PLANT POPULATION AND SUGAR BEET YIELDS

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Plant population, or stand, in its relation to the yield to be obtained has always been a question of primary interest and importance to the growers and processors of sugar beets and many efforts, both here and abroad, have been made to determine this relationship. In this country one such attempt was made during the seasons of 1938 to 1942 inclusive, when Mr. John Kelly, Manager of the Lake Shore Sugar Company factory at St. Louis, Michigan, directed that the number of beets in each tare sample be recorded on the tare slip.2/ The plant population maintained under each contract was then estimated in the following manner:

2/ Although the load weights varied under individual contracts and between contracts, a tare sample of 25 pounds of dirty beets was taken on the average in 1938 from each 5.574 tons of beets, raw weight.

1939	5.918
1940	5.978
1941	5.775
1942	5.174

The tare percents of all the different samples under a contract were totalled and divided by the number of samples to obtain an average tare figure for that contract. Since twenty-five pounds of dirty beets were taken for each tare sample, the total weight of dirty beets in the samples could be readily determined. The total weight of dirty beets minus the weight of dirt indicated by the average tare figure, gave the total weight of clean beets in the samples. The total weight of the clean beets divided by the total number of beets in the samples resulted in an estimated average weight for the individual beet delivered under the contract. The yield per acre in pounds, divided by the estimated weight of the individual beet, resulted in an estimated plant population per acre.

The above described method of estimating the plant populations maintained has been compared with a "by-the-load" estimate of the number of beets delivered in each load under 61 different contracts. Ten of these 61 contracts delivered less than ten loads of beets; ten delivered from 11 to 20 loads; and 11 delivered more than 20 loads. The comparison of the estimated plant populations maintained under these 61 different contracts, according to the two methods used, is shown in table 1. This comparison was made by dividing the factory method estimates by the "by-the-load" estimates.

Table 1. Classification of percentage differences of plant population estimates. The "by-the-load" estimate is used as a basis.

The numbers of contracts with the determined difference between estimates.

Per cent difference	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
- 5.	-	-	-	-	-	-	-	1(22)*	-	-
- 4.	-	-	-	-	-	-	-	-	-	-
- 3.	-	-	-	-	-	-	-	-	-	-
- 2.	-	-	1	-	1	1	2	1	1	1
- 1.	1	1	1	1	2	2	1	5	2	3
- 0.	2	5	2	4	3	-	2	1	2	-
1.	1	1	-	1	1	-	-	2	-	-
2.	-	-	2	-	-	-	-	-	1(15)	-
3.	-	-	-	-	-	-	-	-	-	-
4.	-	-	-	-	-	-	-	-	-	-
5.	-	-	-	-	1(18)	-	-	-	-	-
6.	-	-	-	-	-	-	-	-	-	-
7.	-	-	-	-	-	-	-	-	-	-
8.	-	-	-	-	-	-	-	-	-	-
9.	-	-	-	-	-	-	-	-	-	-
10.	-	-	1(7)	-	-	-	-	-	-	-
11.	-	-	-	-	-	-	-	-	-	-
12.	-	-	-	-	-	-	1(12)	-	-	

* The figure in parentheses indicates the number of loads delivered under the contract.

The plant population estimates as made by the factory method with the exception of a few, were found to agree quite closely with the estimates as made by the "by-the-load" method[3/] and hence were judged to be sufficiently accurate to serve as the basis for calculations.

3/ all questions and operations relative to the tare figure could have been eliminated if the estimate had been based upon the average weight of the dirty beets in the tare sample, the number of dirty beets in each load determined and the total number of dirty beets delivered under each contract. The plant population estimate would then have been made by dividing the total number of dirty beets by the acres harvested.

The plant population estimates as made would not correspond exactly with a population count of the plants in the field but would be an estimate of the per acre number of marketable roots delivered to the receiving station. However it can be assumed that the estimate of the number of marketable roots as made, bears a very close and approximately constant relationship to the number of plants living at harvest time. Therefore the data should contain interesting information relative to the relationship between the plant population and the yield of sugar beets obtained. Mr. Kelly has kindly permitted these data to be studied for the development of such information and this examination has been carried out to the fullest extent of the available data.

The recorded data consisted of the season, the width of the rows in the field, the estimated plant population, and the acre-yield. All fields on which these data were taken were located in the factory district, were scattered throughout this district, and presumably represented a wide variation in all conditions of soil productivity and crop production. The number of fields upon which these data were taken varied from season to season and the number of fields having each width of row also varied. Table 2 gives the total number of fields for each season together with the percentage of fields of each row width.

Table 2. Number of fields for each season and percentage of fields having the different row widths.

Year	Fields	Percentage of the total number of fields having the indicated row width.							
		18"	20"	21"	22"	23"	24"	26"	28"
	Number	%	%	%	%	%	%	%	%
1938	1365	0.15		0.22	3.44	0.15	57.00	9.96	29.08
1939	1273		0.08	0.24	2.20	0.16	58.68	9.27	29.38
1940	1067		0.19	0.19	2.81		45.17	14.90	36.74
1941	913				3.18	0.22	43.70	14.90	38.00
1942	987		0.71		1.11		32.12	18.54	47.52
Total	5605								

Since the data were taken during more than one season, the possibility of a seasonal relationship between the estimated plant populations and the yields obtained exists and must be taken into consideration. Table 3 gives the average estimated plant population for each season together with the average yield obtained without regard to the row width.

Table 3. Seasonal averages.

Season	Harvested roots per acre	Average acre-yield	Estimated roots per ton	Acre-yield per 1000 roots, estimated population
	number	ton	number	ton
1938	14266	8.748	1631	0.613
1939	14437	7.988	1807	0.553
1940	14238	8.498	1675	0.597
1941	13806	10.965	1259	0.794
1942	11712	10.162	1153	0.868
Direct) Average)	13692	9.272	1505	0.685

It will be noted from table 3 that the seasonal effect upon the relationship between the estimated plant population and the acre-yield obtained was quite definite, the estimated plant population per ton of yield ranging from 1153 in 1942 to 1807 in 1939 while the tons per 1000 of estimated plant population ranged from a low of 0.553 in 1939 to a high of 0.868 in 1942. The influence of the seasonal factor upon the relationship of the estimated plant population and the acre yield obtained having been determined and having been found to be very appreciable, the data must be so handled that such seasonal effect shall have no influence upon the findings made. Each season must be given equal weight with every other season in the compilations.

As is shown in table 2 the number of fields upon which data were taken varied from year to year and the proportion of fields with certain row widths also varied. When the data were classified according to season and row width and the average estimated plant population and acre-yield for each season and row width determined, the results presented in table 4 were obtained.

Although field practices have a very definite relationship to the plant populations maintained, the width of row did not, on the average, affect the estimated plant populations nor the acre-yields obtained nearly so much as the seasonal conditions. The extreme variation in estimated plant population and acre-yield as affected by row width, that between the 22 inch and the 28 inch rows, was only 2068 plants per acre and 0.775 ton per acre while the extreme variation caused by seasonal conditions was 2725 plants and 2.977 tons. However the width of row factor is important in that the higher estimated plant populations, on the average, were found where the narrower rows had been used. In fact, as the rows became wider the average estimated plant populations decreased and the average acre-yield also decreased but it is worth noting that as the rows became wider, the feet of row per beet decreased and the percentage stand increased.

The results presented in table 4 give the average plant populations and the average acre-yields obtained with the different width rows. The tabular material necessary to show the relationship between the width of row, the estimated plant populations and the acre-yields obtained is too voluminous for ready presentation but it can be readily and definitely presented in graph form. Plat I gives the graphis presentation of the relationship between the width of row used, the estimated plant populations, and the acre-yields obtained. It will be readily recognized from this plate that while the width of rows used did have a definite effect upon the yields obtained, this effect was relatively slight when compared with that of the variation in the estimated plant populations. Since the effect of the row width was found to be relatively unimportant while the seasonal effect was relatively important, the data were further studied without regard to row width used but with regard to the season in which the data were taken. If the data had been classified according to three factors, the seasons, the row widths, and the estimated plant populations, many more incomplete series would have been found than when classified by season and estimated plant populations only.

Table 4. Number of fields, average estimated plant population and acre-yield for each row width for each season. 4/

Season	With 22 inch rows			With 24 inch rows			With 26 inch rows			With 28 inch rows		
	Fields	Est. plant pop.	Acre-yield	Fields	Est. plant pop.	Acre-yield	Fields	Est. plant pop.	Acre yield	Fields	Est. plant pop	Acre-yield
	number	number	tons	number	number	tons	number	number	tons	number	number	tons
1938	47	15015	8.835	778	14682	8.862	136	14187	8.991	397	13402	8.448
1939	28	16138	9.320	747	14754	7.855	118	14405	7.697	374	13651	8.228
1940	30	16049	8.766	482	14781	8.650	159	14019	8.333	392	13506	8.344
1941	29	15369	12.026	399	14238	10.955	136	14047	11.721	346	13077	10.597
1942	11	12491	10.515	317	12413	10.384	183	12072	10.475	469	11083	9.868
Total	145			2723			732			1978		
Direct average		15012	9.872		14174	9.341		13746	9.443		12944	9.097
Acre-row-feet		23760			21780			20105			18669	
Feet per beet		1.583			1.537			1.463			1.442	
Roots per 100 ft. of row		63.18			65.08			68.37			69.34	

4/ Fields with 18, 20, 21, and 23 inch rows did not appear in the data for all seasons so were left out of the comparison.

Following the determination that the seasonal effect upon the relationship between the estimated plant populations and the acre-yields obtained could not be ignored, but that the between-the-row-widths used and the acre-yields could be, the data for each season were classified in two ways: They were first classified according to the estimated plant populations and then the average acre-yield obtained under each population class determined. This method of classification obtained the average acre-yield in all fields of like estimated plant populations. Secondly the data were classified according to the acre-yields and from this classification, the average estimated plant population of all fields with like acre-yields was obtained. The data, classified according to the above, are shown in tables 5, 6, 7, and 8. Table 5 shows the numbers of fields in each estimated plant population class for each season; table 6 shows the numbers of fields in each acre-yield class for each season; table 7 shows the average acre-yield of the fields occurring in each estimated plant population class for each season; and table 8 shows the average estimated plant population of each of the acre-yield classes for each season.

It will be noted from tables 5 and 6 that the numbers of fields in the various classes or groups vary widely within the season and between seasons and that the middle groups under each manner of classification are large and that the extreme groups are small. This should indicate that such differences as might be found to exist between the middle or larger groups, where many fields representing a great variety of conditions are included, would be quite reliable while such differences as might be found to exist between the smaller or extreme groups, consisting of only a few fields representing a very limited number of conditions, would be relatively unreliable. In summarizing these data, the average estimated plant population and the average acre-yield were determined for each group in the seasonal columns in tables 5 and 6. Where any classification group was represented in each of the five seasons even though it were represented in some seasons by only one field, the five seasonal averages were again averaged to obtain the final summary figures presented in the last three columns of tables 7 and 8. No figure is given in the final summary columns unless such classification group were represented in each of the five seasons. Tables 7 and 8 give the seasonal averages and the final summary figures. Table 7 gives the average acre-yields obtained when the fields had been classified according to the estimated plant populations and table 8 gives the average estimated plant populations when the fields had been classified according to the acre-yields obtained.

The results presented in table 7 are shown graphically in plate II. The average acre-yields resulting from the average estimated plant population of each class are indicated by the small circles on the graph. These have been joined by a solid line to emphasize the relationship of one point to another. In order to accentuate the apparent linear relationship of the estimated plant population and the acre-yield obtained, a straight line, calculated by mathematical methods, has been entered on the graph as a line of short dashes. In addition to this, the average slope[8] of the data has been determined and this has been entered on the graph as a dotted line. The mathematical straight line and the line indicating the average slope intersect each other at the point of average estimated plant population and average acre-yield for all the data.

8/ The line of average slope is drawn through the point of origin, 0 estimated plant population and 0 acre-yield, and the point of intersection of the average estimated plant population and average acre-yield for all the data.

Table 5. Numbers of fields in each class when the data for each season were classified on the basis of the estimated plant populations.

Class limits. Estimated plant population. Number inc.	For the season of: 1938 number	1939 number	1940 number	1941 number	1942 number	Total number
0 - 999	1				1	2
1000 - 2999	3		2		1	6
3000 - 4999	2	3	5		14	24
5000 - 6999	7	10	8	5	33	63
7000 - 8999	36	32	32	37	117	254
9000 - 10999	116	105	101	101	227	650
11000 - 12999	277	237	181	213	280	1188
13000 - 14999	367	347	331	245	198	1488
15000 - 16999	339	305	240	207	82	1173
17000 - 18999	157	169	112	78	24	540
19000 - 20999	43	48	39	20	7	157
21000 - 22999	9	11	8	4	1	33
23000 - 24999	2	3	5	1	1	12
25000 - 26999	1	1	1	1		4
27000 - 28999	1		1	1		3
29000 - 30999	3	2			1	6
31000 - 32999						
33000 - 34999						
35000 - 36999	1		1			2
Totals	1365	1273	1067	913	987	5605

Table 6. Numbers of fields in each class when the data for each season were classified on the basis of the acre-yields obtained.

Acre-yield obtained. Class limits. Tons inclusive	For the season of: 1938 number	1939 number	1940 number	1941 number	1942 number	Total number
0.000- 0.999	3				1	4
1.000- 1.999	2	3	4		6	15
2.000- 2.999	6	7	11	1	15	40
3.000- 3.999	15	30	29	2	15	91
4.000- 4.999	52	61	38	11	33	195
5.000- 5.999	107	134	76	17	52	386
6.000- 6.999	150	179	124	36	75	564
7.000- 7.999	180	238	175	53	73	719
8.000- 8.999	238	216	168	74	88	784
9.000- 9.999	188	179	148	116	108	739
10.000-10.999	173	117	128	146	130	694
11.000-11.999	133	66	82	141	88	510
12.000-12.999	67	23	40	121	85	336
13.000-13.999	36	14	23	89	85	247
14.000-14.999	8	2	13	57	55	135
15.000-15.999	1	4	5	20	31	61
16.000-16.999			2	19	21	42
17.000-17.999	1		1	5	13	20
18.000-18.999	1			2	7	10
19.000-19.999	2			1	6	9
20.000-20.999				1		1
21.000-21.999	1					1
22.000-22.999	1					1
23.000-23.999				1		1
Totals	1365	1273	1067	913	987	5605

Table 7. Average acre-yield of each group of fields when fields had been classified according to the estimated plant populations.

Estimated plant population. Class limits.	Average acre-yield of class for indicated season: 1938	1939	1940	1941	1942	Average estimated population of class.	Average acre-yield of class	Estimated population per ton 6/ acre-yield
numbers	tons	tons	tons	tons	tons	number	tons	number
0- 999	0.300				0.690			
1000- 2999	1.159		1.335		1.670			
3000- 4999	1.848	2.289	3.012		2.795			
5000- 6999	3.964	4.000	3.699	5.516	4.723	6245	4.380	1426
7000- 8999	4.995	4.369	4.632	7.241	6.513	8209	5.550	1479
9000-10999	5.980	5.904	6.174	8.638	8.661	10166	7.071	1438
11000-12999	7.315	6.890	7.196	9.912	10.874	12090	8.437	1433
13000-14999	8.567	7.817	8.502	11.220	12.424	13984	9.706	1441
15000-16999	10.016	8.755	9.449	12.278	13.320	15916	10.764	1479
17000-18999	10.872	9.668	10.745	13.370	14.641	17828	11.859	1503
19000-20999	11.794	10.872	11.508	13.958	15.044	19720	12.635	1561
21000-22999	11.952	11.124	12.161	14.378	19.660	21563	13.855	1556
23000-24999	15.155	11.520	13.616	19.610	12.630	24244	14.506	1671
25000-26999	11.929	7.572	14.740	18.880				
27000-28999	19.790		17.500	23.230				
29000-30999	20.404	12.998			18.860			
31000-32999								
33000-34999								
35000-36999	21.004		13.540					

6/ Based upon the average estimated plant population and average acre-yield of class.

Table 8. Average estimated plant population of each group of fields when fields had been classified according to the acre-yield obtained.

Acre-yield obtained. Class limits	Average estimated plant population of class for indicated season. 1938	1939	1940	1941	1942	Average estimated population of class	Average acre-yield of class	Estimated population per ton 7/ acre-yield
Tons inc.	number	number	number	number	number	number	tons	number
0.000- 0.999	1187				632			
1.000- 1.999	3148	5375	3399		4487			
2.000- 2.999	7214	7673	7207	9790	5544	7486	2.511	2981
3.000- 3.999	8980	8700	9369	5809	7303	8032	3.587	2239
4.000- 4.999	10693	11164	10759	8752	8660	10006	4.551	2199
5.000- 5.999	11302	12242	11716	10314	8385	10792	5.559	1941
6.000- 6.999	12158	13373	12552	10968	9309	11672	6.526	1789
7.000- 7.999	13269	14397	13524	11416	10338	12589	7.513	1676
8.000- 8.999	14224	15073	14649	12027	10735	13342	8.486	1572
9.000- 9.999	15039	15652	15149	12730	11499	14014	9.481	1478
10.000-10.999	15913	16521	15917	13705	12105	14832	10.467	1417
11.000-11.999	16560	16996	16311	14186	12884	15387	11.480	1340
12.000-12.999	17419	17588	17099	14816	13189	16022	12.438	1288
13.000-13.999	17398	19138	18769	15285	13993	16917	13.418	1261
14.000-14.999	18386	17435	18022	16032	14119	16799	14.395	1167
15.000-15.999	21736	21571	21895	17606	14424	19446	15.452	1258
16.000-16.999			20354	16837	15033			
17.000-17.999	23419		27006	17542	15237			
18.000-18.999	29406			22656	17052			
19.000-19.999	28741			24776	17244			
20.000-20.999				19300				
21.000-21.999	36979							
22.000-22.999	29863							
23.000-23.999				28538				

7/ Based upon average estimated plant population and the average acre-yield resulting therefrom for each class.

Attention is directed to the fact that the data, summarized in table 7 and graphed in plate II, presents a sloping but approximately straight line which would, according to the averages, indicate a linear or straight line or constant relationship between the estimated plant populations and the yields obtained. The constance of this apparent relationship is further emphasized by the straight, short dash, line which was passed through the data by mathematical methods and the average slope or dotted line. It will be observed in plate II that these lines are very close together throughout the extent of the data but it should be noted that the mathematical straight line does not coincide with the average slope line. This divergence is 0.0757 ton per 1000 plants estimated population, the mathematical straight line being above the average slope line with the lower estimated plant populations and below the average slope line with the higher estimated plant populations. This divergence of the mathematical straight line from the average slope line is probably due to competition or lack of competition between the plants.

The summary columns of the data presented in table 8 are shown in graph form in plate III where the average acre-yield of the acre-yield classes has been plotted against the average estimated plant populations which resulted in such yields. These data points are indicated by the small circles on the graph and the small circles have been connected by solid lines to indicate their relationship. Attention is directed to the fact that these data when presented in graph form appear as a sloping but approximately straight line. To emphasize this feature, a straight line has been passed through the graphed data by mathematical methods. The actual data, as graphed, follow this straight line very closely from one end of the data to the other. A second line, the line of average slope, has also been passed through the data. It will be noted in this case, as compared with the data as presented in plate II, that the mathematical straight line and the line of average slope are definitely divergent. When acre-yields were low, the average slope line is above the mathematical straight line and when acre-yields were high, the average slope line is below the mathematical straight line. This divergence is at the rate of 0.496 ton per 1000 plants estimated population. Attention is drawn to this feature of the data because it indicated that some factor or factors, other than the estimated plant population, exerted a very definite and effective influence upon the acre-yields obtained.

The influence of the unknown factor or factors is again emphasized when the number of plants, estimated population, per ton of yield obtained, table 7, is plotted against the population class average, plate IV, in comparison with the number of plants, estimated population, per ton of yield determined when the fields had been classified according to acre-yields, table 8. This graph clearly demonstrates the approximately straight line, or linear, or constant, relationship existing between the estimated plant populations and the acre-yields obtained when the fields were classified according to the estimated plant populations, the extreme difference in number of plants per ton of yield in this case being only 245, a few more beets being required per ton of yield as the estimated plant populations became higher. But when the data were classified according to the acre-yields obtained, the average plant populations resulting in such yields and the number of plants per ton of yield determined, table 8, the difference between the extremes of the data was 1723 plants, estimated population, per ton of yield, the higher the yield class, the less the number of plants

per ton. The contrast presented in plate IV is worthy of note. As the estimated plant populations became higher or more competitive, more plants were required per ton of acre-yield. As the acre-yields became higher, fewer plants were necessary per ton of yield.

Field practices have a very definite influence upon plant populations maintained. When contract labor blocked, thinned, hoed, pulled and topped the beets at so much an acre, many of the fields were planted with the narrow rows, sometimes as narrow as 16 or 18 inches but generally about 20 inches apart, and the contract labor was required to space the beets at close intervals, sometimes as close as 6 or 8 inches but generally between 8 and 12 inches apart in the row, thereby insuring high plant populations. In many instances in the eastern sugar beet area, the narrower rows have been abandoned for the wider ones when the field bean was included in the farming system, the same implements being used in planting and cultivating both crops. Later when the contract labor which blocked and thinned the beets began to be paid according to the width of row used, the toppers according to the acre yield, and the growers began using tractor implements, many of the growers still using the narrower rows, abandoned them in favor of the wider ones. This drift from the narrower rows to the wider ones is indicated in table 2 where the proportion of fields with 24 inch rows decreased from 57.00 per cent in 1938 to 32.12 per cent in 1942 and the proportion of fields with 28 inch rows increased from 29.08 per cent in 1938 to 47.52 per cent in 1942. At the present time a very considerable portion of the sugar beets in the eastern area are planted in rows 28 inches apart.

This drift from the narrower rows to the wider ones has, in all probability, as indicated in table 4, operated to reduce the plant populations maintained to some extent. The data would indicate that on the average, the change from the narrower to the wider rows reduced the estimated plant populations by about 690 plants per acre for each 2-inch increase in the row width and the acre-yield obtained by about 0.258 ton.

While the row width has not been shown to be very important in the maintenance of a high or satisfactory plant population, the importance of maintaining a high plant population no matter what the row width may be, has been clearly demonstrated. If satisfactory yields are to be obtained, the plant population maintained must be high. This has been clearly shown by the data when classified either as to the estimated plant populations or according to the acre-yields obtained. In the first case the higher acre-yields accompanied the higher plant populations and in the second case the higher yields resulted from higher plant populations. The relationship of the estimated plant population to the yield obtained in each case being approximately straight line, linear, or constant.

While the data presented in this report have tended to show that the relationship between the estimated plant populations and the acre-yields obtained is linear, straight line, or constant, such cannot be the case. Brewbaker and Deming[9] state "from regression values presented, it appears that this relationship is essentially linear within observed stand limits. It is apparent however, that this relationship would be non-linear with wider variations in stand." It is of interest to note that the stands Brewbaker and Deming referred to varied from 11435 to 27770 plants per acre.

9/ H.E. Brewbaker and G.W. Deming. "Effect of variation in Stand on Yield and Quality of Sugar Beets Grown under Irrigation." Journal of Agricultural Research. Vol. 50, No. 3, pp 195-210. February 1935.

Willcox[10] in his description of the Universal Yield Diagram[11], a

10/ O. W. Willcox, A B C of Agrobiology.
11/ J. G. Lill. "Universal Yield Diagram Table." Journal of the American Society of Agronomy. Vol. 38, No. 6, June 1946.

form of the law of diminishing returns, states that the first Baule unit[12] of plant population results in the production of one-half of the maximum possible yield, the first and second in 75 per cent, the first, second, and third in 87.5 per cent, and the first ten units in 99.9 per cent or that the relationship between the plant population and the yield obtained is a curve of very definite characteristics when the plant population maintained is sufficiently high to cause those characteristics to become apparent.

12/ The number of plants constituting a Baule unit of population is believed to vary according to several factors surrounding the production of the crop.

The relationship between the plant population of sugar beets and the yield obtained, while it may be approximately proportional or linear for fractional populations, cannot be regarded as being continuously so for although in the lower populations it may be and has been found that each 1000 plant increase in population results in an almost definite increase in yield, such increase in the yield with the increase in the population cannot continue indefinitely. A point must finally be reached where each increase in the plant population results in smaller and yet smaller increments of yield until finally there would be no yield increment even though the plant population were increased without limit. That such has not been plainly evident in the data studied is believed to be entirely due to the fact that the plant populations maintained where the populations were estimated, were all too low to permit the operation of the law of diminishing returns to be apparent.

Close scrutiny of the data however, revealed indications that the law of diminishing returns may have had a slight effect upon the acre-yields obtained. In plate II, the straight line passed through the data points is shown to be above the average slope line with the lower estimated plant populations and below it with the higher plant populations. Also in plate IV, line A, it is shown that more beets were required per ton of yield with the higher plant populations than with the lower. These points would indicate competition between the plants in the higher plant populations, that the denser plant populations had not permitted the individual plant thereof to attain its maximum possible size and though higher yields were obtained, the increase in yield was not strictly proportionate to the increase in the plant population but had been influenced to a slight extent by inter-plant competition or the law of diminishing returns.

The operation of the law of diminishing returns is again indicated by line B, plate IV. When the fields had been classified according to the acre-yields and the average estimated plant population resulting in such yields, determined, it was found that the number of beets per ton of yield decreased very definitely from the lower acre-yields to the higher. This decrease in the number of beets per ton of yield is probably largely accounted for by the higher productivity of the soil in the fields with the higher yields. Yet line B, representing the number of beets per ton of yield, is not a straight line. From the lower acre-yields to the higher, this line presents a curve. If the number of beets necessary for each ton of yield were determined entirely by the productivity of the soil, line B should show a straight line relationship. The curve in line B is accounted for by the fact that as the productivity of the soil increased, the weight of the individual root increased and also the estimated plant population but the competition resulting from the increased population prevented the individual plant from making a proportionate increase in weight. If the data had continued to higher and higher plant populations, line B would in all probability have reached a low point where a minimum number of beets would have been necessary for each ton of yield and then would have turned upward again as the weight attained by the individual root decreased due to inter-plant competition even though the acre-yields might have continued to increase.

As a result of the study of the estimated plant population and acre-yield data collected by Mr. Kelly, the following conclusions seem warranted and substantiated:

1. The relationship between the estimated plant populations and the acre-yields obtained may vary from season to season but the essential characteristics of the relationship remain the same.

2. The influence of the width of row upon this relationship is slight but definite, higher plant populations having been maintained and higher acre-yields having been obtained on the average in the fields with the narrower rows.

3. In the data examined, the relationship between the estimated plant population and the acre-yields obtained was essentially straight line or proportionate.

4. When the numbers of beets per ton of yield were considered, some evidence of the operation of the law of diminishing returns was established.

5. From the apparent straight line relationship between the estimated plant populations and the yield obtained, in the data examined, and from the slight evidence of the operation of the law of diminishing returns that was developed, it is concluded that the plant populations maintained in many of the commercial fields of sugar beets in the eastern area, are too low to result in more than one half of the maximum possible yield being obtained.

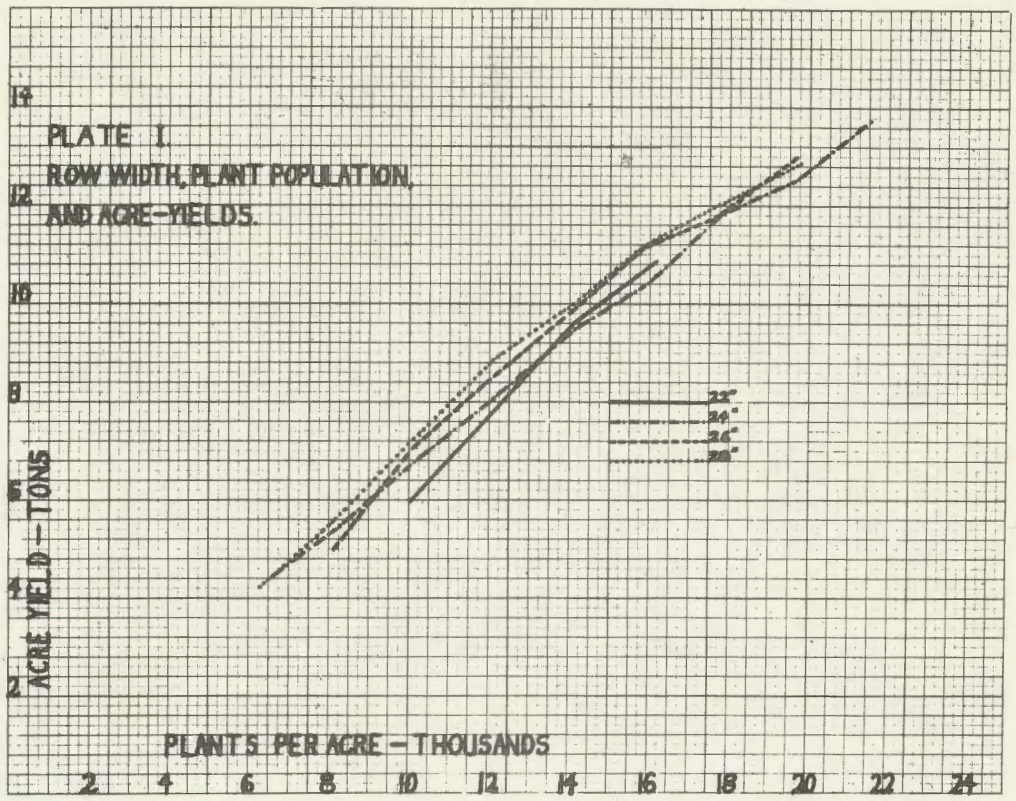
PLATE I.
ROW WIDTH, PLANT POPULATION,
AND ACRE-YIELDS.
ACRE YIELD - TONS
PLANTS PER ACRE - THOUSANDS
22"
24"
26"
28"

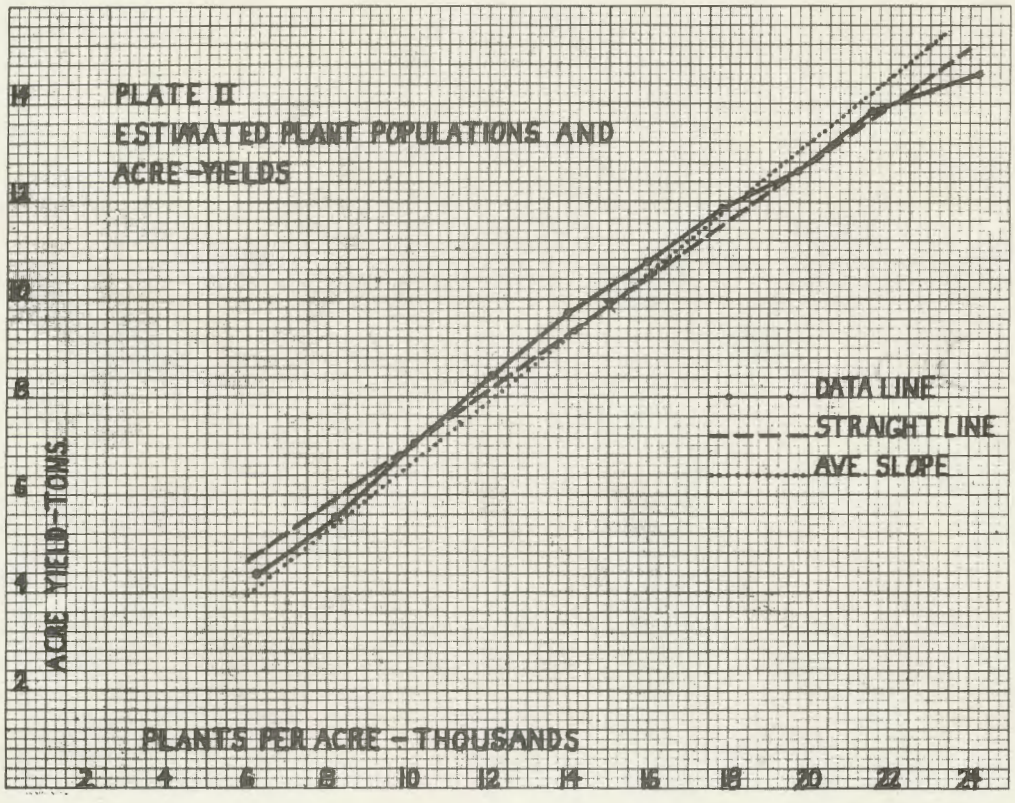
PLATE II.
ESTIMATED PLANT POPULATIONS AND
ACRE-YIELDS
ACRE YIELD - TONS
PLANTS PER ACRE - THOUSANDS
DATA LINE
STRAIGHT LINE
AVE. SLOPE

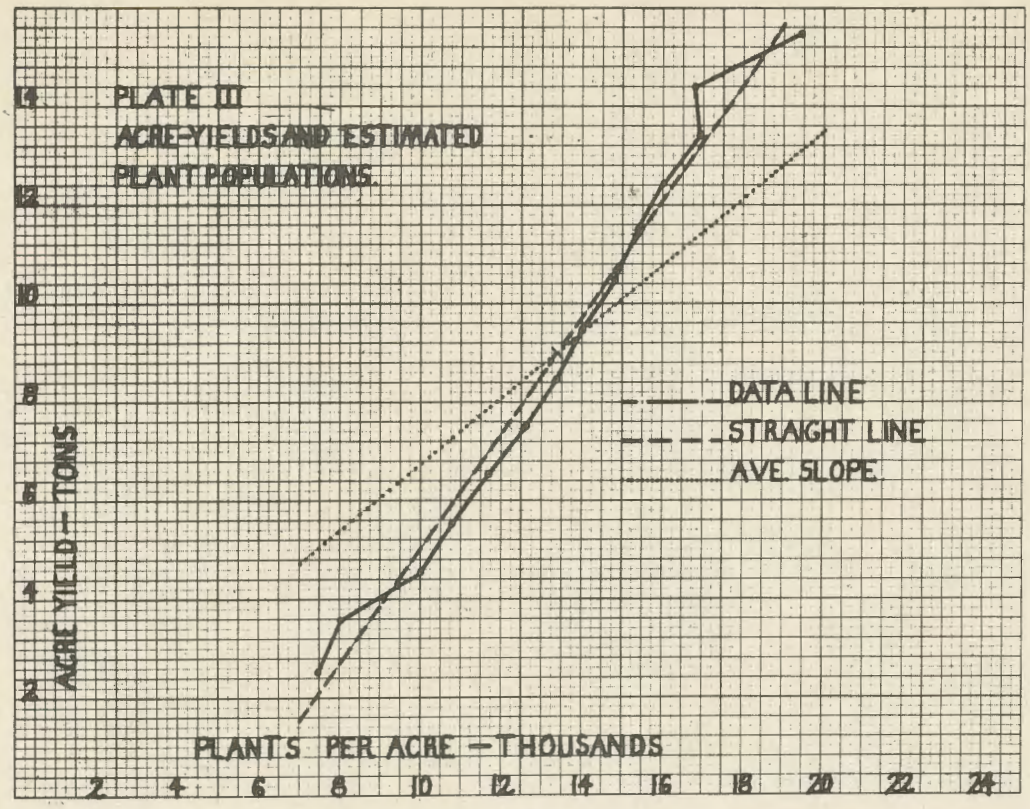
PLATE III
ACRE-YIELDS AND ESTIMATED
PLANT POPULATIONS.
ACRE YIELD — TONS
14
12
10
8
6
4
2
DATA LINE
STRAIGHT LINE
AVE. SLOPE
PLANTS PER ACRE — THOUSANDS
2
4
6
8
10
12
14
16
18
20
22
24

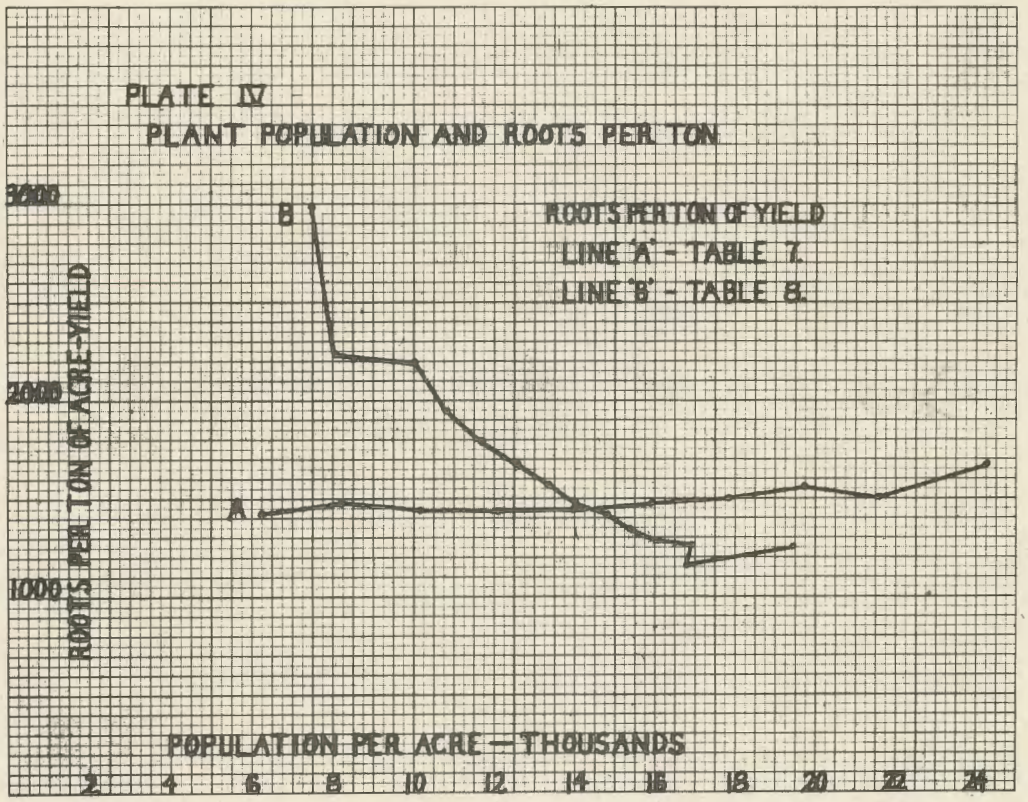
PLATE IV
PLANT POPULATION AND ROOTS PER TON
ROOTS PER TON OF ACRE-YIELD
3000
2000
1000
B
A
ROOTS PER TON OF YIELD
LINE 'A' - TABLE 7.
LINE 'B' - TABLE 8.
POPULATION PER ACRE — THOUSANDS
2
4
6
8
10
12
14
16
18
20
22
24