water content and assumed organic content of the soil. Will not the data justify us in making this connection triple, by stating that greater water content in the soil means more moisture in the plant, when the same plant is grown under different conditions ? We have already stated that the factor, evaporation, may be eliminated since it is practically uniform. Then the two factors directly responsible for the difference in water content are pore space (water capacity) on the one hand and water use by the plants on the other. An interesting query presents itself: "If the presence of more capillary water is associated with higher water content in the plant, should not the tendency to equalize conditions in the soil exist?" We can present two possible answers: First we have a condition relative to that existing in clay and sand. Clay has smaller capillary spaces associated with greater water capacity than sand and will not yield up its moisture to as low a degree - in other words it has a higher percentage of non-available water. May not our soils, showing greater pore space in this cropping experiment behave the same way in relation to plant growth ? Another explanation, and one we would consider more logical, is that as the amount of water increases the obvious thing happens - we have a heavier, softer growth of foliage resulting. This of course means a greater transpiration of water, but the relative moisture content of the several soils will remain unchanged as long as the ground water beneath is sufficient in quantity to satisfy the demands of the surface soils and plants growing upon them.

Briefly, then, the water content in the region of the feeding roots is regulated by pore space as affected by decaying vegetable matter; secondly, by the water use of plants; thirdly, by evaporation, which, however, being nearly uniform in all cases, may be passed over in observing differences. Greater pore space appeared to be associated with greater moisture content in soil and plant and vice versa. This relation would probably be maintained as long as the supply of ground water was adequate to satisfy all surface demands.

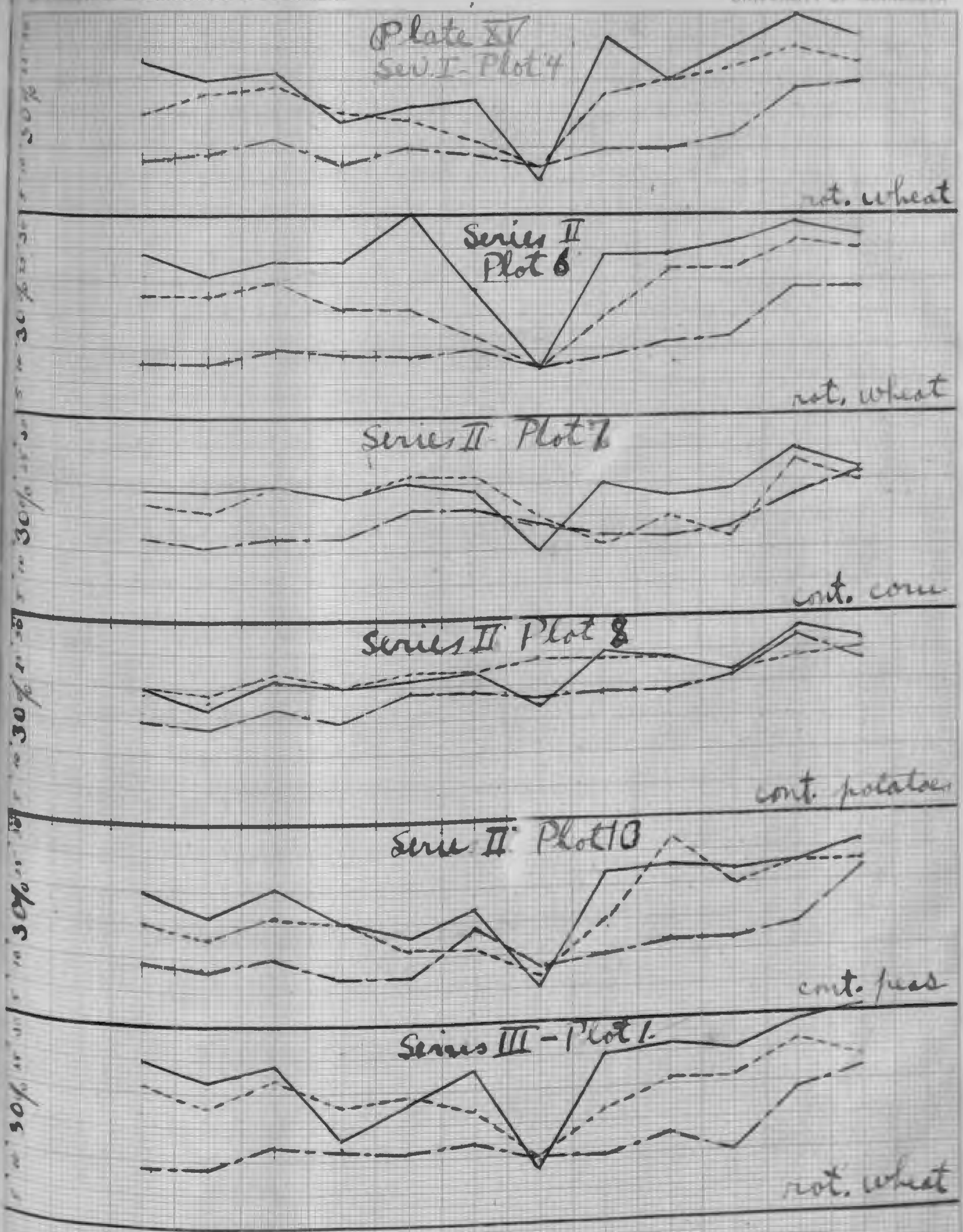
The following set of tables marks the last section of that division of our thesis relating to moisture problems. The work was carried on from April 20th to September 20th and samples were taken bi-monthly. The object was to study the variations of moisture content in the several plots under different systems of management and learn whether or not any relationship exists between the cropping of the plot, the crop grown, and moisture content. The samples were taken in three sections - the surface 0" - 9 inches; sub-surface 9" - 24 inches; subsoil 24" - 36 inches. Each sample was composite i.e. taken from different places in the same plot. The same problem has been handled under different circumstances which we shall refer to in our work.

Table XLV.

Bi-monthly Moisture Determinati[redacted] of Surface, Subsurface and Subsoil Samples.

Plot	Date April [redacted]	Rain fall 4/21	Date May 5	Rain fall 5/5	Date May 19	Rain fall 5/19	Date June 1	Rain fall [redacted]	Date June 15	Rain fall 6/16	Date June 30	Rain fall 7/1	Date July 15	Rain fall 7/15	Date July 29	Rain fall 7/30	Date Aug. 12	Rain fall 8/13	Date Aug. 26	Rain fall 8/26	Date Sept. 9	Rain fall 9/10	Date Sept. 22	Average
Plot 4 Series I																								
Surface	22.59	.02"	20.43	0	20.89	0	14.20	.02"	15.81	.84"	16.97	0	5.29	0	25.58	0	19.98	T	24.59	.09"	29.48	0	26.89	20.22
Subsurface	14.59	0	17.71	0	18.73	T	15.31	1.59"	14.36	0	11.40	0	6.87	0	17.81	.39"	19.53	.68"	22.14	0	25.05	1.27"	23.04	17.24
Subsoil	8.44	0	8.69	T	10.77	.54"	8.21	.51"	9.92	0	9.45	T	6.93	T	9.71	.02"	9.80	.34"	11.85	0	18.66	T	19.36	10.96
Plot 6 Series II																								
Surface	23.51	0	20.95	0	22.82	.24"	22.98	.70"	30.27	0	19.48	.61"	6.64	1.23"	23.93	0	23.63	.02"	26.12	0	28.65	0	26.89	22.82
Subsurface	18.29	0	17.58	T	24.46	0	15.61	T	15.71	0	12.34	.16"	7.14	0	15.22	.10"	22.46	0	22.45	.44"	26.24	.05"	22.60	18.00
Subsoil	8.00	.01"	8.16	.09"	10.25	0	8.55	0	9.15	0	9.59	0	7.89	.01"	8.62	.02"	11.25	0	12.50	.02"	18.89	0	18.61	10.95
Plot 7 Series II																								
Surface	19.26	0	16.82	T	20.12	0	17.72	0	19.96	0	19.25	.05"	9.93	0	19.90	0	18.42	0	18.60	T	25.50	0	22.49	18.90
Subsurface	17.21	T	15.76	0	19.62	0	18.17	.45"	20.55	0	20.68	0	14.82	.01"	10.71	.34"	15.37	0	12.24	0	22.94	.16"	20.25	17.36
Subsoil	12.45	0	11.40	.14"	11.93	.12"	11.96	0	15.57	.06"	16.10	.11"	13.85	.86"	12.18	2.56"	12.11	.46"	13.01	0	17.77	0	21.06	14.11
Plot 8 Series II																								
Surface	20.31	.08"	16.65	.49"	20.93	0	19.6	0	21.14	.02"	22.14	.01"	16.57	.10"	24.86	0	24.32	0	22.18	1.10"	27.96	0	25.97	21.88
Subsurface	19.90	0	19.03	2.14"	21.91	0	20.27	.63"	21.77	.67"	21.96	0	23.52	.01"	23.40	T	23.99	0	22.11	T	24.00	.26"	25.00	22.23
Subsoil	15.27	0	13.73	.22"	17.02	.01"	15.42	.01"	18.78	0	18.65	0	17.57	0	19.47	.39"	18.51	.02"	20.96	.54"	26.64	.02"	22.86	18.74
Plot 10 Series II																								
Surface	19.79	0	16.25	0	20.08	0	14.64	.01"	12.82	0	16.51	.03"	5.11	1.14"	22.17	0	22.59	0	22.34	T	23.43	T	26.15	18.48
Subsurface	14.75	0	13.48	T	16.35	0	14.79	0	11.27	.28"	11.05	0	7.34	.33"	14.86	0	27.22	0	19.77	.04"	22.98		23.34	16.43
Subsoil	8.77	0	8.29	T	9.97	0	7.32	T	6.97	0	13.51	0	7.86	.07"	9.64		11.84		11.89		13.96		22.28	11.02
Rainfall Total for 2 weeks		.11"		3.08"		.91"		3.92"		1.87"		1.00"		3.76"		3.86"		1.52"		2.23"		1.76"		
Plot 1 Series III																								
Surface	25.01		21.59		24.09		13.05		17.86		23.36		7.52		25.32		26.06		24.59		28.69		31.13	22.35
Subsurface	21.18		18.07		21.80		18.02		19.02		16.88		10.17		17.37		21.16		20.66		26.21		24.27	19.56

Plot 2 Series III													
Surface	25.31	21.01	22.98	19.31	21.12	23.21	10.83	18.92	28.50	25.72	29.39	29.41	23.22
Subsurface	20.24	15.84	20.36	18.08	16.50	12.43	15.81	19.30	21.61	23.22	28.48	27.51	19.94
Subsoil	13.03	9.29	11.79	13.54	12.72	12.29	11.45	13.10	11.11	14.92	24.61	24.25	14.34
Plot 3 Series III													
Surface	24.76	22.55	25.12	20.02	22.44	22.71	15.04	25.25	28.59	27.02	31.41	29.21	24.51
Subsurface	21.34	17.03	29.32	18.89	19.15	17.29	11.47	29.40	22.94	23.51	27.61	25.65	19.52
Subsoil	10.29	13.81	15.50	15.69	16.31	12.70	14.02	12.58	13.67	15.32	21.97	23.11	15.41
Plot 7 Series III													
Surface	26.05	18.06	21.03	13.73	20.94	21.50	9.13	21.46	25.46	23.17	29.11	24.61	21.18
Subsurface	20.08	16.58	13.80	15.82	15.33	17.17	11.83	12.86	16.92	17.78	25.62	23.83	17.30
Subsoil	9.61	10.22	11.58	10.55	9.64	12.26	10.15	8.15	12.48	12.20	16.14	17.41	10.78
Plot 4 Series IV													
Surface	24.86	21.01	24.89	18.22	21.73	22.70	12.31	25.21	25.54	23.92	28.69	26.98	22.92
Subsurface	20.58	19.53	21.82	18.38	20.06	18.98	15.76	18.51	21.66	22.21	27.12	25.20	20.81
Subsoil	9.44	10.85	11.86	11.67	11.84	12.82	11.66	11.32	13.45	15.21	22.36	22.34	13.31
Plot 10 Series IV													
Surface	22.01	17.49	21.75	15.89	17.20	14.72	5.42	22.92	24.99		28.62	27.82	18.23
Subsurface	17.36	13.25	18.24	14.75	12.17	10.55	7.02	15.59	18.55	21.01	25.44	21.80	16.31
Subsoil	9.77	8.34	10.29	5.30	9.69	9.77	8.76	10.02	9.69	11.35	15.13	21.17	10.76



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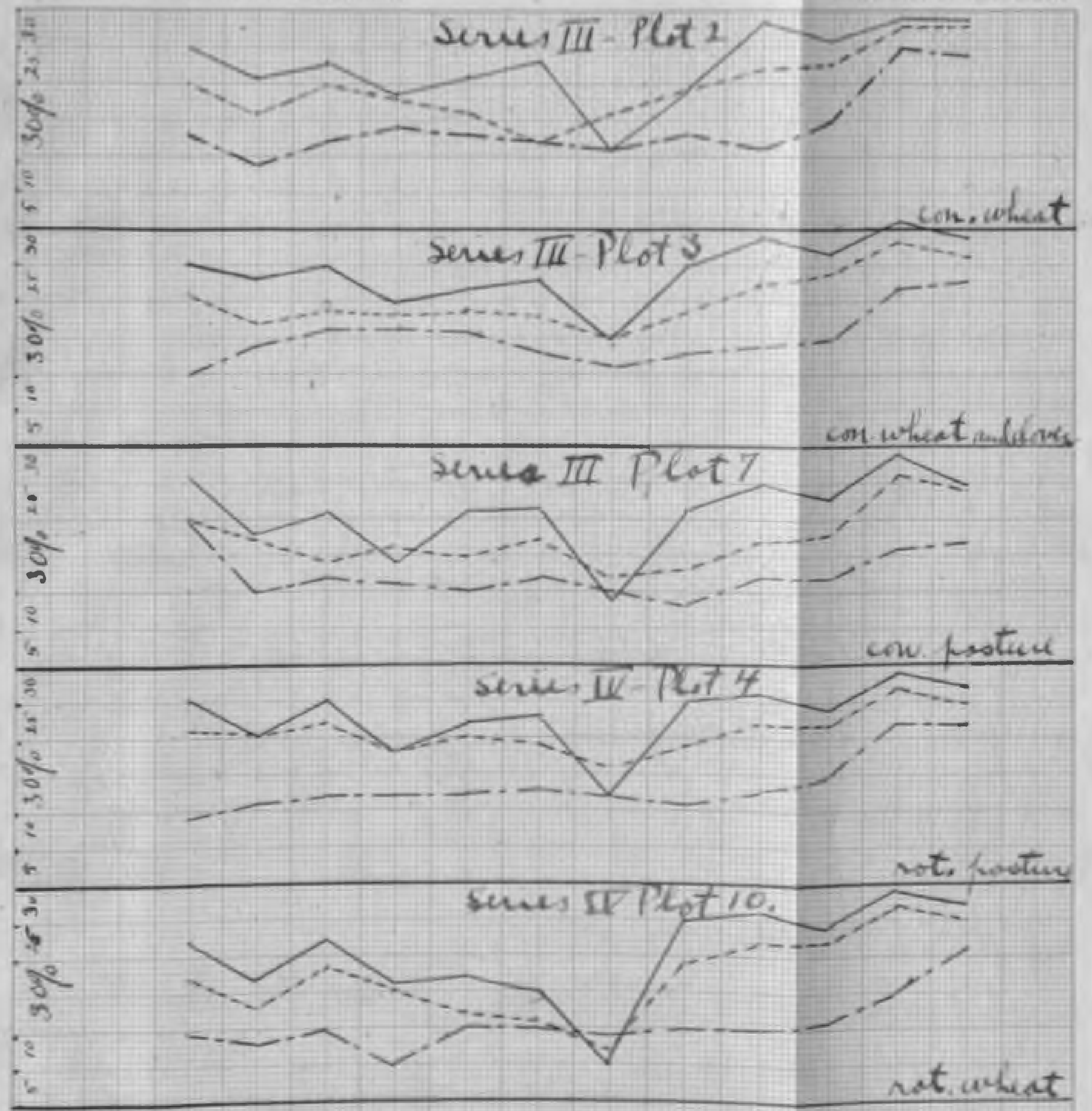


Plate XV Table XLV
bi-monthly moisture determinations

———— surface moisture
- - - - - sub. "
— - — - — subsoil "

At this point, conclusions that may be drawn from our table are in order. The first samples were taken April 21st, just as frost was coming out of the ground and following upon a dry summer and winter, the rainfall for 1911, up to this date, being four and one-third inches. As a consequence, we would expect a moderately moist surface soil and a very dry subsoil. Such we found to be the case, with two plots, 7 and 8, of Series II in distinct contrast. The surface here was drier and the subsoil wetter by 3-6 per cent than the other plots. This would normally be ascribed to effect of culture were it not that continuous wheat, Plot 2 Series III, behaves much the same. The samples taken May 5, with 11 inches of rain in the intervening two weeks, show some very slight changes. The ground water had settled in all the plots making differences less. Continuous peas, Plot 10 Series II, and continuous wheat, Plot 2 Series III, show subsoil water content very similar to other plots but continuous wheat and clover behaves like continuous potatoes. By May 19th, the effect of heavy rains appear - all plots contain about two per cent more water, the surface soils are nearly equalized and the dry subsoil has been somewhat affected and is now less dry. The effect of hot, dry winds, a scant rainfall, and the heavy draught of the growing crop are very telling factors in the determinations, June 1. Observe the wheat plots, 4 in Series I, 1 in Series III, 10 in Series IV. The soil, on the whole, is drier in all three sections in several plots than it had been before this year. Continuous potatoes and wheat still show moister subsoils. The mid June findings express most forcibly the neutralization of heavy rainfall thru extensive use by the growing crop, shown most clearly by continuous peas, Plot 10 Series II. This set of tests and the following demonstrate clearly the stimulation of capillarity due to cultivation. For our corn and potato soils contained 19-22 per cent while the grain plots ranged as low as 15.8% in moisture content. Samples taken July 14 were interesting in several ways. The observations just made can here by emphasized and repeated. Our two cultivated plots now show excess in both surface and subsoil. Continuous wheat and clover, Plot 3 Series III, seems to be maintaining a seasonal average approaching these two plots. In several of the grain plots at this date, moisture conditions are somewhat reversed, the surface soil becoming drier than the subsoil. Three factors contributed toward this result: a light rainfall,excessive use of water, absence of cultivation and excessive evaporation due to the hot winds of late June and early July. At this point the value of cultivation in conserving soil moisture stands out and a comparison of cultivated with grain and grass crops is instructive indeed. (See Plate XV). By July 29th, the crops were mostly removed, rainfall increased, hot, dry winds ceased. Hence we find the surface soils charged, in some cases, with the highest per cent of ground water for the season. However, it was not until August 26th, one month later, that we find the subsoil coming back to its normal water content. This gradually increases until September 22nd, when the plots showed the highest water content of the season.

A few facts disclosed here are worthy of emphasis. Following a dry season, altho over 20 inches of rain fell between April 1st and September 1st, the subsoil did not attain normal moisture conditions until the latter half of August, one month after the removal of crops.

Early seasonal data disclosed the fact that continuously cropped soils, irrespective of cultural methods, seemed to permit a more rapid passage of water into the subsoil.

The draught of the growing crop on soil moisture was strongest and could be most readily traced in tests made between June 1st and August 1st, with due consideration of rainfall during the same period.

The grain crops almost uniformly showed very low water content the middle part of July after the hot wave had passed over. This would tend to support the contention of New Mexico station that the moisture demands of wheat are greatest during the filling period.

During the driest atmospheric conditions, our cultivated crops indicated a high content of water in surface, subsurface, subsoil samples.

While some general relationships exist between moisture present and loss on ignition, the comparison cannot be made direct for several reasons.,

1. Crops are not the same in moisture demands.
2. Crops on these plots were not always exposed to identical atmospheric conditions. Thus Plot 1, and in a measure, Plots 2 and 3, Series III are somewhat shaded.

3. Crops were not all subjected to the same tillage comparisons.

In order to facilitate comparisons, we will show the average of bi-monthly surface samples, average of daily samples in region of feeding roots and loss on Ignition.

Table XLVI.

Moisture Comparisons and Loss on Ignition.

Plot	Daily Moisture Determination	Bi-monthly Moisture Determination	Loss on Ignition.
Plot 4 Series I	18.43 %	20.22 %	8.3 %
Plot 5 Series I	13.16 %		7.8 %
Plot 6 Series II	12.59 %	22.82 %	7.25 %
Plot 10 Series II	18.09 %	18.48 %	6.19 %
Plot 1 Series III	22.33 %	22.35 %	7.49 %
Plot 2 Series III	24.22 %	23.22 %	7.69 %
Plot 3 Series III	29.23 %	24.51 %	8.14 %
Plot 10 Series IV	13.46 %	18.23 %	7.72 %

This table shows that the connection tho evident in the latter portion, is quite remote between loss on ignition and moisture content of the surface 9" of soil, since it is but one of several factors. Likewise the two tables on moisture content do not entirely agree since the first deals almost wholly with capillary water and the second with ground water as well. Our results are emphasized by determinations taken in Massachusetts showing the relation between free or surface water and organic matter.

Table XLII.

From Massachusetts (Hatch) Report for 1899.

Location of Soil	Per cent of Organic Matter	Grams Water
Montague	1.86	114
Easthaven	2.00	115.9
Bridgewater	2.10	99.5
Orleans	2.20	105
Concord	4.19	145.3
Amherst	7.31	200.6
Attleboro	7.64	168.9

This work supplements ours, for it indicates that organic matter is but one of several factors influencing moisture content. The study of crops produced in relation to moisture content will be observed in Part III, which follows immediately at this point.

PART III.

STUDY OF THE CROPS ON RESPECTIVE PLOTS IN RELATION TO DATA OF PARTS I. AND II.

The final section of this paper deals exclusively with the cropping features of the field plots we studied. Notes on the growing crop come first, and following naturally after this comes the score card study of the several plots. This work has been broadened by an intensive study of weight, weeds, plump and shrunken seed content. The activity of plant growth in later stages, as measured by glucose production, is discussed just preceding the final section relating to crop yields.

The two wheat crops in Series I., were heavy and healthy looking all spring. The color was good, the stem long, and the soil in good condition at all times. At maturity, Plot 5 was a trifle later, the straw was slightly longer, but the crops were very even. The grain on Plot 6 Series II attained an equal height with those above, but stood a little thinner. The catch of clover, however, was fully equal to those in Series I. and even better in some places. I would ascribe this to the effects of less shading. The plot matured earlier and grew a crop appreciably lighter in yield. The factors, seed and seeding, were practically uniform and the season's average showed two per cent more moisture than Plot 4 Series I. Both effects noted then, I would ascribe to the somewhat thinner stand and more exposed position to the hot winds of late June. The duller luster, more uneven color, and greater per cent of shrunken kernels here would tend to support this last statement. The three wheat plots, 1, 2, 3, Series III, were the last to mature. This was largely due to the shade produced by the forest plantation just to the east, which, in checking and reducing sunshine, forced a lengthening of the ripening season. Slow evaporation was naturally associated with the heavy, dense growth of foliage, resulting in a large quantity of straw on Plot 1. This plot showed kernels of distinctly better type than Plot 6 Series II which doubtless was largely due to protection from hot winds, while the best catch of clover of the whole group was attained here. The early dry weather did not hit it. The continuous wheat plots, 2 and 3, Series III, showed no marked difference from the rotation plots until late in May when the stand began to grow less vigorous and more uneven. Gradually the foul seed took precedence, and by June 20th, on casual observation, one would say that wild oats dominated the continuous wheat plot to extent of 75 per cent and the continuous wheat and clover plot to lesser degree. A study of wild oats from all plots except continuous wheat - an interesting fact, for the seed sown was absolutely free from weed seed and these two plots had never been manured. At maturity, one would detect but little difference in the spikes. They were of nearly the same length. The great surprise was, that altho the greater quantity of shrunken seed, we had expected to find, materialized, yet the plump kernels present showed color, plumpness and weight in a marked degree. When sifted, the heavy portion made a better showing than several rotation plots. Notice the weights of cleaned grain further on. The lighter yield was due largely to the thinner stand as well as large amount of shrunken kernels. The clover catch of Plot 3, was second only to that upon Plot 1, largely because of repetition from year to year.

The last wheat plot to be studied was Plot lo, Series IV. A pesuliar feature here was the out standing dry, loose, character of the soil thraughout the summer. We found here the shortest straw, the thinnest stand, and earliest maturing crop. Altho the per cent of weed seed was but 25 per cent greater than in the standard rotation, laboratory study indicated fewer plump kernels, more uniformly shrunken one, lightest weight, a very dull amber color and no lustre - on the whole a somewhat frosted appearance. The stand of clover obtained was the thinnest of the series. Since the plot was harvested and threshed among the first, we know that seasonal conditions were not responsible. The plot is located on a slight rise - the highest position of the plots studied. Drainage would naturally make it drier; greater exposure to the hot winds of late June would intensify this feature and offer a ready explanation for early maturity and poor quality of grain.

Following the wheat plots, we will study the remaining crops in order of arrangement, the first one being continuous corn, Plot 7 Series II. The soil here seemed fairly friable and mellow considering the cropping scheme followed, altho it showed a distinctly lighter color. The corn, on coming up, looked good. It came on quite uniformly and the stand was of good color and fair growth when compared with neighboring rotation plots. By middle June, however, one could note differences that became more pronounced as the season advanced. The explanation that seemed most ready was that with uniform seed on all plots, all plants would start on the same basis. When the food in the grain was exhausted, the plant would draw on the accumulated supply in the soil. The continuously cropped plot, having a smaller total to draw from, would have its total available portion utilized more quickly than the rotation plots and from this point the crop would lag, because, for reasons given above the preparation of additional quahtities thru the summer would be on a smaller scale, thus systematically retarding the plant. The ears were very short, the largest scarce averaging seven inches in length, and the per cent of shelled corn running under 75 per cent, altho selected seed had been used. Altho mature and dry, the cobs broke very easily as if rotted. A chemical study would probably explain this and possibly show deficiency in mineral matter. The data relating to comparative diameter and height of stalk indicates a smaller plant and food making capacity.

Continuous potatoes, Plot 8 Series II, lying next to the continuous corn plot, was found to be in worst condition of all.

As already shown, the soil was hard, coked, compacted, in strong contrast to continuous corn or peas. When wet, it ran together, forming a sticky mass, which on drying, cracked and baked like gumbo. Thus a good seed bed was impossible and the potatoes, unlike the corn, showed a short stunted growth almost from the first. At no time was the ground more than half shaded, so scant was the vegetation. Yet, up to this season, the yield has been slightly higher than corn, when compared to rotation yields on University Farm, but lower when compared to state average. The soil, almost impenetrable, forced the development of a surface root system which explains both the scant growth above ground and the light crop beneath, the non-marketable portion of which was nearly three times that of the common varieties grown on University Farm and the marketable part only eleven per cent of the saleable portion of the varieties described above.

The plot which has grown peas continuously for seventeen seasons showed a condition much more mellow and open than the corn soil and afforded a strong contrast to the potato soil just described. The vegetation stood thickly enough on the surface, but was short in length. This was not caused by lack of moisture, as the rainfall was normal most of the growing season. It was interesting to observe how the water content fell, coincident with the development of the crop, until the filling period had passed. The drain of transpiration, then lessened, caused the moisture percentage to rise in the soil once more. April 21st, the soil contained 19.79% water; May 5th, 16.25%; June 1st, 14.6%; June 15th, 12.82%. By July 1st, the watery stem had attained full growth and soil moisture began to increase, showing 16.51%, July 1st. As peas were not grown to maturity elsewhere in Field C, comparisons cannot be made. Two features stood out, the pod and contents seemed small, and the crop matured several days earlier than others on University Farm. The smaller quantity of available nourishment would explain both.

Of the remaining plots, little can be said. For Plot 4 Series III was sown to oats and peas for feed instead of a two year wheat and clover rotation. The stand was very heavy. The continuous and rotation pastures can be considered together. The former had a stand of grass more dense, and naturally a thicker sod. This sodded condition would probably explain its greater loss of water during the season.

In order to test the accuracy of field observations during the spring, a laboratory test was planned by which the same plant was grown in different soils in a situation where conditions were under perfect control. Thirteen plots were secured, each was filled with soil from the surface six inches of a given plot and planted to corn, kernels one inch each way. Water was offered at intervals of forty-eight hours, to each plot and not in excess of 500 cc; the plots were placed in a north light to secure absolute uniformity. The temperature was moderate to cool, insuring slow growth. The readings (average of 14 plants) were made on the 24th, the 26th and the 30th day.

Table XLVI.

Measurements on Plant Growth.

Plot	24th Day	26th Day	30th Day
Plot 4 Series I	7.62"	8.74"	8.75"
Plot 5 Series I	8.20"	8.60"	10.08"
Plot 6 Series II	8.04"	8.83"	9.83"
Plot 7 Series II	7.54"	8.37"	8.46"
Plot 8 Series II	6.54"	6.83"	7.96"
Plot 10 Series II	7.37"	8.08"	9.16"

Plot	24th Day	26th Day	30th Day
Plot 1 Series III	7.79"	8.40"	9.25"
Plot 2 Series III	7.37"	8.16"	8.82"
Plot 3 Series III	6.50"	7.50"	8.16"
Plot 4 Series III	7.25"	7.80"	8.62"
Plot 7 Series III	6.79"	7.87"	8.25"
Plot 4 Series IV	7.08"	8.25"	9.41"
Plot 10 Series IV	8.41"	9.75"	10.04"

This test, altho of little absolute value, tended to support field observations that during the early period of growth there is practically no difference in the relative ratio of growth which becomes so pronounced later on. Closer observation and measurement show variation, however, in favor of the soils under rotation cropping.

The score card study normally follows after the notes upon the growing crop. The first table deals with the wheats only, corn and potatoes coming later.

Table XLVII.

Score Card Record of Wheat from the Plots under study.

		Standard	Plot 4 Series I	Plot 5 Series I	Plot 6 Series II	Plot 1 Series III	Plot Series II	Plot 3 Series III	Plot 10 Series IV
Yield	Weight	25	16	16	17	17	16	16	13.5
	Uniformity	5	3.5	3.5	4	3.5	2.	2.5	2.25
Variety Characters	Color	3	2	2	2	2	1	1.5	0
	Purity	10	9.5	9.5	7.50	9.50	7.	9.0	9.0
	Kernel Shape	2	1.75	1.75	1.50	1.60	1.	1.0	.50
Vitality	Luster	5	2	1	2.50	1.50	1.	1.50	0
	Plumpness	15	7.0	7.0	9.0	8.0	7.	6.0	5.0
	Germ	3	2.75	2.25	1.75	2.50	1.	1.75	1.50
	Odor	7.0	6.50	6.50	7.0	6.0	6.	6.0	6.0
Marketable Condition	Weed Seed	10.0	9.0	9.0	8.70	8.0	5.	5.0	7.0
	Dirt - Dust	3.0	2.75	2.50	2.70	2.50	2.	2.50	2.50
	Injured Kernels	2.0	2.0	2.0	2.0	2.0	2.	2.0	2.0
	Smut	5.0	5.0	5.0	5.0	5.0	5.	5.0	5.0
	Condition of bran	5.0	3.50	3.50	3.70	4.0	3.	3.50	4.0
Totals		100	73.25	71.50	74.35	73.10	61.	64.25	57.75

Altho a score card study is, at best, of secondary value, yet a comparative, mathematical study of the grains emphasizes, as no other method would, their relative value. The variations in weight are considerable; so likewise were such factors as luster, plumpness, weed seed content. Uniformity was usually cut not less than 33%, while the large weed seed content cut the yield in some cases 25-40%. Plot 5 Series I was exposed to the weather longer, hence it suffered more. The score card comparison does not bear out the difference in yield since quality was poor in all cases due to seasonal causes. A long period of wet weather, directly after cutting, nearly ruined the crop of continuous peas, unfitting it for technical study; and the pea crop, mixed with oats and growing on Plot 4 Series IV was cut green. While a score card study thus became impossible, our crop notes and the data or yields, given later, furnish considerable information.

This leaves two plots, continuous corn and potatoes, to observe in detail. During season of 1911 corn was grown only on the continuous plot of the one-tenth acre plots of Field C, so the measurements on foliage and yield are compared to the results on the five year rotation corn plot, one-half acre, at southwest corner of Field C. This is included in Table XLV. Table XLVI shows a contrast of several characters of continuous corn and corn of the same variety (No. 13) grown upon the variety test plots under ordinary rotation conditions.

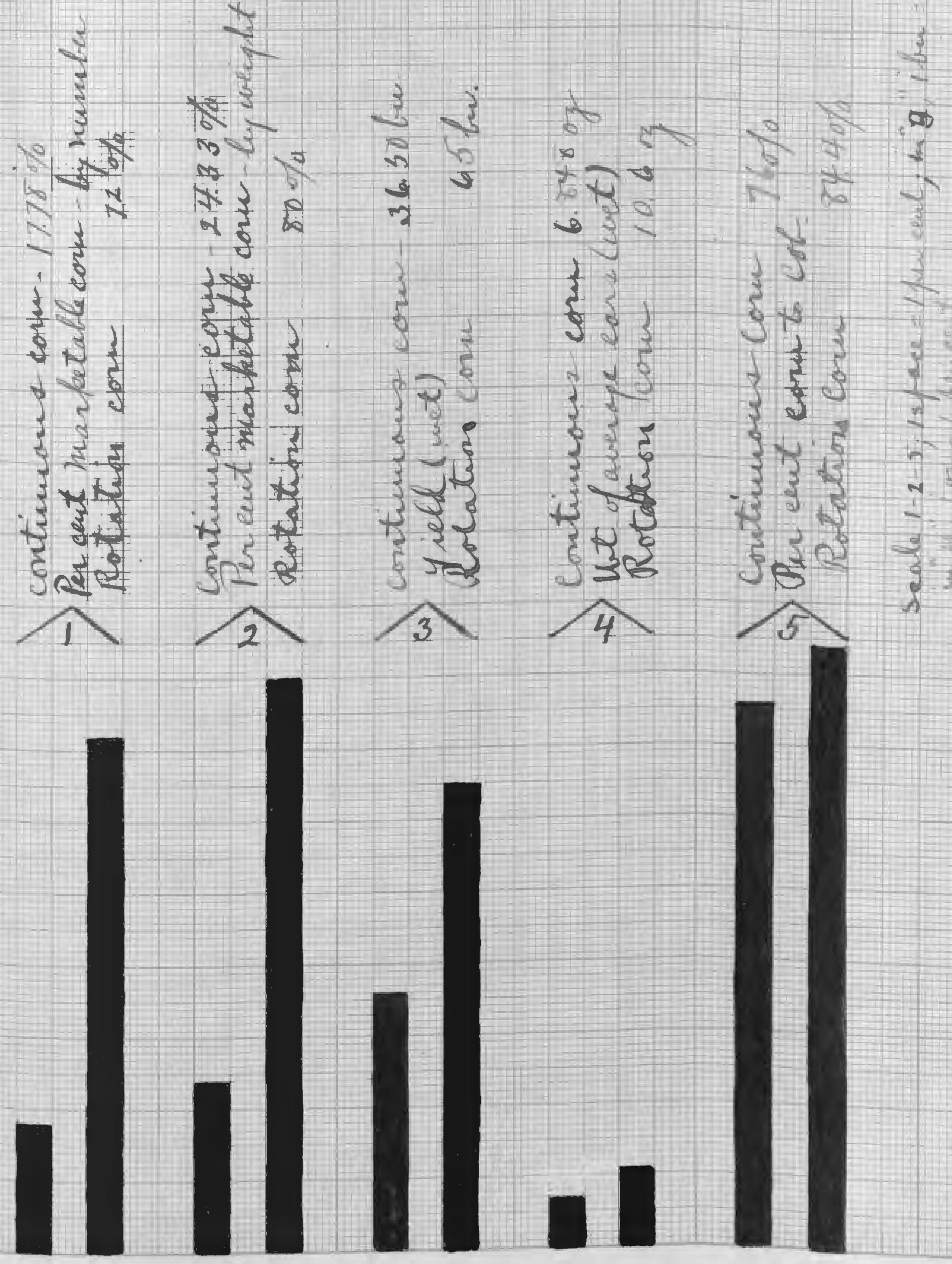
Table XLVIII.

Comparative Study of the 18th Successive Corn Crop.

	Corn Grown Continuously	Corn grown in Variety Test on Rotation Soil.
Per Cent marketable by number	17.78 %	72 %
Per cent marketable by weight	24.33 %	80 %
Per cent not marketable by number	82.22 %	28 %
Per cent not marketable by weight	75.67 %	20 %
Wet Yield	36.50 Bu.	65 Bu.
Dry Yield	30.50 Bu.	50 Bu.
Per cent shrinkage	17.35 %	13 %
Weight Average Wet Ears	6.848 oz.	10.6 oz.

Plate XVI - Table XLVIII

Comparison of corn crops grown under rotation and successive cropping schemes.



	Corn Grown Continuously	Corn grown in Variety Test on Rotation Soil.
Weight Average Dry Ears	5.82 oz.	7.4 oz.
Per cent corn to cob.	76.00 %	84.4 %

Table XLIX.

Comparison of Corn Plant in Rotation and Continuous Cropping.

	Height of Stalk	Diameter of Stalk	Yield
Continuous Corn	64"	2.333"	36.5 Bu.
Rotation Corn	81"	3.215"	69.7 Bu.

This data represents averages of fifty plants. The high shrinkage is largely due to the wet fall. The cobs were rather soggy and partially decayed. While the first yield, 36.5 bushels, is surprisingly high, the loss of water reduces these figures considerably. The very best ears from the plot weigh but 60% of the standard for southern Minnesota and the saleable portion is but one-fourth of the whole crop. The plant in rotation shows 27% advantage in height and 30% in

Plate XVII Table XLIX

Comparison of corn plant in Continuous and Rotation cropping.

circumference, 91% in yield.

As no other potato plots were available for study in Field C, several of the typical varieties discussed in bulletin 114 have been selected for comparison here. These potatoes have been grown in variety tests upon soils in three year rotation. All available data has been used, and the average yields are on a minimum basis of three years.

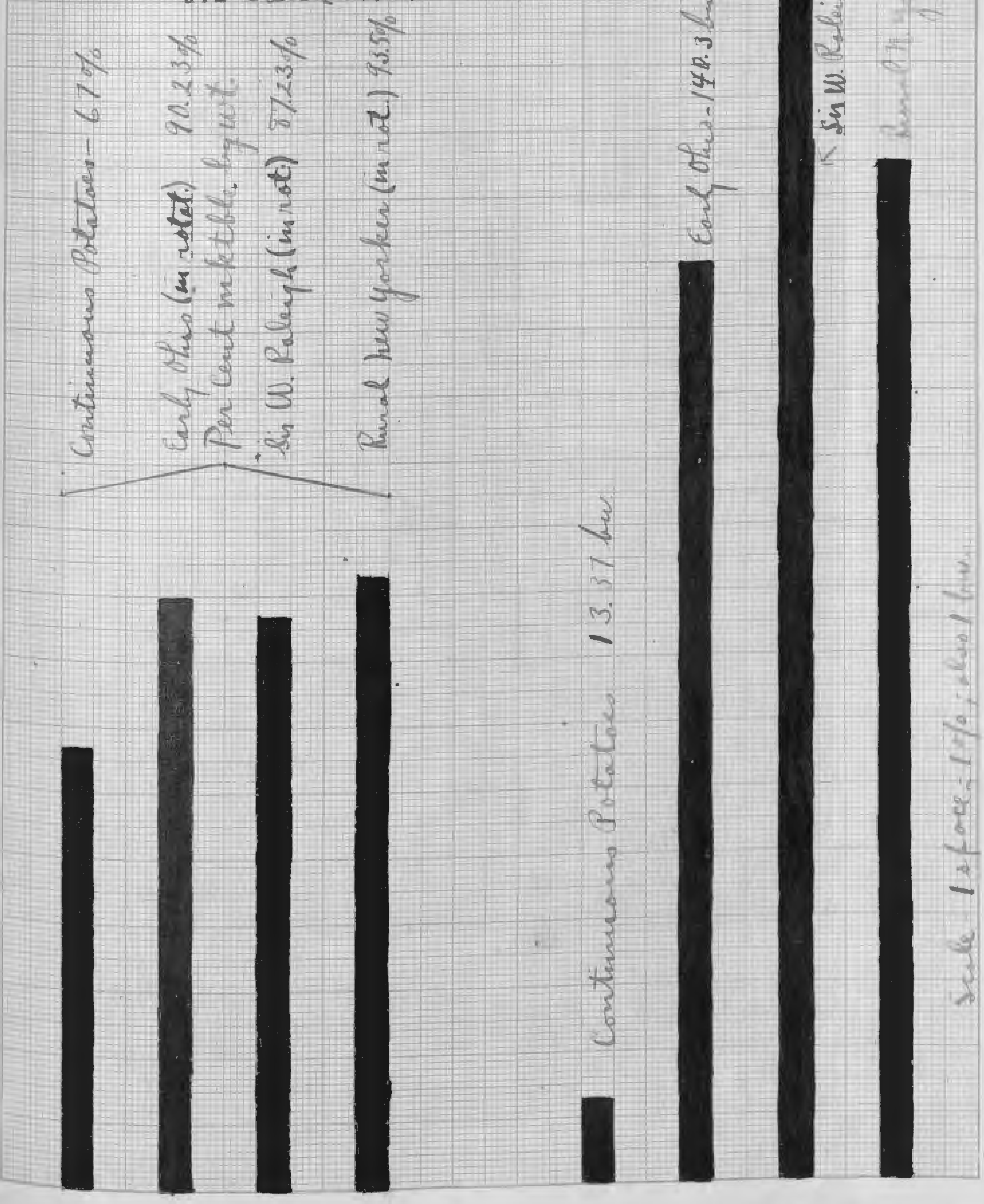
Table L.

Comparative Study of Continuous Potato Crop.

	Continuous Potatoes	Early Ohio	Sir Walter Raleigh	Rural New Yorker.
Per Cent Marketable by number	40.86			
Per Cent Marketable by weight	67.00	90.23	87.23	93.50
Per Cent Not Marketable by number	59.14			
Per Cent Not Marketable by weight	33.00	9.77	12.77	6.50
Marketable Weight	47#			
Non-marketable Weight	23#			

Plate XVIII Table I. Yields

Comparative Study of successive potatoes on same soil.



	Continuous Potatoes	Early Ohio	Sir Walter Raleigh	Rural New Yorker
Total Weight	70"			
Disease	33 1/3 %			
Uniformity	50 %			
Yield per Acre				
1911	13.77 Bu.			
17 year average	56.37 "	140.3	195.9	154

This was the most unsatisfactory plot of all. The soil tends to bake hard in dry weather and runs together in a slimy mass when wet. Hence the crop was very muddy, and about half the lot showed a strong peeling tendency. The comparison intensifies the low scale of yield and marketable product. Further data on yield will appear in connection with that topic.

An interesting study is that of the mechanical composition of the crops grown upon the several grain plots. The following tables will include a relative study of the proportions of seed grain, saleable grain, chaffy grain, weed seed; the relative weights before and after cleaning and a tabulation of the different weed seeds found.

Table LI.

Percentage of Shrunken Kernels and Weed Seed

Separated by Laboratory Fanning Mill.

Plot	Per Cent Offal
Plot 4 Series I	8.0
Plot 5 Series I	7.0
Plot 6 Series II	5.22
Plot 1 Series III	5.05
Plot 3 Series III	20.58
Plot 10 Series IV	14.92

Attention is directed to the similarity of the 1st four rotation plots as compared to continuous wheat, Plot 3 Series III, and the last plot, the poor showing of which has already been explained.

Table LII.

Percentage of Weed Seed in the Total Refuse

Separated by Laboratory Fanning Mill.

Plot	Per Cent Weeds	Per Cent Refuse.
Plot 4 Series I	23.37	8.0
Plot 5 Series I	17.08	7.0
Plot 6 Series II	28.12	5.22
Plot 1 Series III	46.40	5.05
Plot 3 Series III	68.13	20.58
Plot 10 Series IV	35.54	14.92

One of our standard rotations indicate rather a high weed seed content in total impurities, but when this is based on total yield it is minimized in large degree.

Table LIII.

Percentage of Weed Seed in Crop.

Plot	Per Cent Weed Seed	Total Yield
Plot 4 Series I	1.86	20.16
Plot 5 Series I	1.19	22.33
Plot 6 Series II	1.46	18.66
Plot 1 Series III	2.32	20.16
Plot 3 Series III	14.92	13.83
Plot 10 Series IV	5.30	15.83

The quality of weed seed, with a minor exception varied directly as the total yield of the crop and illustrated conclusively the efficiency of a rotation system in weed eradication. While fluctuations occur in the rotation plots, they are slight when compared to continuous wheat and clover, Plot 3 Series III, the corresponding crop of which, without clover, was worse if anything. With the exception of wild oats which prevailed so strongly in the continuous wheat plots, the weed seeds present in one case are present in all, altho the proportion varied somewhat. The chief weed seeds present were: Choetochloa Viridis (Green Foxtail) which usually formed nearly 90 per cent of the total weed seed present; Choetochloa Glauca (Yellow Foxtail) was present in considerable quantity; the remainder consisted of a few seeds of each type: Polygonum Persicaria (Lady's Thumb); Polygonum Convolvulus (Black Bindweed, commonly called wild buckwheat); Chenopodium Album (Lamb's Quarter); Amaranthus Retroflexus (Pigweed); Transparent Polygonum; Linum Usitatissimum (Flax); Polygonum Sagittatum (Narrow Leaf Tear Thumb).

In order to show the economic application of this data, we will now present a composite table showing the value of a rotation system from another viewpoint - the statistical ratio of weed seed and shrunken kernels to total production.

Table LIV.

Composite Table on Mechanical Analysis of

Grain Crops.

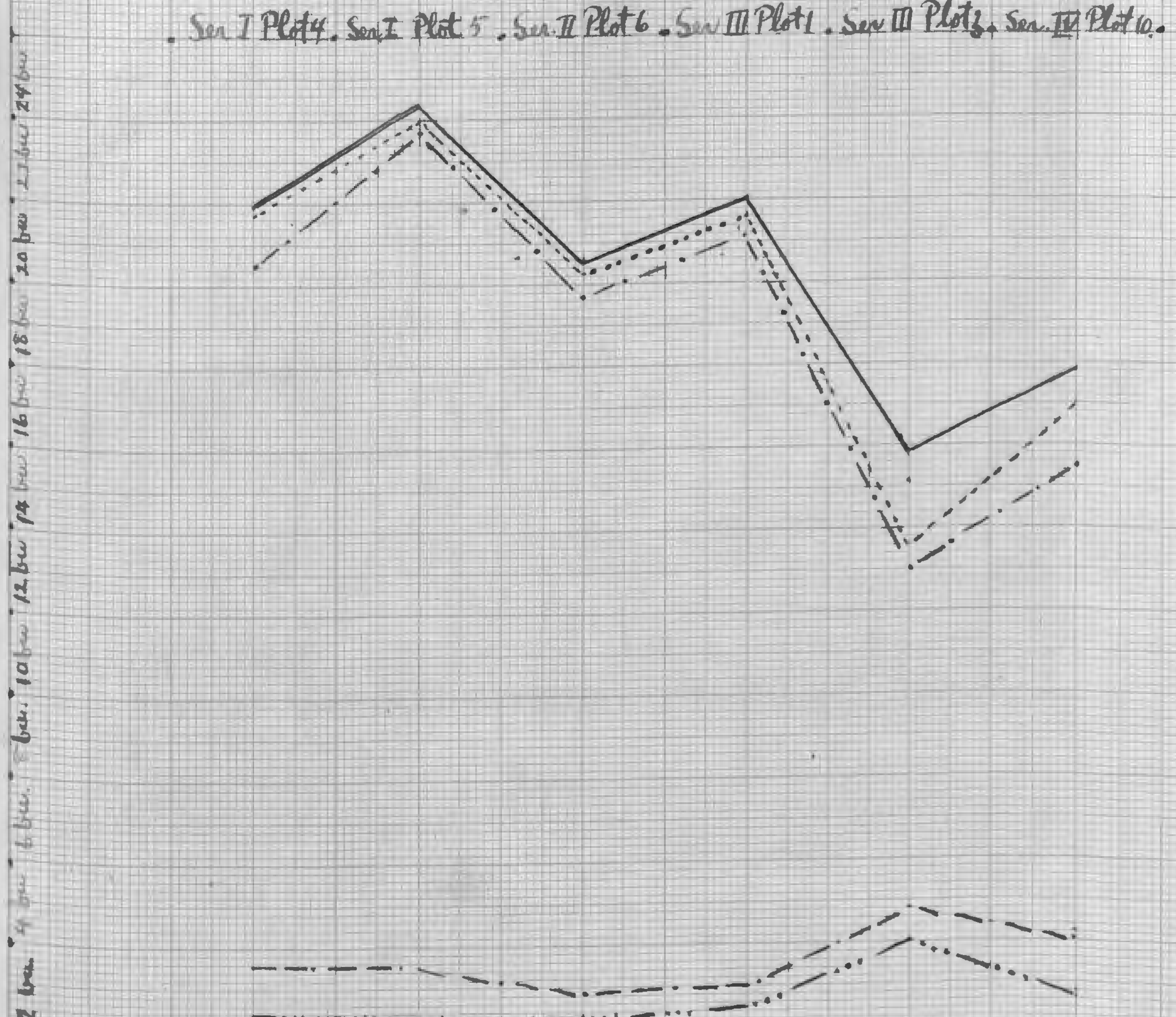
Plot	Total	Salable Grain	Seed Grain	Shrunken Seed and Weeds	Weed Seed
4 - I	20.16 Bu.	19.78 Bu.	18.55 Bu.	1.61 Bu.	.38 Bu.
5 - I	22.33 "	22.06 "	21.77 "	1.56 "	.27 "
6 - II	18.66 "	18.39 "	17.69 "	.97 "	.28 "
1 - III	20.16 "	19.69 "	19.15 "	1.01 "	.47 "
3 - III	13.83 "	11.77 "	10.99 "	2.84 "	2.06 "
10- IV	15.83 "	15.00 "	13.47 "	2.36 "	.83 "

A note of explanation is due at this point. Continuous wheat, Plot 2 Series III, has been omitted in the last few tables. At threshing time it was misplaced or mislabelled and was only found after it had been recleaned. Hence, the weed data was unavailable. Altho this plot was much weedier in the growing season and showed a yield 16% less, we will be conservative and accept the weed and shrunken kernel data of continuous wheat and clover as identical for both altho continuous wheat, alone, would doubt-

——— Total yield
- - - - - - salable grain
—·—·— seed grain
—+—·— shrunken Kernels + weed seed.
—+··—··· bu. weed seed per acre.

Plate XXVIIA - Table LIV

Analytical study of the grain crop.



less by shown in worse condition on close study.

The salable grain included the whole amount except the weed seed while the seed grain includes the plump kernels only. In an analytical study such as this, the difference between continuous and rotation cropping is emphasized because we have a measure of the efficiency of crop rotation in disposing of weeds and the inability of a system of continuous cropping to cope with them. The content of shrunken seed runs nearly the same throughout.

Two factors of economic importance in the matter of growing wheat are moisture content and germinative power. Both tests were made, but since the grain on all the plots was not subjected to the same weather conditions, the data could not be used. The next table shows the relative weights of grain before and after cleaning, the weight of 100 kernels (before cleaning) and a comparison with Rothamsted work.

Table LV.

Comparative Weights of Grain.

Plot	Weight of Grain Before cleaning	After cleaning	Weight 100 Kernels	Bushels Per Acre
Plot 4 Series I	51#	51.5#	1.969 grams	20.16
Plot 5 Series I	52#	52.5#	1.962 "	22.33
Plot 6 Series II	52#	54.25#	2.27 "	18.66
Plot 1 Series III	52.5#	53.25#	2.20 "	20.16
Plot 2 Series III	51.6#	55.00#	2.109 "	12.00
Plot 3 Series III	51.25#	55.00#	2.039 "	13.83
Plot 10 Series IV	48.00#	50.00#	1.709 "	15.83
Rothamsted 14 Year Average		60.70#	3.699 "	

The high weight of cleaned grain from continuously cropped plots is outstanding. The quantity of shrunken kernels was so great that it tended to carry thru the sieve all possible pernels and weed seeds, leaving only the very plump kernels thus increasing weight. When the weeds and shrunken kernels were few, the tendency was to go over with plump grain thus reducing weight.

The grain in each plot is much below standard weight which fact is due to adverse seasonal conditions. A comparison of weight of grain per bushel and also of yield substantiates a common observation: the quality and quantity of grain are not necessarily associated. The season of 1910 demonstrated this fact. For, altho the yields in the drouth stricken areas of the west were low, the quality was high, which fact increased the weight per bushel.

In view of our findings, disclosing good color and large measure of plumpness and other desirable qualities in continuous wheat, a quotation from "Lawes and Gilbert" is pertinent. "It is important to notice that the continuously unmanured plots, with its small yield, yet produces grains of corn almost up to the average in size, weight per bushel, and value from a commercial point of view. The plant, when starved, diminishes the number but not the quality of the seed. Even the proportion of tail corn is not above the average on this plot. The proportion of corn to straw is highest on this plot as the starvation resulted in concentrating the highest proportion of the material on the reproductive portions of the plant." Before passing on to the final topic, yield, we must briefly consider the topic of glucose production.

Since we experience a variation in yield in crops in the several plots, we may naturally expect variation in food making activities and the process of growth. The life processes are carried on in the leaf and centered upon the production of carbohydrates. It was to study this question, then, whether the soil environment of the plant, the relative availability of plant food could retard or accelerate the combined action of chloroplasts and sunlight, that this work was undertaken. Leaf samples were taken June 21st from wheat plants in milk stage and again July 7th, when in soft dough stage. Allin's modification of Fehling's solution was the test used to determine the presence of glucose, all determinations being repeated several times. Altho subjected to repeated tests, the first set of samples failed to show any uniformity in relation to yield so this data has been omitted. During this formative period, this factor may have been disturbed by many others that are operating, which fact may justify our findings. Note results on second series of samples taken July 7th, in soft dough stage.

Table LVI.

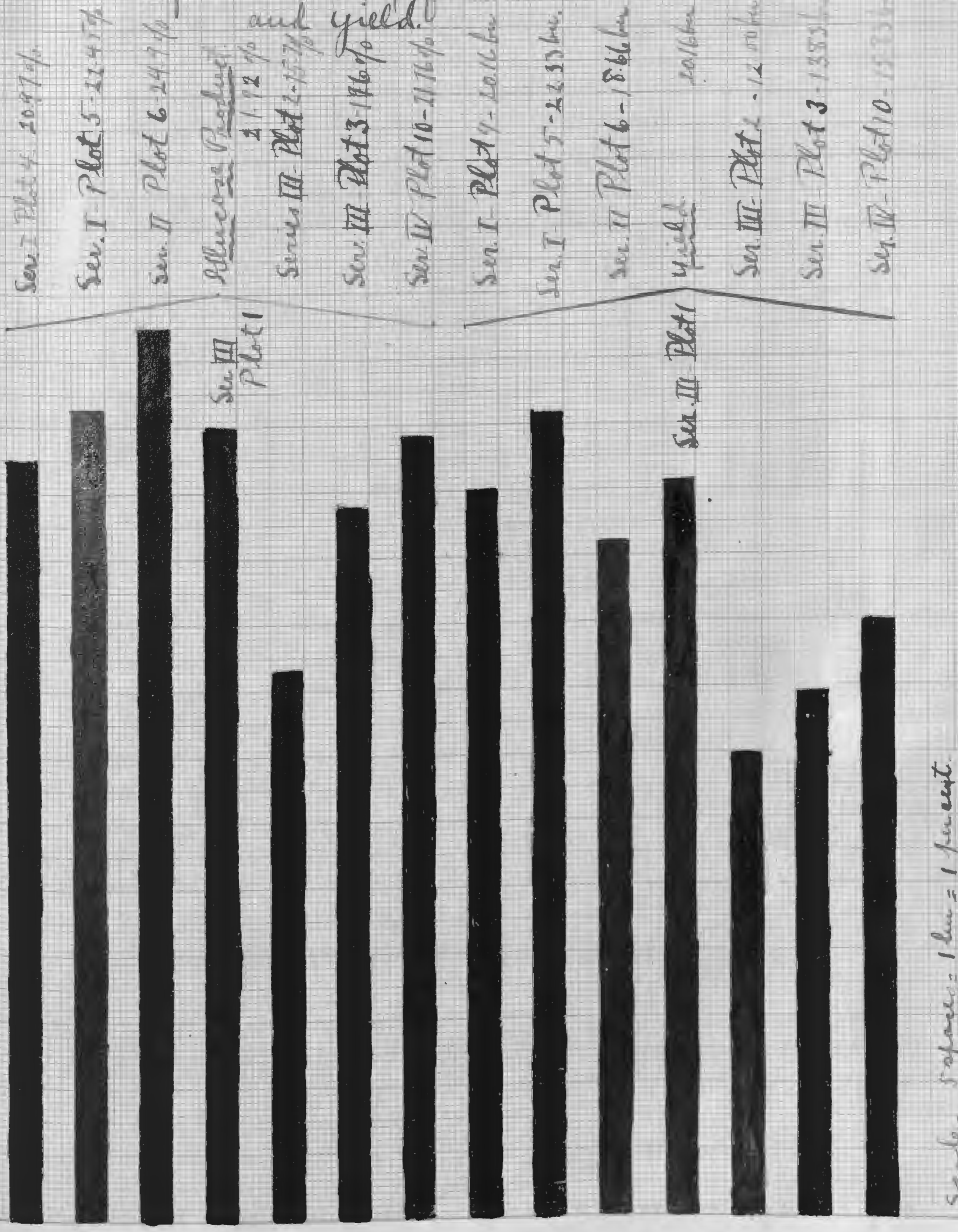
Glucose Production and Yield.

Plot	Per Cent Glucose	Yield in Bushels.
Plot 4 Series I	20.97	20.16
Plot 5 Series I	22.45	22.33
Plot 6 Series II	24.91	18.66
Plot 1 Series III	21.92	20.16
Plot 2 Series III	15.71	12.00
Plot 3 Series III	19.59	13.83
Plot 10 Series IV	21.76	15.83

As our yield fluctuates upward or downward, the percentage of glucose content follows it, a good barometer of plant activity in carbohydrate production. One plot, Plot 6 Series II, is a marked exception, combining the highest sugar content with moderate yield. But the fact, that in earlier determinations it repeatedly showed the same results, tends to reassure us and indicate the activity of some other factor. One might explain the small yield and diminished glucose content upon the respective basis of thinner stand and smaller plant, holding that

Plate XVIX Table LVI

Comparative Study of Glucose Production and yield.



carbohydrates were manufactured in proportion to leaf surface. But this argument is disqualified, for our findings are percentages based on actual dry weight of powdered leaves. One explanation remains. Since the presence of nitrogen, phosphorus and potash is essential in food making activities of the plant, it would seem that the smaller percentage of glucose per unit weight of powdered leaf of continuous wheat is due to a soil solution, too dilute for efficient work. We believe, then, that further work will show, not only that continuous cropping reduces yield of grain and straw, but by affecting strength of soil solution, it influences activity of chloroplasts in carbohydrate production.

The final portion of Part III deals with the question of yield, the major factor in study of crop production. We will observe this from the viewpoint of the 1911 crop and the eighteen year average. Comparisons will occur at several places with similar data gathered at other stations and also in relation to moisture content and loss on ignition. We will first present tables showing the history of cropping upon each plot for the whole period and follow this by a summarized study.

Table LVII.

Production of Wheat in Bushels for 18 Year Period.

Plot	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	Average
Plot 4 Series I	11	30.3	0	0	0	30.5	24,6	0	0	35.6	0	0	0	29.2	0	0	0	20.16	27.18
Plot 5 Series I	12.6	27	0	0	0	0	26.6	0	0	0	0	27.5	0	0	0	0	0	22.33	23.64
Plot 6 Series II	15.8	25.4	0	0	0	0	25.5	0	0	0	0	27.6	0	0	0	0	0	18.66	23.41
Plot 1 Series III	10.16	28.6	0	0	21.8	0	23.3	0	0	0	0	28.3	0	0	0	0	0	20.16	22.93
Plot 2 Series III	11	24.7	14.66	17.8	21.4	22.5	14.5	16	17	16.3	20.8	20.8	14.1	24.5	19.1	22.67	25.8	12.00	18.64
Plot 3 Series III	14.5	25.6	20.0	22.2	23.5	24.0	19.8	11.3	15.0	24.1	32.5	23.3	15.0	25.3	20.0	25.00	27.2	13.83	21.24
Plot 4 Series III	14.91	28.2	0	20.0	24.3	24.2	20.8	0	18.8	0	0	15.1	0	0	0	0	29.2	0	21.72
Plot 10 Series IV	14.58	24.7	0	0	22.0	0	21.0	0	22.5	0	0	15.8	0	0	0	0	0	15.83	19.49
Average	13.07	26.81	17.33	20.0	26.6	25.3	22.01	13.6	18.3	25.3	26.6	22.63	14.5	26.3	19.5	23.8	27.4	17.56	22.28

Table LVIII.

Production of Oats in Bushels for 18 Year Period.

Plot	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1909	1911	Average
Plot 4 Series I	0	0	0	26.3	0	0	67.2	0	0	0	0	48.6	0	0	53.4	0	0	0	48.87
Plot 5 Series I	0	0	0	0	50.3	0	0	0	0	76.8	0	0	0	0	43.9	0	0	0	57.00
Plot 6 Series II	0	0	0	0	58.4	0	0	0	0	62.1	0	0	0	0	45.3	0	0	0	55.27
Plot 1 Series III	0	0	0	0	0	0	0	0	0	59.0	0	0	0	0	37.8	0	0	0	48.40
Average	0	0	0	26.3	54.3	0	67.2	0	0	65.9	0	48.6	0	0	45.1	0	0	0	52.38

Plate XX Table LVIII

Average production of wheat per plot for 18 yr. period

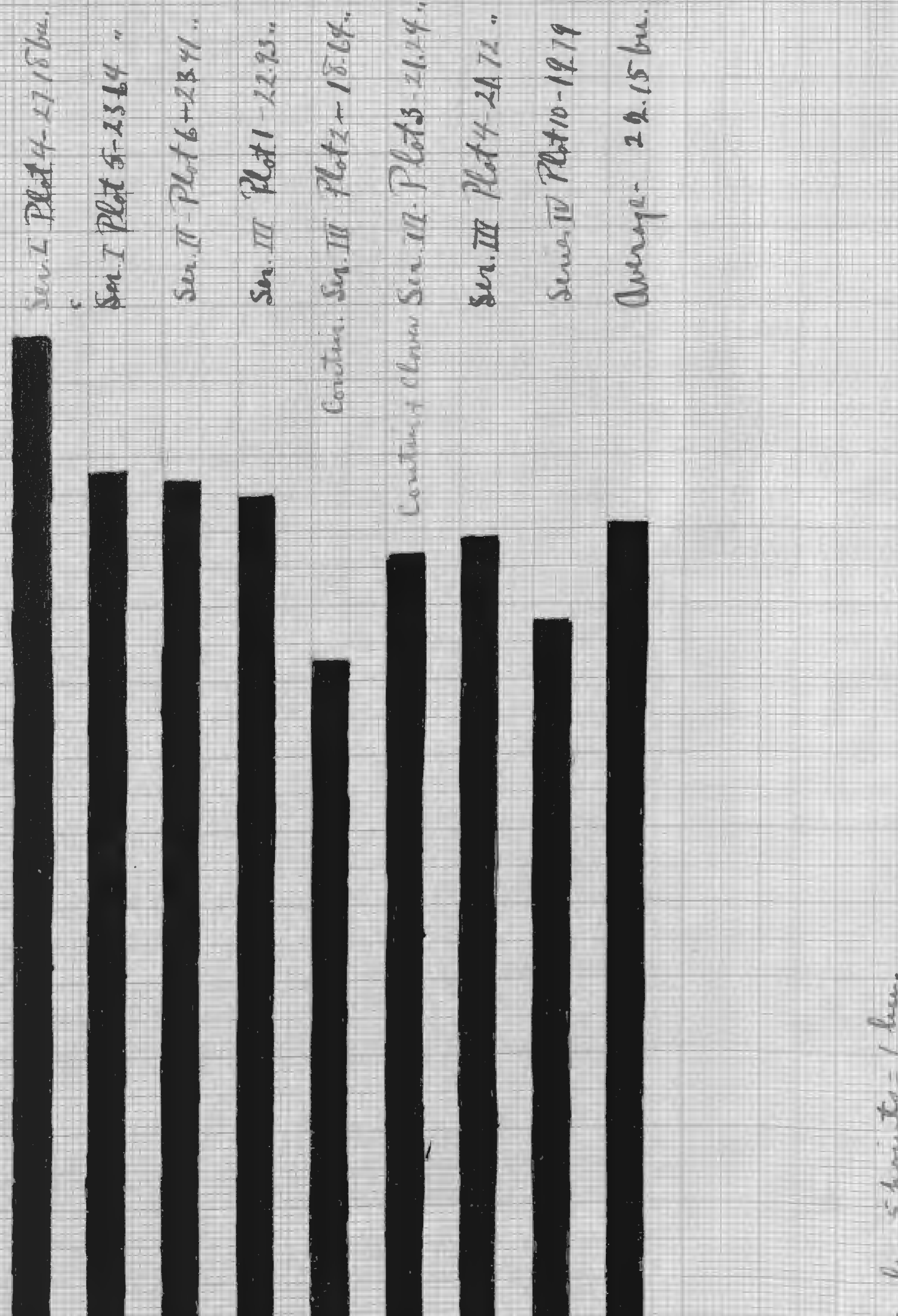


Table LIX.

Production of Corn in Bushels [redacted] ear Period.

Plot	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	Average
Plot 4 Series I	0	0	0	0	65.2	0	0	0	0	0	0	0	41.3	0	0	0	36.11	0	47.5
Plot 6 Series II	0	0	0	0	0	48.6	0	0	0	0	47.9	0	0	0	0	73.6	0	0	56.7
Plot 7 Series II	18.16	29.30	31.90	29.90	27.70	20.80	37.50	13.90		23.6	11.1	25.1	27.6	23.6	33.3	41.6	30.5	31.38	26.87
Plot 1 Series III	0	0	0	0	0	57.6	0	0	0	0	58.3	0	0	0	0	77.7	0	0	64.5
Plot 4 Series IV	0	0	0	0	0	48.6	0	0	0	0	0	0	0	0	68.0	0	0	0	58.3
Average	18.16	29.30	31.90	29.90	47.40	43.90	37.50	13.90	0	23.6	39.1	25.1	34.45	23.6	50.7	64.3	33.3	31.38	50.85

Table LX.

Production of Hay in Tons for 18 Year Period.

Plot	1894	1895	1896	1897	1898	1899	[redacted]	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	Average
Plot 4 Series I	0	0	2.15	0	0	0	0	0	0	0	4.75	0	0	0	0	3.4	0	0	3.43
Plot 5 Series I	0	0	3.37	3.27	0	0	0	3.05	2.05	0	0	0	1.95	1.97	0	0	0	0	2.61
Plot 6 Series II	0	0	2.4	3.17	0	0	0	2.5	1.75	0	0	0	1.55	1.62	0	0	0	0	2.16
Plot 1 Series III	0	0	3.22	3.62	0	0	0	3.25	2.1	0	0	0	3.7	2.17	0	0	0	0	3.0
Plot 4 Series III	0	0	1.42	0	0	0	0	1.12	0	5.5	0	2.27	0	0	0	0	0	0	2.57
Plot 8 Series III	0	0	1.87	2.47	0	0	.9	.95	1.27	3.65	1.95	1.70	0	1.15	1.55	1.50	0	.8	1.64
Plot 4 Series IV	0	0	3.87	3.45	2.5	0	0	1.12	0	2.8	0	0	0	0	0	0	0	0	3.15
Plot 10 Series IV	0	0	2.47	2.9	0	0	[redacted]	[redacted]	1.70	0	4.77	3.55	0	0	0	0	0	1.0	2.64
Average	0	0	2.6	3.14	2.5	0	.9	2.01	1.77	3.98	3.82	2.50	2.40	1.73	1.55	2.45	0	.9	2.65

Plate XXI Table LIX

Average production of Corn per plot for 18 yr. period.

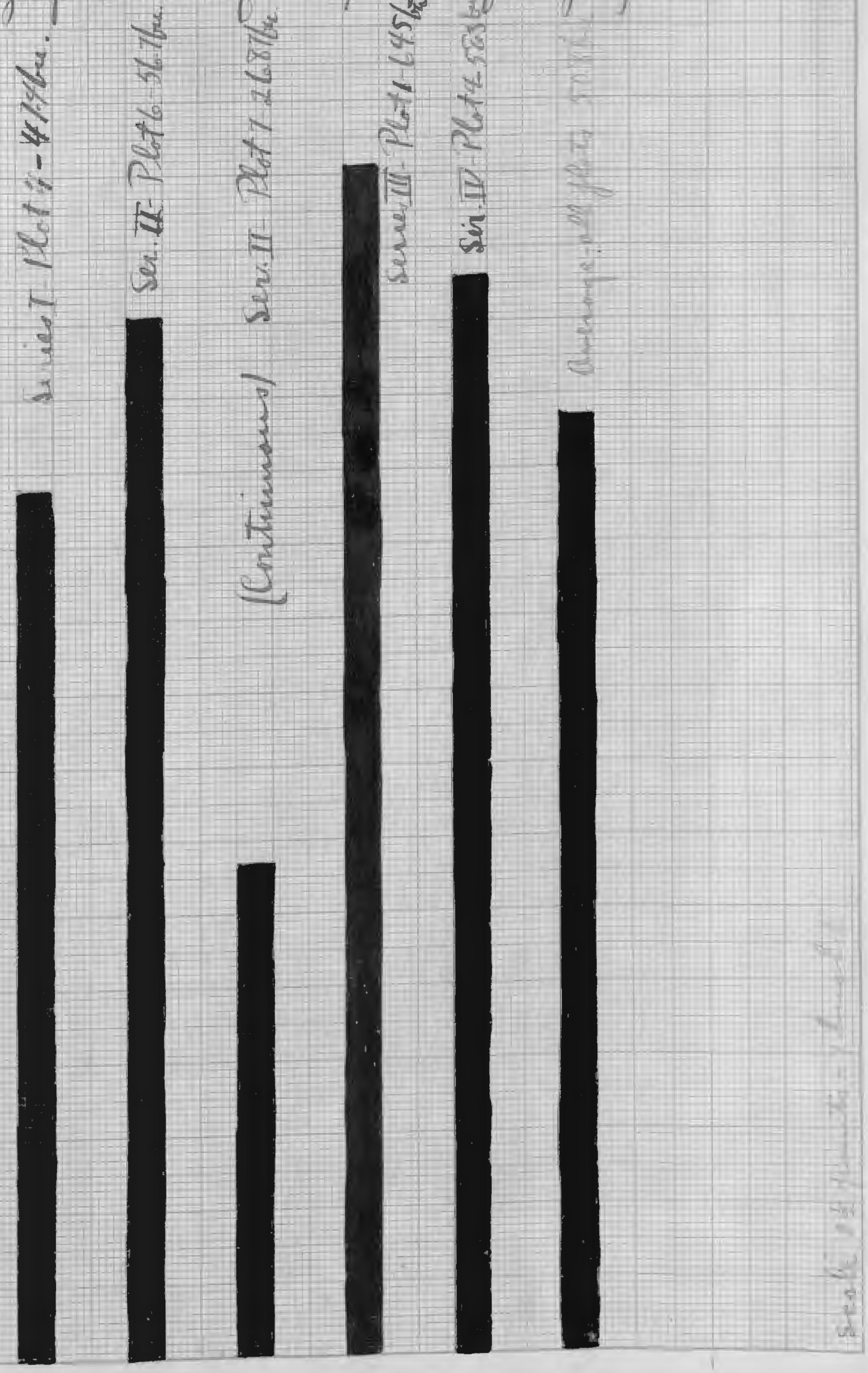


Plate XXII Table LX

Average production of hay per plot for 18 year period.

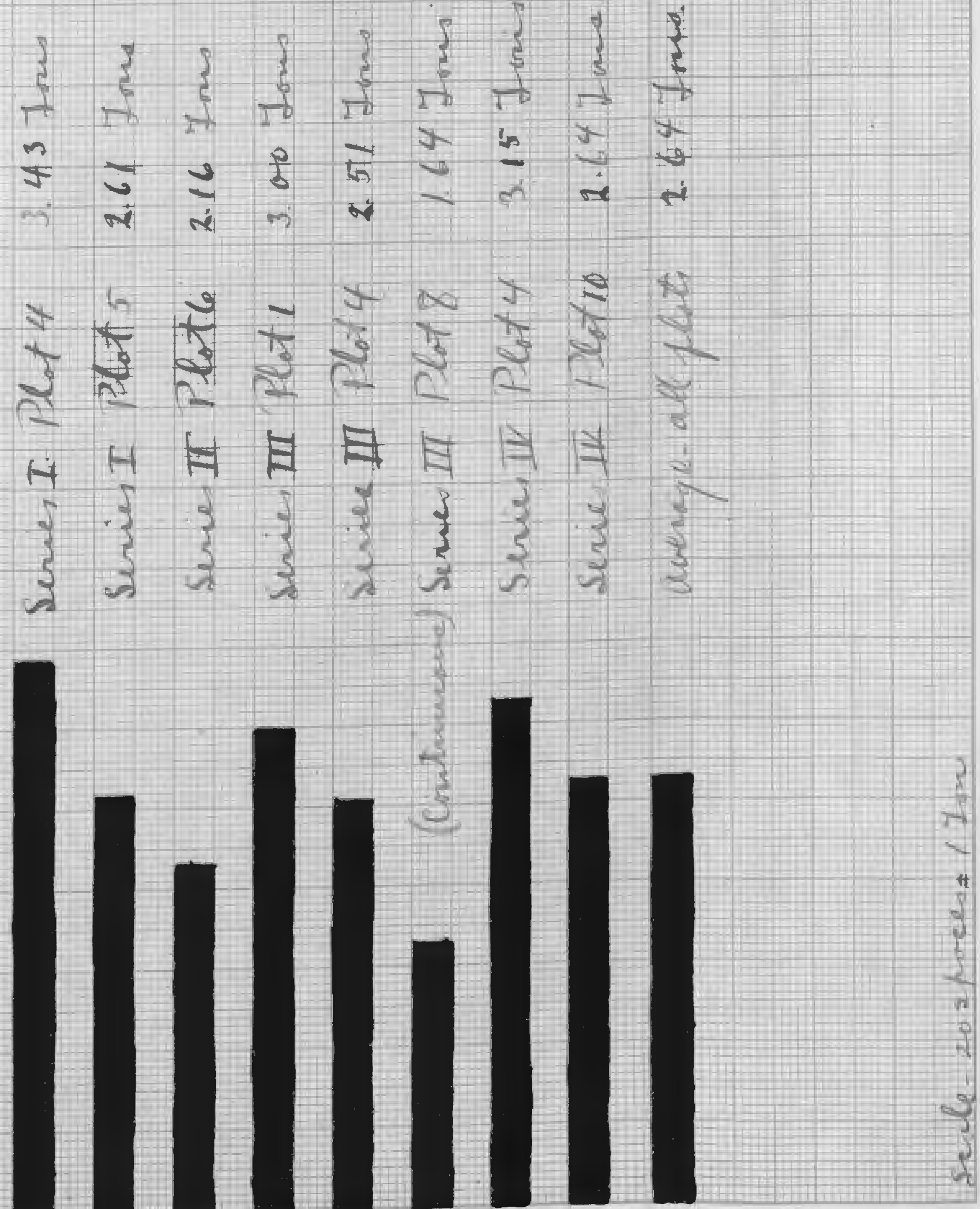


Table LXI.

Table of Averages - By Plot.

Plot	Wheat Bu.	Corn Bu.	Potatoes Bu.	Oats Bu.	Hay Tons	Peas Bu.
Plot 4 Ser. I	27.18	47.53		48.87	3.43	
Plot 5 Series I	23.64			57.00	2.61	
Plot 6 Ser. II	23.41	56.70		55.27		
Plot 7 Ser. II		27.18				
Plot 8 Ser. II			56.37			
Plot 10 Ser. II						14.24
Plot 1 Ser. III	22.93	64.56		48.40	3.00	
Plot 2 Ser. III	18.64					
Plot 3 Ser. III	21.24					
Plot 4 Ser. III	21.72				2.37	
Plot 4 Ser. IV		58.30			3.15	
Plot 10 Ser. IV	19.49				2.64	
Averages	22.28	50.85	56.37	52.38	2.65	14.24

Table LXII.

Table of Averages by the Year.

*Crop	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903
Wheat	13.07	26.81	17.33	20.0	26.6	25.3	22.0	13.6	18.3	25.3
Oats				26.3	54.3		67.2			65.9
Corn	18.16	29.3	31.9	29.9	47.4	43.9	37.5	13.4		23.6
Hay		2.7	3.28	2.5			2.4	1.9	4.1	4.76
Peas										
Potatoes										

*Crop	1904	1905	1906	1907	1908	1909	1910	1911	Average
Wheat	26.6	22.6	14.5	26.3	19.5	23.8	27.4	17.5	21.46
Oats		48.6			45.1				51.5
Corn	39.1	25.1	34.4	23.6	50.7	64.3	33.3	31.4	33.9
Hay	2.9	2.4	1.92		3.4		1.00		2.3
Peas									14.24
Potatoes									56.37

* Figures indicate bushels of grain and tons of hay.

The notable feature of these tabulated results is the splendid showing of the continuous wheat plots, especially the second, where clover is sown annually. These yields bear out our findings in physical and moisture tests which showed very normal conditions existing in these plots. Corn was grown for more than one year on but five of the plots. With few crops, the results are less reliable than in the case of wheat. Peas and potatoes are practically confined to their respective continuous plots, and we have no continuous oats in this series. Attention is called to continuous wheat - first in comparison with the wheat average of each plot for the whole period - Table LVIII; second, in comparison with the average of all the plots for a given year - Table LXIX. The corresponding study of corn, using the same tables, makes a further interesting study. The continuous wheat varies from (16-50) per cent below the produce of other plots for the whole period, (Table LVIII) and continuous corn is 75% below the lowest yield in corresponding corn study. Table LXIX registers a decided cut for each crop below the annual average. Note how continuous wheat, sown with clover, averages 2.6 bushels annually in excess of the yield of continuous wheat only.

To make this data still more outstanding, we will show an average of all yields, wheat and corn, from 1894 on, and observe how this may change as the period of cropping increases. Opposite this, we will place the average annual yield of all plots for the last year of the period studied.

Table LXIII.

Study in Yields - Continuous and Rotation Wheat

Average yield - continuous wheat			Average annual yields of all plots in wheat
1894		11.00 Bu.	13.07 Bu.
1894-95	2 yr. Average	17.8 "	26.81 "
1894-96	3 " "	16.78 "	17.33 "
1894-97	4 " "	17.04 "	20.00 "
1894-98	5 " "	17.91 "	26.6 "
1894-99	6 " "	18.69 "	25.3 "
1894-00	7 " "	18.09 "	22.01 "
1894-01	8 " "	17.83 "	13.6 "
1894-02	9 " "	17.74 "	18.30 "
1894-03	10 " "	17.59 "	25.30 "
1894-04	11 " "	17.82 "	26.40 "

Plate XXIII Table LXIII

Study of yields of continuous wheat, averaged for periods of 11-18 years

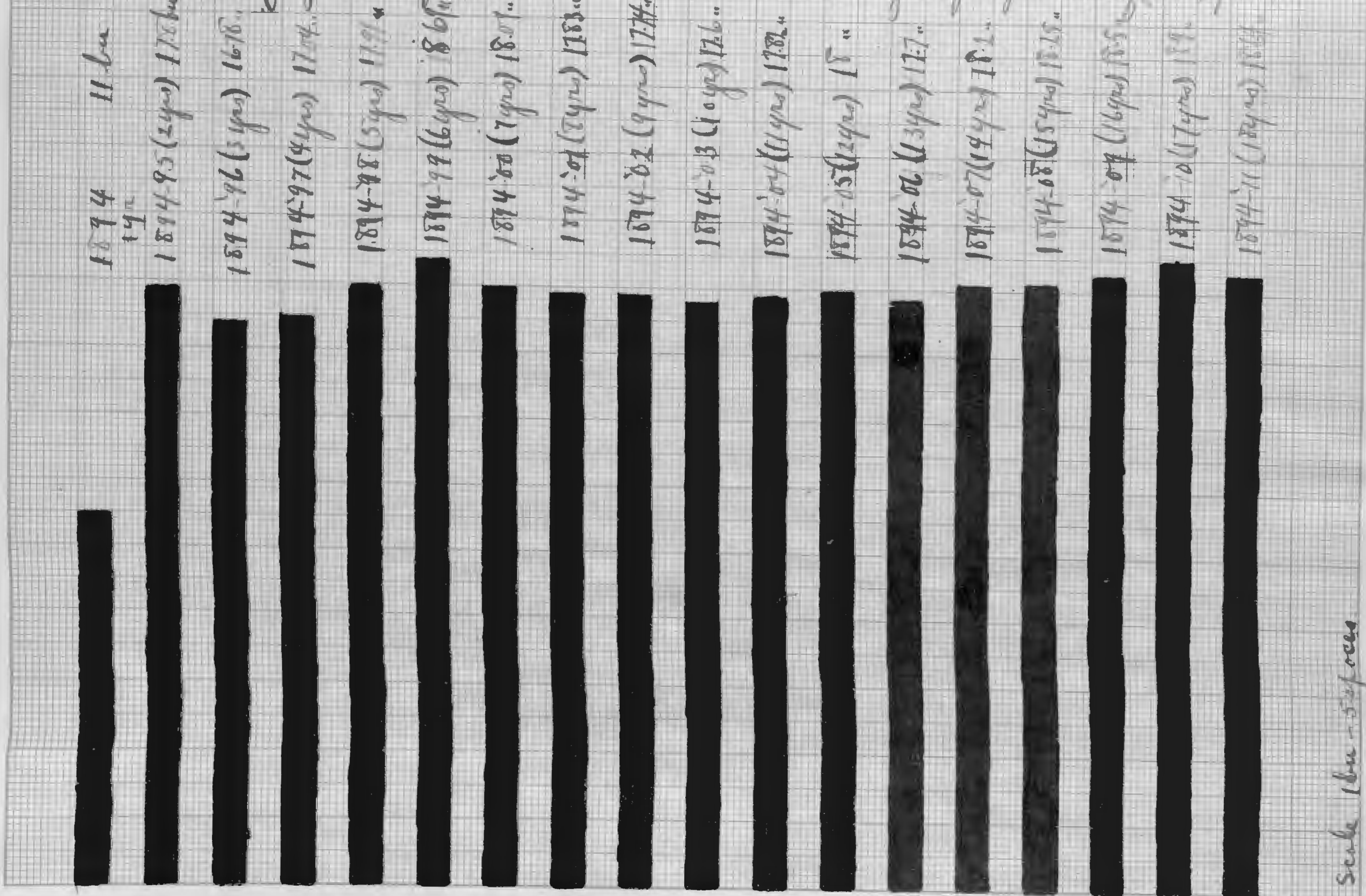
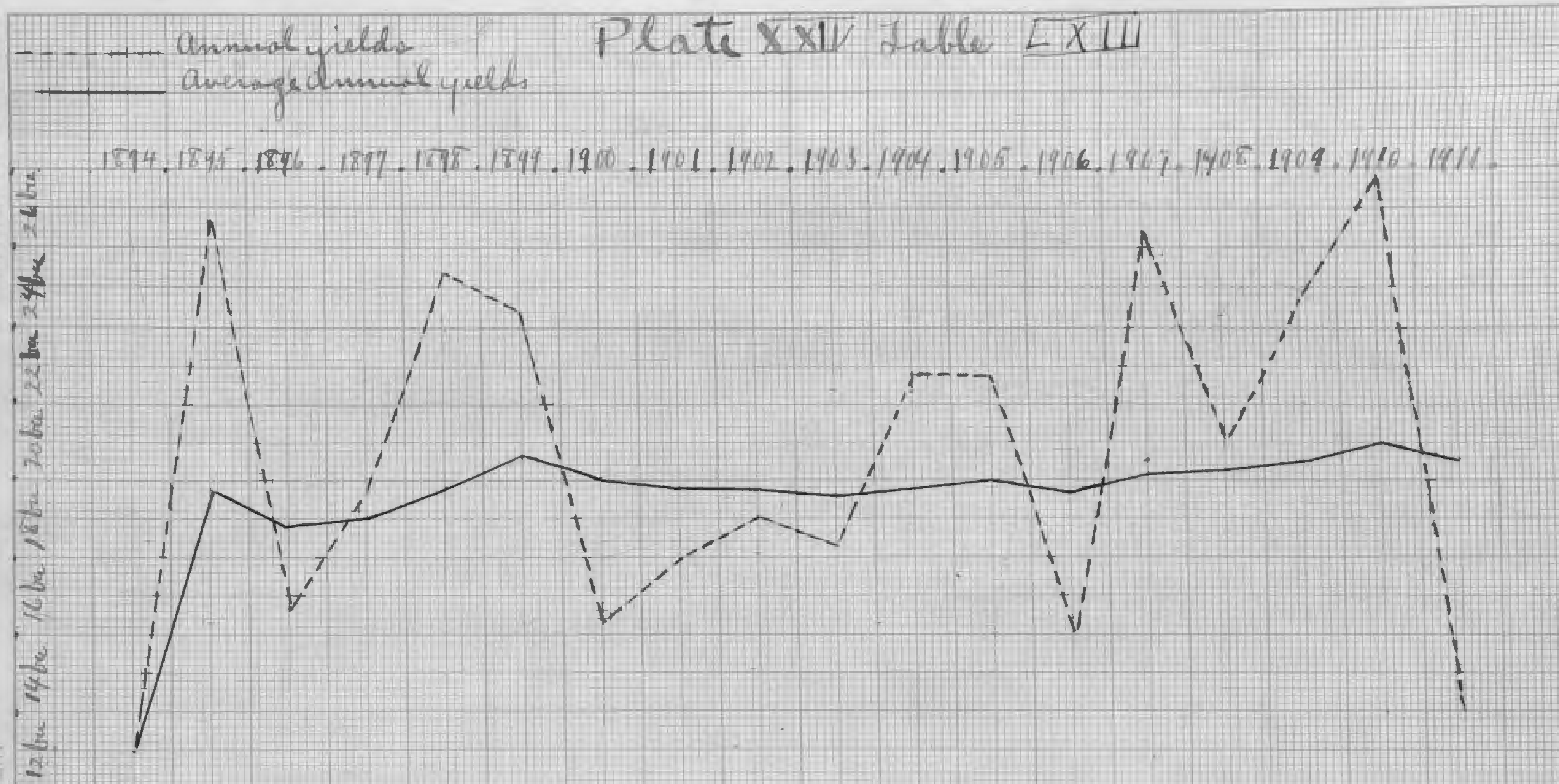


Plate XXIV Table LXIII



Comparison of Annual yields Continuous wheat and average annual yields of same plot for periods ranging from (1–18) years

Average Yield - Continuous Wheat			Average Annual Yields of all plots in Wheat
1894-05	12 Yr. Average	18.01 Bu.	22.63 Bu.
1894-06	13 " "	17.70 "	14.50 "
1894-07	14 " "	18.19 "	26.30 "
1894-08	15 " "	18.25 "	19.50 "
1894-09	16 " "	18.53 "	23.80 "
1894-10	17 " "	18.94 "	27.40 "
1894-11	18 " "	18.64 "	17.56 "
	AVERAGE	18.64 "	21.46 "

Table LXIV.

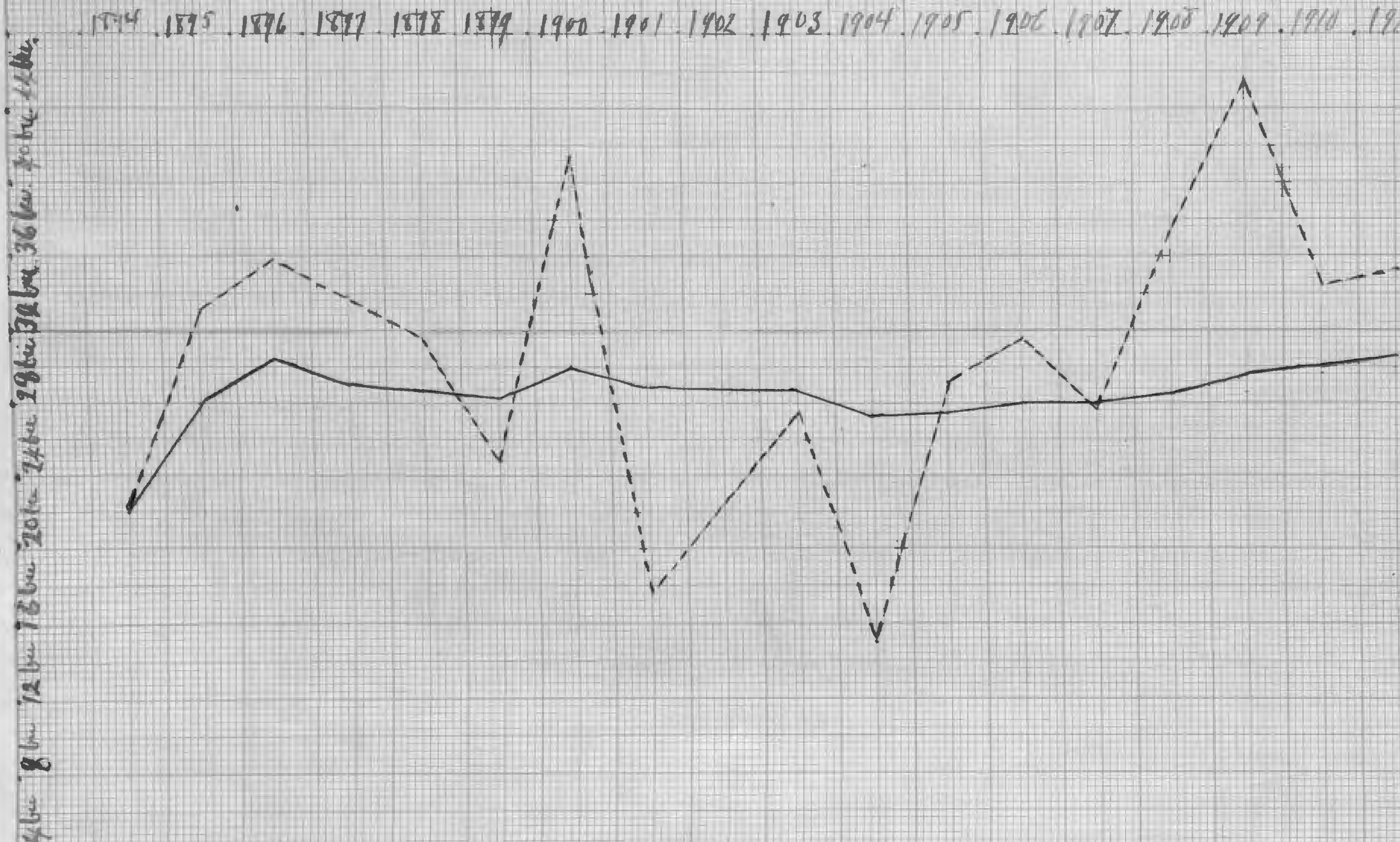
Study in Yields - Continuous and Rotation Corn.

Average Yield - Continuous Corn			Average Annual Yields of all plots in Corn.
1894		18.16 Bu.	
1894-95	2 Yr. Average	23.73 "	
1894-96	3 " "	26.45 "	
1894-97	4 " "	25.06 "	
1894-98	5 " "	25.59 "	
1894-99	6 " "	24.79 "	43.9 Bu.

Plate XXV Table LXIV

- - - - Annual yields
——— Average annual yields

Comparison of annual yields, continuous corn, and average annual yields of same plot for periods ranging from 1 to 18 years.



Average Yield - Continuous Corn			Average Annual Yields of all Plots in Corn.
1894-00	7 Yr. Average	26.61 Bu.	
1894-01	8 " "	25.02 "	
1894-02	9 " "	*	
1894-03	9 " "	24.86 "	
1894-04	10 " "	23.48 "	39.1 Bu.
1894-05	11 " "	23.63 "	
1894-06	12 " "	23.96 "	34.45 "
1894-07	13 " "	23.93 "	
1894-08	14 " "	24.60 "	50.70 "
1894-09	15 " "	25.73 "	64.3 "
1894-10	16 " "	26.03 "	33.00 "
1894-11	17 " "	26.87	
AVERAGE		26.87 "	50.8 "

Reviewing the wheat table, the outstanding feature is the uniformity of yield for nearly two decades. The variations observed follow the character of seasons quite closely. The average for the whole period is 15% below the average of annual yields. Corn shows greater fluctuation, but altogether, behaves much like wheat. The data for 1902 has been lost so our average covers only seventeen seasons altho eighteen crops have been grown. The continuous corn runs 48% below the rotation yield or three times that of wheat.

A comparison of our results for the whole period with data or losses on ignition is an indication of possible relation between organic content and yielding properties follows in the next table.

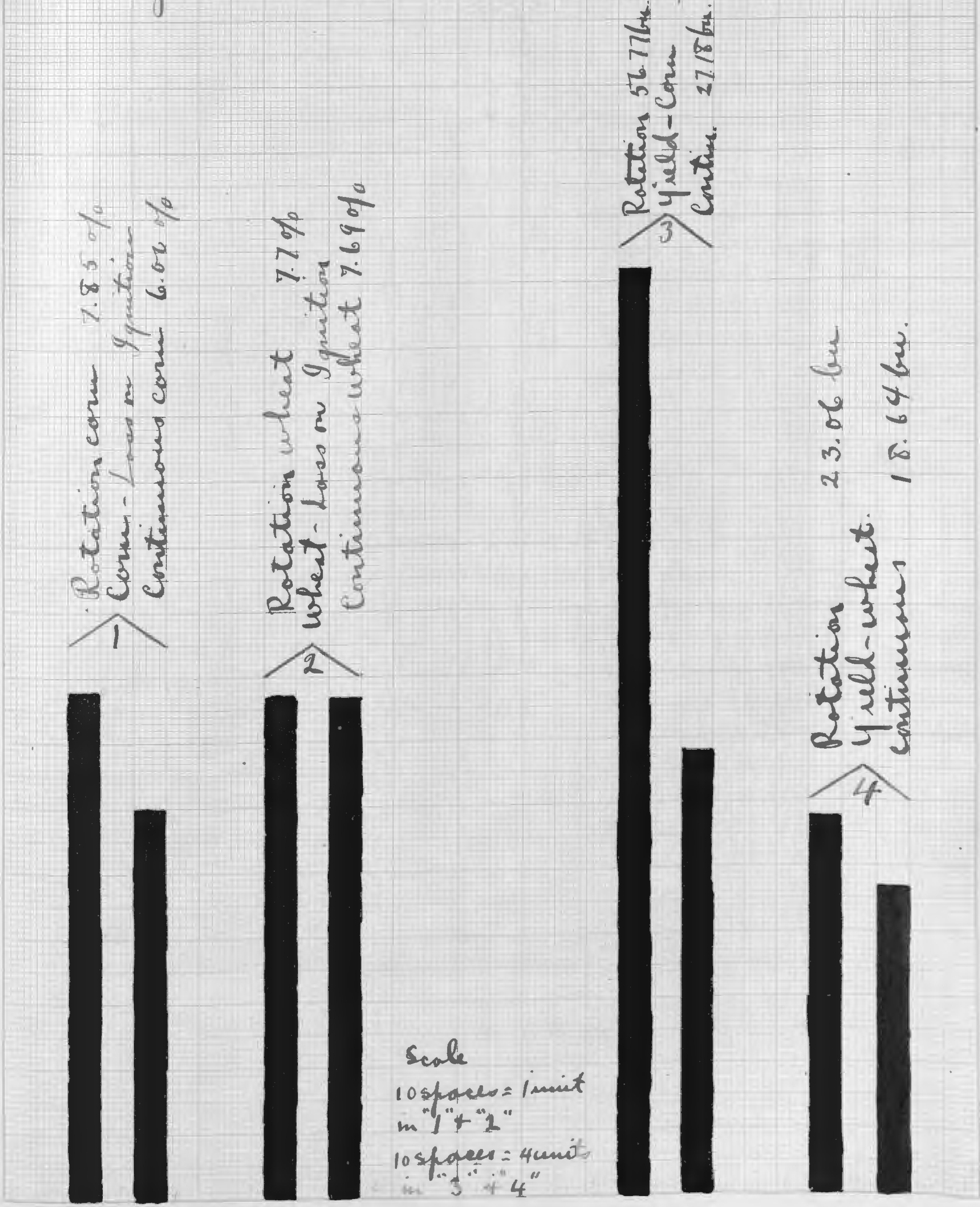
Table LXV.

Yield Contrasted with Loss on Ignition.

Plot	Loss on Ignition	Wheat	Corn	Peas	Potatoes
Plot 4 Ser. I	8.30%	27.18	47.53		
Plot 5 Ser. I	7.80%	23.64			
Plot 6 Ser. II	7.25%	23.41	56.70		
Plot 7 Ser. II	5.99%				
Plot 8 Ser. II	6.55%				56.37
Plot 10 Ser.II	6.19%			14.24	
Plot 1 Ser. III	7.49%	22.93	64.56		
Plot 2 Ser. III	7.69%	18.64			

Plate XXVI Table LXV

Yields contrasted with Losses on Ignition.



Plot	Loss on Ignition	Wheat	Corn	Peas	Potatoes
Plot 3 Ser. III	8.14%	21.24			
Plot 4 Ser. III	8.36%	21.72			
Plot 7 Ser. III	8.08%		58.30		
Plot 4 Ser. IV	7.78%				
Plot 10 Ser. IV	7.72%	19.49			

This comparison is, on the whole, significant. The first two plots of Series III are a trifle lower in yield of wheat than Plot 6 Series II, but this is more than neutralized by the lower yield of corn in the latter.

Table LXVI.

Summary of Table LXV.

Plot	Loss on Ignition	Yield
Rotation Corn	7.85%	56.77 Bu.
Continuous Corn	5.99%	27.18 "
Rotation Wheat	7.70%	23.06 "
Continuous Wheat		

The continuous corn is less than half in quantity compared with rotation corn and the loss on ignition is markedly less. The second part of table emphasizes previous observations on the peculiar behavior of the continuous wheat soil under test. Altho markedly lower in yield, it has retained a very mellow, friable texture and other physical qualities in like degree, showing either the operation of other factors or that, under right cultural methods, wheat does not naturally alter the soil materially.

The relation of yield to moisture content is an interesting field of study and it shall be discussed here in relation to both daily and bi-monthly determinations. The yields of the current year only can be studied here, but considerable data has been accumulated elsewhere that can here be utilized on a comparative basis.

Table LXVII.

Comparison of Yield and Bi-monthly Determinations of Water Content - Season of 1911.

Plot	Surface	Subsurface	Subsoil	Yield
Plot 4 Ser. I	20.22%	17.24%	10.96%	20.16 Bu.
Plot 6 Ser. II	22.82%	18.00%	10.95%	18.66 "
Plot 7 Ser. II	18.91%	17.36%	14.11%	31.38 " *
Plot 8 Ser. II	21.88%	22.23%	18.74%	13.33 " **
Plot 10 Ser. II	18.48%	16.43%	11.02%	12.16 " ***
Plot 1 Ser. III	22.35%	19.56%	12.30%	20.16 "
Plot 2 Ser. III	23.22%	19.94%	14.34%	12.00 "
Plot 3 Ser. III	24.51%	19.52%	15.41%	13.83 "
Plot 7 Ser. III	21.18%	17.30%	10.78%	Pasture
Plot 4 Ser. IV	22.92%	20.81%	13.31%	Pasture
Plot 10 Ser. IV	18.23%	16.31%	10.76%	15.83 "

* Corn - ** Potatoes - *** Peas.

Perhaps it is due to the fact that the season was wet and an abundance of moisture was available, but what ever the cause, there was no direct relation between yield and moisture content in the surface 9" of soil. The behavior of the wheat plots indicate, in a measure, that soils with less moisture yielded the larger crops. Compare Plot 4 Series I with Plot 6 Series II and with

Plots 1 and 3 Series III. This would indicate a surfeit of water that retarded plant growth. In the next table we will contrast water content in region of feeding roots and yield.

Table LXIII.

Daily Moisture Determinations in Comparison with Yield.

Plot	Moisture Content (21 Day Average)	Yield
Plot 4 Series I	18.43%	20.16 Bu.
Plot 5 Series I	13.16%	22.33 "
Plot 6 Series II	12.59%	18.66 "
Plot 10 Series II	18.09%	12.16 "
Plot 1 Series III	22.33%	20.16 "
Plot 2 Series III	24.22%	12.00 "
Plot 3 Series III	29.23%	13.83 "
Plot 10 Series IV	13.46%	15.83 "

This table but emphasizes the findings of the former in a season of normal rainfall, no relation can be traced between water content and yield such as would be possible were the year dry and water at a premium. The other tendency exists, however, for the yield to drop in the presence of excess of moisture.

Widtsoe states that if every inch of water that falls could be utilized, it would produce two and one-half bushels wheat. On this basis, since 10.87" fell during the growing season, our yield would be over 27 bushels, if this annual factor worked alone and in full measure. On a basis of 300# water for 1# dry matter, we find that 6" of water would be the highest yield of wheat recorded above. Viewed from another angle, one inch of water during the growing season produced 1.87 bushels wheat in standard rotation and 1.19 bushel of wheat under continuous cropping.

Work at the North Dakota Station (Bulletin No. 148) substantiated our results in that they found 9 per cent higher yields on plots where manure had been added, while the moisture content was lower by 5 per cent at harvest time. Where manure had been added about three years previous to rotation plot, it showed striking differences compared with plots continuously cropped.

Table LXIX.

Relation of Moisture Content at Maturity and Yield.

Plot	Moisture Content at Maturity	Yield
Rotation Plots	7.13%	19.41 Bu.
Continuously Cropped Plots	12.93%	12.91 "

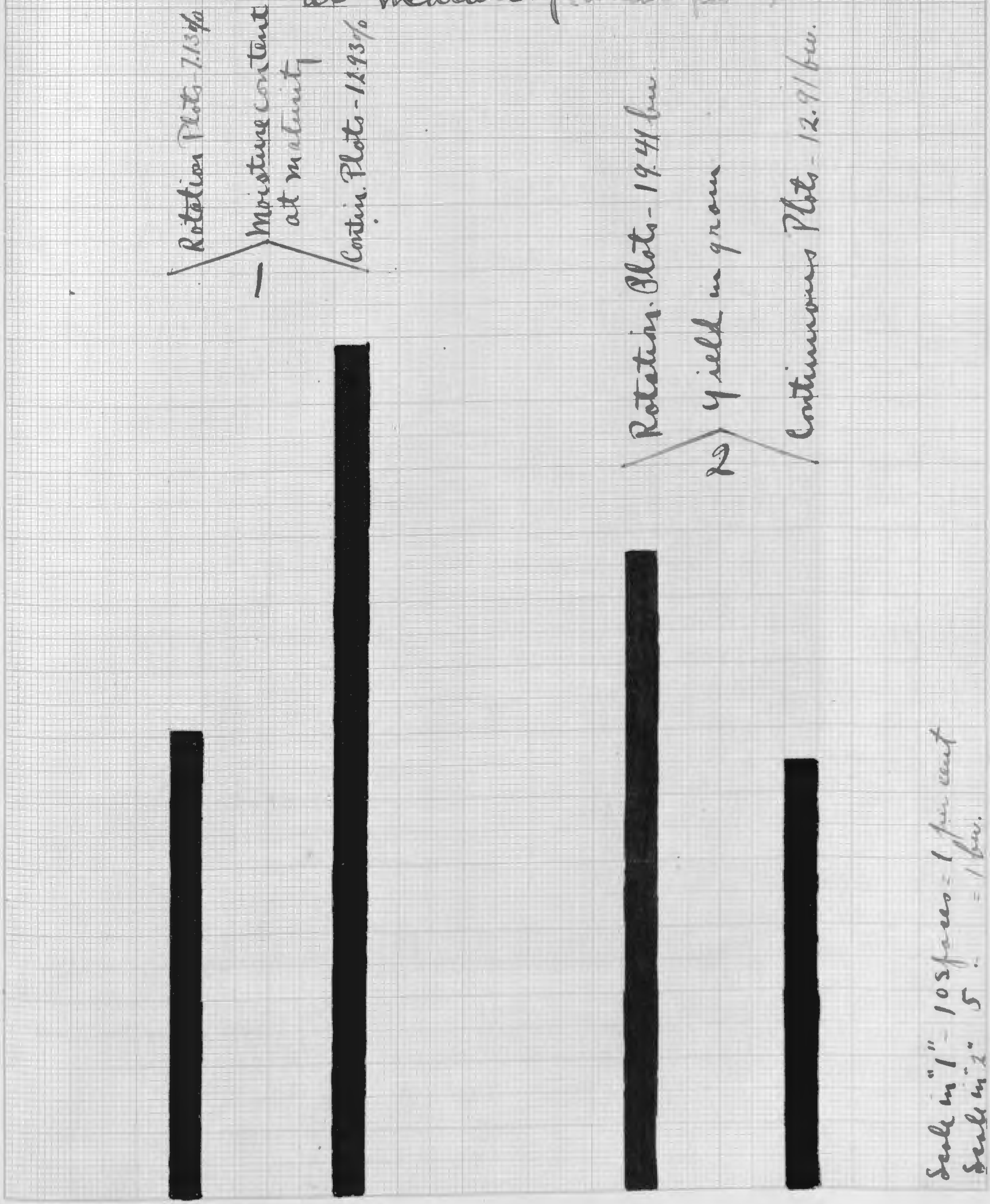
These facts go to prove that a greater quantity of available water is to be found in manured rotation plots.

Our conclusions regarding the lack of correlation between moisture content and yield of plots is substantiated by findings at New Mexico Station (Bulletin No. 48) "Adjacent plots, kept in nearly the same moisture conditions, show considerable difference in yield and also plots which vary much in moisture may give nearly the same yield. This shows that other factors exert a marked influence on yield.

Before closing Part III, we will make a few comparisons on yield. We have several good sources of information. The Snyder Plots on Field J, the Work at Indiana Station, the Rothamsted tests, and the State average yields will be used for comparison. The work on Field J forms an excellent check on results se-

Plate XXVII - Table LXIX

A comparison of yield and moisture content at maturity (wheat plots)



cured on Field C. It includes a series of rotated and continuously cropped plots which in period of operation, soil type, location and treatment closely resemble the conditions on Field C.

Table LXX.

Comparison of Yields - Minnesota Data only.

	Continuous Wheat	Continuous Corn	Continuous Barley	Continuous Oats	Cont. Potatoes
Field C	18.64	27.18			
Field J	18.42	37.4	27.7	39.34	50
State Avge.	13.3	29.1	26.4	33.3	87

	Rotation Hay	Rotation Wheat	Rotation Corn	Rotation Oats
Field C	2.58 T.	23.17	60.63	51.83
Field J	3.08 T.	22.60	53	50.64

* State Avge. 1.66 T.

* 1896 - 1905 (10 year period*.

The State average is based on all possible conditions of production. The blank spaces indicate the absence of that particular crop study in the given field. Field C shows greater activity in the rotation product while Field J runs higher on basis of continuous cropping. Thus, results are neutralized. Field C has been operated for 18 years and Field J for 19 years. The facts disclosed here do not reflect much credit upon farm methods in Minnesota, for the ten year average is less than continuous yield in every case but one, altho the land has been cropped thus for nearly a score of years.

The next table will include a comparison of all the data available bearing on this subject.

Table LXXI.

General Comparison of Yields.

	Field C	Field J	State Average	Rothamsted	Indiana Station
WHEAT					
Rotation	23.17	22.60		28.6	21.61
			13.3		
Continuous	18.64	18.42		12.4	15.89
CORN					
Rotation	60.63	53.00			34.76
			29.1		
Continuous	27.18	37.4			30.66

	Field C	Field J	State Average	Rothamsted	Indiana Station.
BARLEY					
Rotation				22	
			26.4		
Continuous		27.7		19	
POTATOES					
Rotation					
			87		
Continuous	50			45.6	
OATS					
Rotation		50.6			
			33.3		
Continuous		39.34		19.9	

A few explanatory notes are in order. All the data from Fields C and J are based upon the 5 year standard rotation except oats (4 year rotation). Rothamsted data on barley and wheat are based upon an average of the respective crops of 12 cycles of 4 year rotation (not manured) and the continuous crop data were based upon average of the crops of the 12 corresponding years. The average for oats covers a 5 year span with no rotation data, and the continuous potatoes a 26 year period. The Indiana data are based upon a 7 year average. The state average represents all conditions of growth so it is placed between the other two.

The absence of manure has made a decided difference in rotation of corn at Indiana, bringing yields closer together, but wheat seemed to flourish in its absence. The data is most complete for corn and wheat, so we will summarise these results upon a percentage basis.

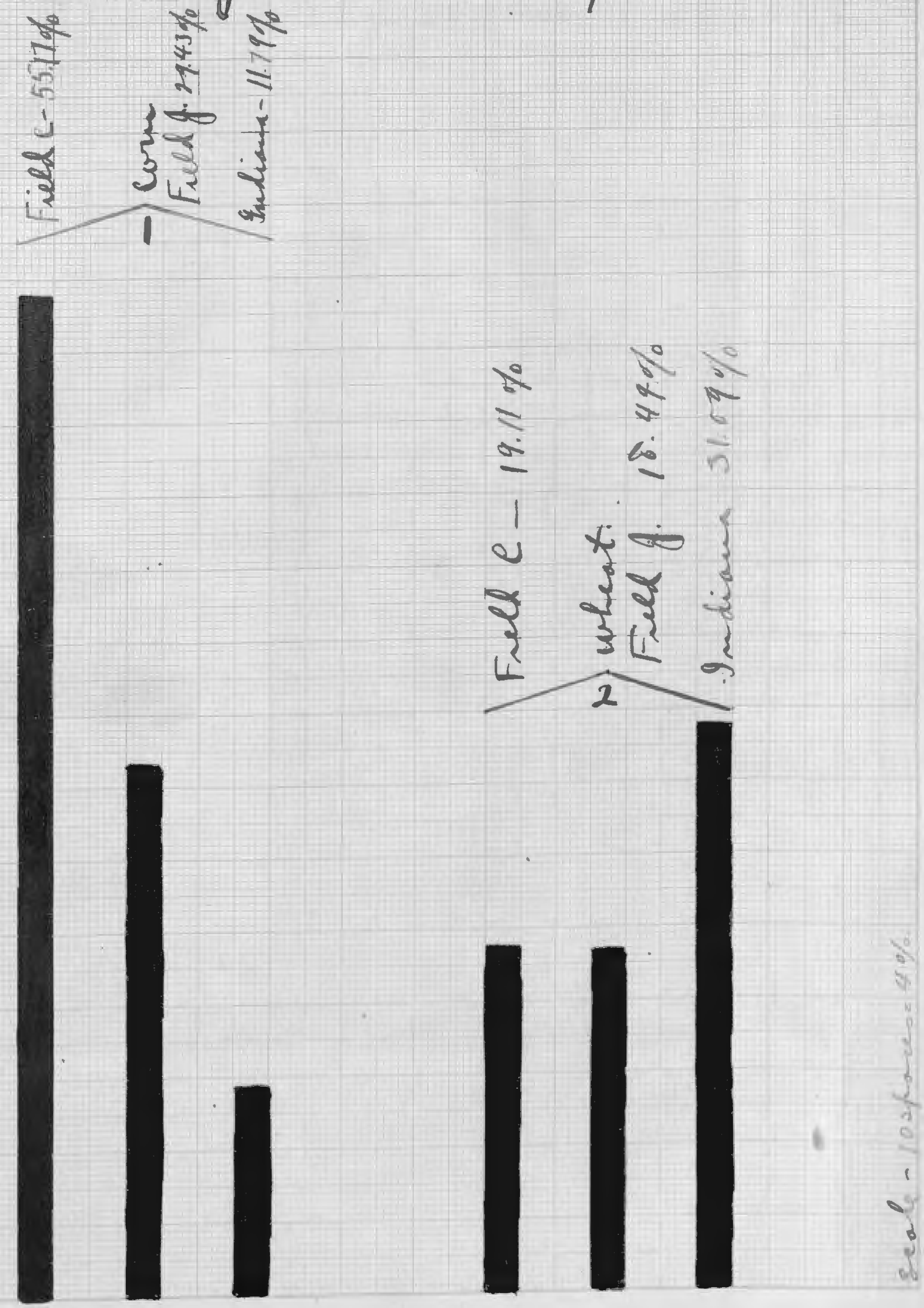
Table LXXII.

Decrease in Yields of Plots Cropped Continuously, based on Rotation Yields.

Place	Corn	Wheat
Field C	55.17%	19.11%
Field J	29.43%	18.49%
Indiana Station	11.79%	31.09%
Rothamsted		56.60%

Plate XXVIII - Table LXXII

Study of decrease in yields of plots cropped continuously based on rotation yields.



The average decrease for the first 3 plots is 32.13% for corn and 22.89% for wheat showing that manure enhances yields of corn more than wheat.

SUMMARY.

1. The title "Crop Production in Relation to Physical Factors" is developed under three heads: physical study of soils; moisture study; study of crop. Thirteen plots were studied.

2. The only plots showing less than 7 per cent loss on Ignition (a measure of organic matter) are continuous corn, potatoes, peas.

3. Apparent specific gravity ranged from 1.117 (4 year rotation) to 1.233 (continuous potatoes) and real specific gravity ranged from 2.526 (4 year rotation) to 2.613 (continuous potatoes). This latter plot also exceeds all others in field weight.

4. With equal weights of soil and water, the moist rotation soil showed greater tenacity than continuously cropped plots. Perhaps particles of organic matter exerted a binding influence; more probably it was caused by the higher saturation point of rotation soils.

5. With sticks of the same dimension of air dry soils from the

several plots, the breaking point of the continuously cropped plots was markedly higher.

6. The greatest pore space was recorded (in laboratory test) in continuous wheat and clover plot and the lowest in continuous potatoes.

7. Pore space was the governing factor in soil aeration.

8. Assuming loss on ignition as a measure of organic content, we can trace a general influence upon every feature studied in Part 1 - such as making heavy soils light, increasing pore space, lowering the breaking point.

9. The outstanding features are the fine showing of continuous wheat plots and the extremely poor condition of continuous potato plot.

10. The quantity of water retained ranged from 37.2% in continuous potatoes (Ignition loss 6.5%) to 44.71% in Plot 4 Series I, 4 year rotation (Ignition loss 8.3%).

11. Hygroscopic moisture varied from 2.5% in continuous potatoes to 3.3% in continuous wheat and clover. Note No. 6 above.

12. Altho the greatest percolation of ground water and the smallest rise of capillary water occurred with continuous pota-

toes, there was no apparent relation between either factor and assumed organic content, presumably since the cropping system has not operated sufficiently long to produce these expected results.

13. The system of continuous cropping so altered the soil as to leave a larger amount of unavailable water in the soil. This bore out findings on hygroscopic water.

14. The amount of water in the region of feeding roots is seemingly governed by three factors: pore space, plant use and evaporation. The last factor was very uniform. The first was governed by organic content in soil and the water portion of plants rose or fell in nearly direct accordance to the quantity in the soil.

15. The bi-monthly determinations disclosed these facts:

a - Altho over 20" of rain fell after April 1, the subsoil did not attain normal moisture conditions until the latter half of August, one month after removal of the crops.

b - Early seasonal data disclosed the fact that continuously cropped soils, irrespective of cultural methods, seemed to permit a more rapid passage of water into the subsoil.

c - The draught of growing crops upon soil moisture was strongest and could be most easily traced between June 1 and July 16, with due consideration of rainfall during the same period.

d - Altho the hot wave had passed over by nearly two weeks, the grain crops almost uniformly showed very low water content July 15, thereby supporting the New Mexico contention that wheat makes its heaviest demands on soil water during the filling period.

e - During driest atmospheric conditions, cultivated crops indicated high water content in surface, subsurface and subsoil.

f - On account of differences in crop demands, atmospheric conditions and tillage methods, we cannot draw a direct comparison between moisture content and loss on ignition, altho a general relationship is evident.

16. With exceptions noted, all tests in Part II (soil moisture) showed a direct bearing of the greater or lesser quantities of vegetable matter present.

17. Field notes disclose influence of repeated cropping in hastening maturity, increasing weediness and affecting volume of growth, catch of clover, etc. The effect of weather, modified by local factors, is also shown.

18. The score card study did not disclose any material difference in wheat, due partly to effect of weather conditions upon crop, but the continuous potatoes and corn showed marked inferiority.

19. The quantity of shrunken kernels was quite uniform, but the weed seed varied in amount from .27 bushels per acre, Plot 5 Series I (rotation wheat) to 2.06 bushels per acre (continuous wheat).

20. Quantity and quality of wheat are not always synonymous. Cleaned grain from continuous wheat and clover plot showed good weight, color and plumpness, equal to all and superior to grain from several plots.

21. The production of glucose at filling time tended to vary as the yield.

22. Continuous wheat varies from 16 - 50% below rotation wheat and corn, 75% below the lowest average yield of rotation plots on 18 year average.

23. For the same period, continuous wheat runs 15% below the average of all wheat plots and continuous corn 90% below the average of all corn plots.

24. Continuous wheat grown with clover averages 2.6 bushels better than wheat only on 18 year average.

25. Decline in organic content hand in hand with decline in yield is very evident with corn, but much less so with wheat, indicating again that wheat is less exacting on soil.

26. There is no relation between water content and yield.

27. The rotation plots left 5.6% less water in soil and yields 6.5 bushels more of grain per acre.

28. Manure in rotation affected wheat less than corn.

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