curve indicates that when the thinned stand is kept at 100 beets per hundred feet there is only a small decrease in yield even with a comparatively high percentage of doubles. On the other hand the lower curve indicates that with increased doubles and a corresponding increase in number of thinned beets per hundred feet there is a significant decrease in yield which reaches a 25-percent decrease at about 80 percent doubles.

It should be pointed out that this set of plots was grown on a field having a 12- to 13-ton-per-acre level of soil fertility. The data probably would have been different on soil of a higher or lower fertility level. The stand of 100 beets per hundred feet of row was taken as a check because that seems to be the commonly accepted desired thinned stand in this area.

Population and Distribution Studies With Sugar Beets

BION TOLMAN[1]

Established sugar beet culture in the intermountain area centers around the planting of beets in 20- and 22-inch rows with a subsequent spacing of plants 11 to 12 inches apart in the row to give a population of approximately 25,000 beets per acre. Recent mechanization of sugar beet agriculture has raised the question as to whether the traditional pattern of distribution may not be changed without adversely affecting yields. The present paper is a report of some studies conducted to determine optimum populations in relation to different distribution patterns and also to determine the effect on yield of varied distribution patterns.

Experimental Procedure

The two major tests reported here include 20-inch, 26-ineh, 32-inch, and 38-inch row. widths with 8-inch, 10-inch, 12-inch, and 15-ineh spacings in the row. These two tests were split-plot experiments with four replicated plots of each of the 16 treatments. The results of these tests are supplemented by results from other spacing studies and population and distribution studies involving a comparison of hand and mechanical thinning.

Experimental Results

Results of the row width test at Granger, Utah, are shown in table 1. It is evident from these results that, under the conditions of this experiment, distribution pattern had more effect on yield and sucrose

[1]Director of Agricultural Research, Utah-Idaho Sugar Company, Salt Lake City, Utah.

Table 1.—Row width and spacing tests, 1945, Granger, Utah. Hill Brothers Farm.

Spacing in Row	Row widths as indicated 20"	26"	32"	38"	Average for spacing in the row
8 inch spacing					
Beets per acre	36,540	29,136	24,560	20,253	27,622
Tons per acre	28.48	26.14	25.56	25.35	26.38
Sucrose percentage	17.24	16.78	16.24	16.16	16.60
Gross sugar per acre	4.910	4.374	4.149	4.096	4.382
10 inch spacing					
Beets per acre	30,697	24,774	20,807	16,639	23,229
Tons per acre	28.26	26.89	26.48	25.24	26.72
Sucrose percentage	17.15	16.75	16.28	15.93	16.53
Gross sugar per acre	4.844	4.500	4.315	4.015	4.418
12 inch spacing					
Beets per acre	25,784	20,938	16,090	13,862	19,168
Tons per acre	30.07	28.40	26.98	25.76	27.80
Sucrose percentage	16.98	16.41	15.98	15.78	16.29
Gross sugar per acre	5.10G	4.665	4.312	4.060	4.536
15 inch spacing					
Beets per acre	21,010	16,636	12,312	10,626	15,146
Tons per acre	29.50	28.48	25.76	26.25	27.50
Sucrose percentage	16.60	16.20	15.61	15.18	15.90
Gross sugar per acre	4.901	4.614	4.019	3.975	4.377
Average for row widths					
Tons per acre	29.08	27.48	26.20	25.65	
Sucrose percentage	16.99	16.54	16.03	15.76	
Gross sugar per acre	4.940	4.538	4.199	4.036	

Replicated test with four replications of each treatment.

content than did per acre population. The effect of population is apparent within any one of the row widths. In almost every case the highest yield of beets per acre occurred where the beets were spaced 12 inches apart in the row. The data indicate that spacing beets closer than 12 inches in the row was not beneficial regardless of the increase in row width. In all cases a spacial allotment per beet which approached a square was more efficient than a spacial allotment which was extremely rectangular. This is evidenced by the fact that the yield decreased progressively as the space allotment became increasingly rectangular in shape. For example : When the per acre beet population was held constant at 20,000 to 21,000 beets per acre the yield was 29.50 tons per acre with 15-inch spacing on 20-inch rows; 28.40 tons per acre with 12-inch spacing on 26-inch rows; 26.48 tons per acre with 10-inch spacing on 32-inch rows and 25.35 tons per acre with 8-inch spacing on 38-inch rows. There was also a progressive drop in sucrose percentage over this same spacial pattern regardless of the fact that each beet had the same total space allotment. The same result was repeated when the per acre population of beets was held constant at approximately 25,000 to 26,000 beets per acre. With 12-inch spacing on 20-inch rows the yield was 30.07 tons per acre; with 10-inch spacing on 26-inch rows the yield was 26.89 tons per acre; and with 8-inch spacing on 32-inch rows the yield dropped to 25.56 tons per acre. Sucrose percentage decreased in a similar manner.

Distorting space allotment had more effect on yield than either increasing or decreasing space allotment within the limits tried. However, increasing or decreasing space allotment had more effect on sucrose percentage than did distortion or pattern of the space allotment. Increasing space allotment, either by increasing row width or by increasing spacing in the row, depressed sucrose percentage. However, the decrease becomes progressively greater as the population per acre decreases or as the space allotment per beet increases. For example: With 8-inch spacing the sucrose percentage decreased 1.08 percent as the row width was increased from 20 inches to 38 inches; with 10-inch spacing the decrease was 1.22 percent; with 12-inch spacing the decrease was 1.20 percent and with 15-inch spacing the decrease was 1.42 percent.

We have seen that distribution pattern had a marked effect on the yield of beets per acre and that population or space allotment as well as distribution pattern had a marked effect on sucrose percentage. Sugar per acre was affected mainly by row width or distribution pattern. It should be noted, however, that in every instance there was a drop in sugar per acre as spacing within the row increased from 12 to 15 inches. Under the conditions of this experiment maximum yields of sugar per acre were produced with 12-inch spacing within the row. With 12-inch spacing within the row, the yield of sugar per acre was 5.106 tons on 20-inch rows and only 4.060 tons on 38-inch rows. This makes a decrease of 2,080 pounds of sugar per acre caused by the combined effect of row width and decreased population per acre. However, if population per acre is held constant at approximately 25,000 beets per acre the yield of sugar per acre ranges from 5.106 tons per acre with 12-inch spacing and 20-inch rows to only 4.149 tons per acre with 8-inch spacing on 32-inch rows. This decrease of 1,914 pounds in the yield of sugar per acre is all due to distribution pattern, inasmuch as population or total spacial allotment was held constant. The same relationship held when population was kept constant at 21,000 to 20,000 beets per acre. The yield of gross sugar per acre was 4.901 tons with 15-inch spacing on 20-inch rows and it decerased to 4.096 tons per acre with 8-inch spacing on 38-inch rows.

The test on Sagar's farm at American Fork, Utah, was somewhat of a contrast to that on the Hill Brothers Farm at Granger, Utah. The results of this test are given in table 2. It is evident from the data that on the average 12-inch spacing watt optimum regardless of row width. In this test, however, the effect of spacial distribution was

Table 2.—Row width and spacing test, 1945, American Fork, Sagar's Farm.[1]

Spacing in row	Row widths as indicated				Average for spacing In the **row**
	20"	26"[2]	32"	38"	
8 inch spacing					
Beets per acre	37,374	30,173	23,849	19,571	27,742
Tons beets per acre	20.82	20.27	21.54	18.80	20.36
Sucrose percentage	12.57	12.15	12.69	12.39	12.45
Gross sugar per acre	2.612	2.400	2.672	2.004	2.437
10 inch spacing					
Beets per acre	29,534	23,909	19,152	14,031	21,656
Tons beets per acre	21.00	21.43	22.36	18.81	21.06
Sucrose percentage.	12.66	12.52	12.15	12.05	12.34
Gross sugar per acre	2.742	2.684	2.715 .	2.256	2.599
12 inch spacing					
Beets per acre	23,000	19,502	15,028	12,243	17,443
Tons beets per acre	22.1.0	20.97	21.46	20.04	21.31
Sucrose percentage	12.37	12.31	11.25	12.35	12.07
Gross sugar per acre	2.930	2.573	2.415	2.548	2.616
15 inch spacing					
Beets per acre	19,898	14,878	J 2,088	9,904	14,192
Tons beets per acre	22.17	19.28	22.58	19.08	20.78
Sucrose percentage	12.67	12.72	12.35	12.35	12.52
Gross sugar per acre	2.798	2.444	2.810	2.355	2.602
Average for row widths					
Tons beets per acre	21.70	20.19	21.98	19.33	
Sucrose percentage	12.57	12.42	12.11	12.28	
Gross sugar per acre	2.770	2.540	2.653	2.291	

Replicated test with four replications of each treatment.

[1]Tests conducted in cooperation with Dr. Bertram Harrison of the Brigham Young University, Provo, Utah.

[2]Some morning glory spots on one set of the 26-inch row no doubt account for the slight decrease in yield as compared to 32-inch rows.

much less than in the one at Granger, Utah. This is no doubt accounted for by the extreme fertility level on the American Fork plot. The contrast in fertility level between these two plots is shown by a comparison of the sucrose percentage figures. The average sucrose percentage at the Granger plot was 15.76 and at the American Fork plot it was 12.28 or a difference of 3.48 percent. The difference in fertility was further borne out by the extreme top growth at the American Fork plot. Further evidence that this plot was located on abnormal fertility is reflected in the results of grower test strip plantings which were located in the same county. The results of these tests are given in table 3. The similarity between these results and the Granger, Utah, test is evident.

The inter-relation of per acre population and distribution was also shown on a series of plots where hand and mechanical thinning were compared. The results of these tests are given in table 4. It is evident that 100 beets per 100 feet of row was optimum spacing on the hand thinning plots. The yields were 23.52, 24.08, and 22.47 tons per

Table 3.—Row width tests, Utah County, 1945. Tons beets per acre from 20-inch rows as compared with 30-inch rows.

Grower's name	Tons beets per acre		Loss in tonnage per acre
	20"' rows Regular	Every 3d row out 20-40 wide and narrow combination	
Jennings Meanson	24.30	22.21	2.18
Bert Hanson	21.23	17.72	3.51
Kenneth S. Christensen	23.10	21.13	1.07
W. .T. Money	20.65	17.16	3.49
Selvoy .T. Boyer	10.29	13.64	5.65
Elden Evans	16.66	13.02	3.64
	21.73	18.37	3.36

Grower strip tests—16 rows wide comparing 16 rows of regular 20 inch rows with 16 rows with every third row cut out giving a 40 inch-20 inch wide and narrow combinations or an average row width of 30 inches.

acre for 75, 100, and 125 beets per 100 feet of row respectively. On mechanically thinned plots it. was advantageous to increase the number of beets per 100 feet of row. The yields were 21.04, 21.87, and 22.45 tons per acre for 75, 100, and 125 beets per 100 feet of row respectively.

With hand thinning all blocks were reduced to singles and these single plants were uniformly distributed over the entire 100 feet of row. Under these conditions of uniform distribution, wide spacing did not greatly affect yields. With mechanical thinning about 20 per-cent of the blocks contained doubles. Consequently, with 75 beets per 100 feet of row there were only 62 blocks of beets; with 100 beets per 100 feet of row there were 80 blocks of beets, and with 125 beets per

Table 4.—Comparison of the yield and population distribution from hand and mechanically thinned plots.

Beets per 100 feet of row	Hand thinned		Dixie thinned		Difference in hand and mech. thinning
	Beet-eontaining blocks per 100 foot of row	Tons beets per acre	Beet-containlng blocks per 100 feet of row	Tons beets per acre	
	Number	Tons	Number	Tons	Tons
Granger, Utah					
75 beets per 100 feet	75	23.52	62	21.04	—2.48
10O beets per 100 feet	99	24.08	81	21.87	—2.21
125 beets per 100 feet	123	22.47	102	22.45	—0.02
Average	aa.rt	23.36	81.7	21.78	—1.58
Belle Fourche, South Dakota					
75 beets per 100 feet	75	10.76	60	8.88	—1.88
100 beets per 100 feet	100	10.93	78	9.23	—1.70
125 beets per 100 feet	134	10.50	107	9.70	—0.80
Average	100	10.73	81.7	9.27	—1.46

Table 5.—Distribution and population studies with hand and mechanical thinning in Idaho.[1]

Thinning method	Beets left per 100 feet of row	Blocks of beets per 100 feet of row	Yield in percent of check	Percent singles
	Number	Number	Percent	Percent
Merrill farm				
Hand thinning (check)	83	81	100.0	94.0
56% machine thinning	83	79	95.6	90.0
71% machine thinning	80	75	91.7	75.0
100% machine thinning	01	75	83.1	00.5
DeKay farm				
Hand thinning (chock)	90	88	100.0	95.0
100% mechanical (Dixie)	100	81	93.2	70.6
100% mechanical (cross cultivated)	82	58	82.3	66.0

[1]Studies by A. J. Bigler.

100 feet of row there were 102 blocks of beets. Increasing the blocks of beets from 62 to 102 per 100 feet of row gave a more favorable distribution and the improved distribution pattern resulted in increased yields.

These results were also borne out by similar studies in South Dakota. The yield on hand thinned plots was 10.76 tons, 10.93 tons, and 10.50 tons for 75, 100, and 125 beets per 100 feet of row respectively. On mechanically thinned plots the yield was 8.88 tons, 9.23 tons, and 9.70 tons for 75, 100, and 125 beets per 100 feet of row respectively. Mechanical thinning tests in Idaho[2] also pointed out the importance of distribution of stand as well as total number of beets per 100 feet of row. In all cases the yield was in proportion to the number of beet-containing blocks left per 100 feet of row. The results of these tests are given in table 5. At the Merrill farm yields decreased as the percentage of machine work increased and distribution became more irregular as the percentage of machine increased. At the DeKay farm, regularity of distribution was in proportion to the number of blocks left per 100 feet of row and yields followed this same relationship.

Discussion

The results reported indicate that distribution pattern affected yields to a greater extent than did the range of population per acre which was included in the tests. This is in accord with the findings of Brewbaker and Deminig (*i*)[3] who state that uniformity of stand is relatively more important than the particular spacing used. The

[2]Mechanical tests in Idaho were conducted by .A J. Bigler.

[3]ltalic numbers in parentheses refer to literature cited.

decrease in yield from 20- to 26-inch rows also follows the pattern indicated by the work of Brewbaker and Deming (*1*). They report a decrease of over 2 tons per acre when row widths were increased from 20 to 24 inches even though poulations were greatly increased in the row to compensate for the wider row.

The limits within which beets can effectively utilize space has been rather definitely defined. Most all spacing studies show a decrease in yield as spacing within the row is increased beyond 12 inches. Under conditions of high fertility, such as that on the Toppenish, Wash., plot, yield may be maintained with row spacings out to 15 inches, but even under high fertility, yields begin to decline as spacing within the row is increased to 20 inches. In consideration of this fact there is no reason to assume that beets can advantageously use a space allotment between rows in excess of 20 inches. In fact spacing data suggest that an increase in number of rows per acre might be advantageous from the standpoint of maximum production.

Mechanical thinning studies indicate that it is more important to consider final distribution pattern than it is total beets per 100 feet of row. In view of this fact the stand on mechanically thinned plots should be calculated in terms of blocks per 100 feet of row rather than in terms of beets per 100 feet of row. Much of the success of mechanical thinning also depends on the ability of beets adjacent to skips to compensate for the skip through increased growth. Brewbaker's and Deming's (.7) work shows that as the size of the gap or skip increases, the percentage of compensation from adjacent beets decreases. Decreased row widths rather than increased row widths would be advantageous in mechanical thinning from the standpoint of making it possible for beets in one row to compensate for skips in an adjacent row. It also becomes evident that a beet can utilize a square space more efficiently than it can an equivalent area which is rectangular in shape. This would suggest that yields might be increased by increasing the number of rows per acre rather than by increasing the number of beets per 100 feet of row.

Increasing space allotment per beet decreased sucrose percentage regardless of whether the increased space allotment resulted from increased spacing in the row or increased width between the rows. There was also a decrease in sucrose percentage as row widths were increased, even though spacing within the row was decreased so that there was no increase in space allotment per beet.

The effect of space allotment on sucrose content indicates that in general spacing within the row should not be wider than 12 inches, inasmuch as wider spacing does not increase yield even under conditions of high fertility.

Summary

The results of tests showing the effect of plant population and the distribution pattern of given populations on yield, sucrose content, and gross sugar per acre are reported. Variations in plant population and distribution pattern were obtained by varying row width and also by varying spacing within the row.

There was no significant difference in tonnage yield between beets spaced 8 inches, 10 inches, 12 inches, or 15 inches in the row on any of the row widths studied. There was a progressive decrease in yield as the row width increased from 20 inches to 26 inches, 32 inches, and 38 inches.

The tests indicated that a square distribution pattern of beet population on an acre was much more efficient than where the space allotment for each beet is extremely rectangular in shape.

The inter-relation of population and distribution was also shown on plots where hand and mechanical thinning were compared. The stand on mechanically thinned plots should be determined on the basis of beet-containing inches rather than total beets. This provides for a better distribution pattern.

In all tests, increasing the space allotment per beet whether within the row or between the rows resulted in decreased sucrose percentage.

Literature Cited

1. Brewbaker, H. E., and Deming, G. W. Effect of Variations in Stand on Yield and Quality of Sugar Beets Grown Under Irrigation. Jour. of Agr. Res., Feb. 1, 1935.