THE EFFECT OF HARDENING TOMATO PLANTS FOR OUT-DOOR CULTURE

THESIS FOR THE DEGREE OF M. S.

Forrest Cleveland Word

1931

Tomatoes

Horticulture Vegetables

THE EFFECT OF HARDENING TOMATO PLANTS FOR OUT-DOOR CULTURE

Thesis

Presented to the faculty of the Michigan State College of Agriculture and Applied Science as partial fulfillment of the requirements for the degree of Master of Science

by

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THESIS

INTRODUCTION

The best prices for tomatoes are usually obtained early in the season. To secure these high prices the truck and market gardener follows the practice of starting tomato plants at an early date hardening them off in cold frames, and then transplanting them in the field. Unquestionably, hardening has but little effect in increasing the resistance of the tomato plant to low and freezing temperatures, Rosa (7); and furthermore, some recent investigations tend to establish some doubt as to the advantage of the practice from the standpoint of total yield of marketable fruits and total net income. The findings of Crist (2) demonstrate the failure of hardening, with respect to tomato plants fruited under greenhouse conditions. Since conditions under glass differ considerably from those in the field, further experimental test of the effect of hardening when tomato plants are grown to maturity in the field seems desirable.

Review of Literature

Several investigations have dealt with the physiological and anatomical antecedents to and associations with the hardening process in various plants, including the tomato plant in some instances. The principal works of this nature are those of Duhamel and Buffon (3), Maximow (6), Chandler (1), Harvey (4), Rosa (7), and Loomis (5). There is no reason for giving a detailed description of these, since the object of the work to be reported here was not to study the biological phenomena connected with the state of the hardening process and its production, but merely to study certain of its effects as expressed in terms of growth, yield, and so forth. There is no doubt that the hardening process causes a check in plant growth. When a tomato plant is removed from a situation where the conditions are more favorable for growth, the question arises, will the tomato plant fully recover from the check? If so, how promptly? Is this check, when once imposed, ultimately beneficial or not? Crist's (2) findings bear directly upon the question in so far as tomato plants forced under glass are concerned. His results are summarized as follows:

"(1) When tomato plants were hardened and forced in the greenhouse, their early yield in quantity of marketable fruit was greatly diminished and their total yield not materially increased.

(2) Hardening appeared to affect and establish a morphological trend in the stem, which was characterized by an excessive differentiation and maturation of the tissues. This trend involved the leaves and fruits and amounted to a permanent check in general development. The upper portion of the plant, which developed subsequent to the period of hardening, had a different morphological trend and was not affected adversely.

(3) The application of nutrient salts to the hardened plants prior to setting them in beds and forcing them did not relieve the check suffered in the hardening process."

As already mentioned, it does not appear certain that the behavior of hardened tomato plants when grown under field conditions and allowed to come to maturity would necessarily be identical with their behavior when cultivated under glass.

Materials and Methods

Stokes' Bonny Best tomato was the variety used in these trials. Two seedings were made in flats - the first on March 15, the second April 18, 1930.

The plants to be hardened were taken from those of the first seeding. On April 8 they were pricked off, selected for vigor, and reset in flats containing a good compost soil. With one lot, designated hereafter as Lot B, the spacing was 1.5 by 1.5 inches; the other, Lot C, 3 by 3 inches. Both lots were placed in the cold frames April 15, watered sparingly thereafter, and exposed gradually to low temperatures until fully hardened.

One lot (Lot A) of non-hardened plants comprised seedlings from the first seeding. These were selected, pricked off, and reset in flats of the same soil used for hardened plants, 3 by 3 inches apart, on April 8. A second lot (Lot D) of non-hardened plants was obtained by the same procedure on May 24 from the seedlings of the second seeding. This arrangement gave non-hardened plants of the same age as the hardened plants but larger at the time of transplanting and also non-hardened plants which were younger than the hardened but of approximately equal size when transplanted. These two lots (A and D) were kept in the greenhouse under optimum conditions for growth, and occasionally received a sodium nitrate solution (2 ozs. Na NO_3 per gal. water).

Transplanting to the field was done May 24 to 29. The plan of the field is shown in Fig. 1. Each plot was one fortieth of an acre (20 x 54.45 ft.). The plants were set 5 rows to the plot, 17 plants per row; with unplanted alleys, each 3 ft. wide, between the plots at sides and ends. The soil is a Miami Sandy Loam and over the area chosen is fairly uniform in profile. Lots A, B and C were carried in triplicate; D only in duplicate.

After transplantation, the plants in the several plots were cultivated the same, after ordinary field practices. On June 3 nitrate of soda was applied around each plant at the rate of 200 lbs. per acre.

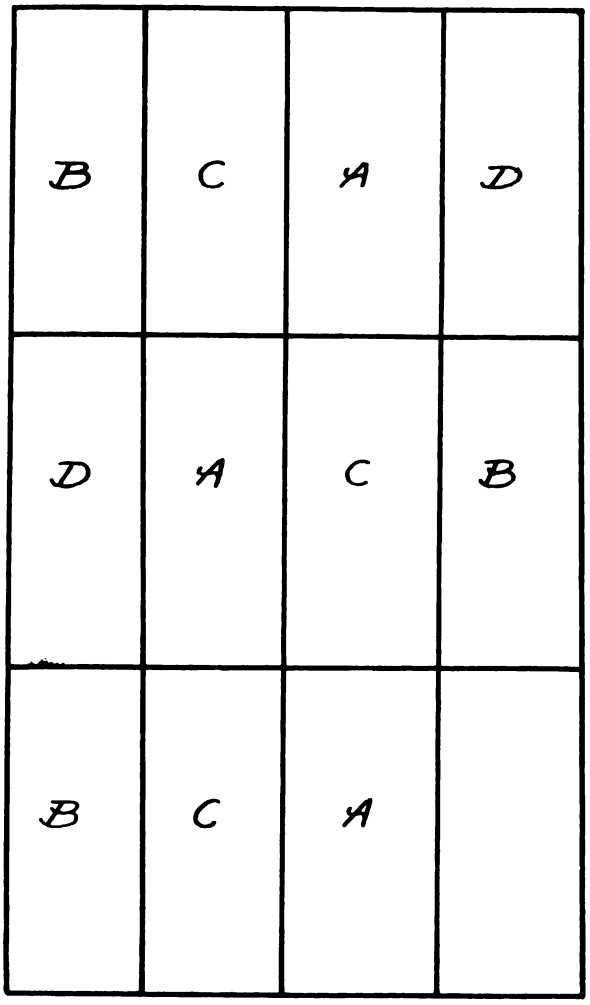


FIG. 1 PLAN OF EXPERIMENTAL PLOTS

Presentation of Data

I. Effect of hardening on fruit quality and yield.

The yields of marketable (first grade pack) and of cull (small size, off shape) fruits from the various plots for the first ten pickings of the season are shown in Table 1. The pickings began on July 13 and extended to August 11, a period of 30 days. Each figure in the table represents the average for the number of plots involved in the respective treatment.

Table 1. Average yields of fruits, first ten pickings.

Lot	Marketable fruit		Cull fruit	
	Number	Total weight (lbs.)	Number	Total weight (lbs.)
A (Non-hardened)	119 ± 2.	35. ± 2.3	183 ± 8	27 ± 1.0
B (Hardened)	31 ± 3.	8 ± 0.8	51 ± 7	7 ± 0.6
C (Hardened)	86 ± 7.	23 ± 1.7	106 ±16	17 ± 3.1
D (Non-hardened)	6 ± 1.	2 ± 0.3	14 ± 1	2 ± 1.4

Table 1 shows that the non-hardened plants of Lot A were far superior to any of the others in early yield of both marketable and cull fruits. The early yields of Lot B and Lot C were greater than that of Lot D. It should be recalled that the non-hardened plants of Lot D were from the later sowing of seed and naturally were much younger when transplanted, and were not as far advanced respecting growth and size. The early yield of Lot C which was significantly greater than that of Lot B may be attributed to the plants of the latter having received a greater check by virtue of having been spaced twice as close together in the flats, a condition that soon brought about over-crowding.

The total average yields of marketable and cull fruits combined for the entire season are presented in Table 2.

Table 2. Total average yields for entire season of marketable and cull fruits.

Lot	Number	Weight (lbs.)
A (Non-hardened)	3195 ± 182.6	369 ± 17.9
B (Hardened)	2662 ± 179.0	330 ± 3.1
C (Hardened)	2660 ± 133.1	344 ± 18.8
D (Non-hardened)	2128 ± 163.5	284 ± 26.3

The order of differences shown in Table 1 appears also in Table 2 and characterized the results at the end of the season. Such differences, as regards both number and weight of fruits, persisted throughout the season but diminished in magnitude as the season progressed. However, none of the differences in total yields for the season is mathematically significant. As regards the combined total average yields of the two non-hardened and two hardened lots, the two non-hardened lots yielded 5323 fruits, weighing 653 lbs., the two hardened lots 5282 fruits, weighing 674 lbs.

The yields by weeks were calculated so as to follow the course of differences in yields through the major part of the season. The results are shown graphically for easy comprehension in Figs. 2 to 7, inclusive. In all cases, the value of the ordinate for August 6 represents the entire yield from July 13 to August 6.

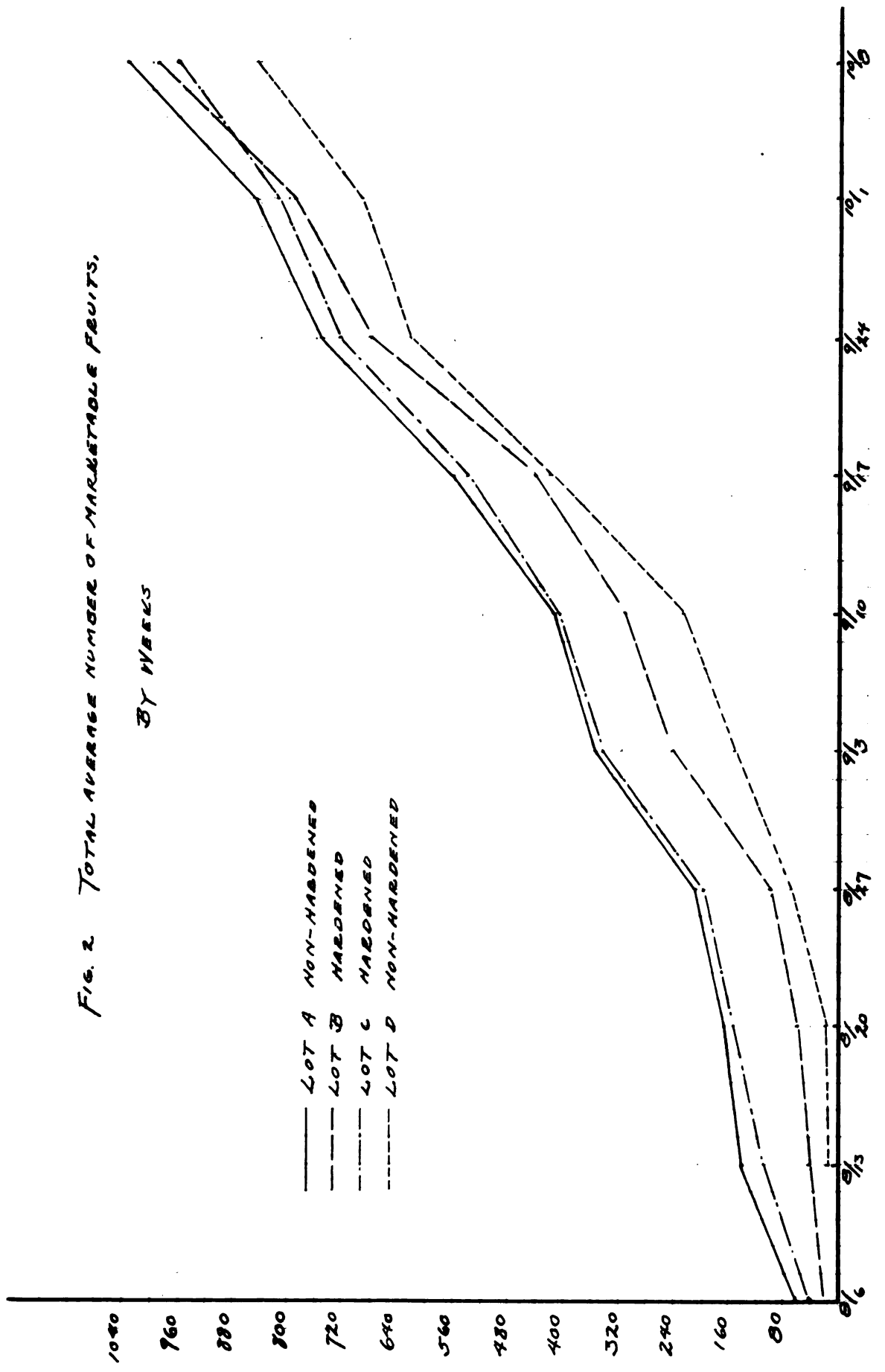


FIG. 2 TOTAL AVERAGE NUMBER OF MARKETABLE FRUITS, BY WEEKS

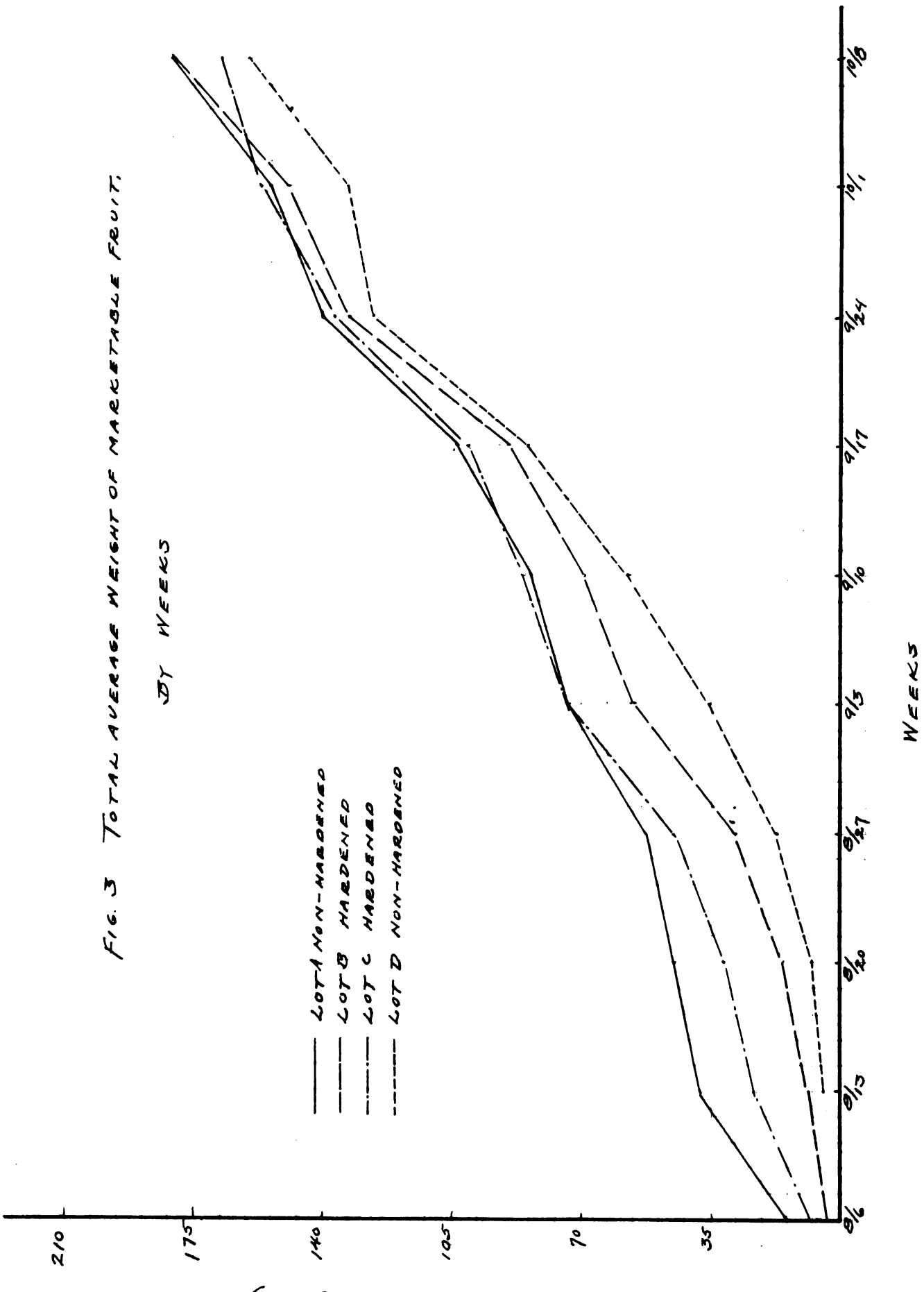
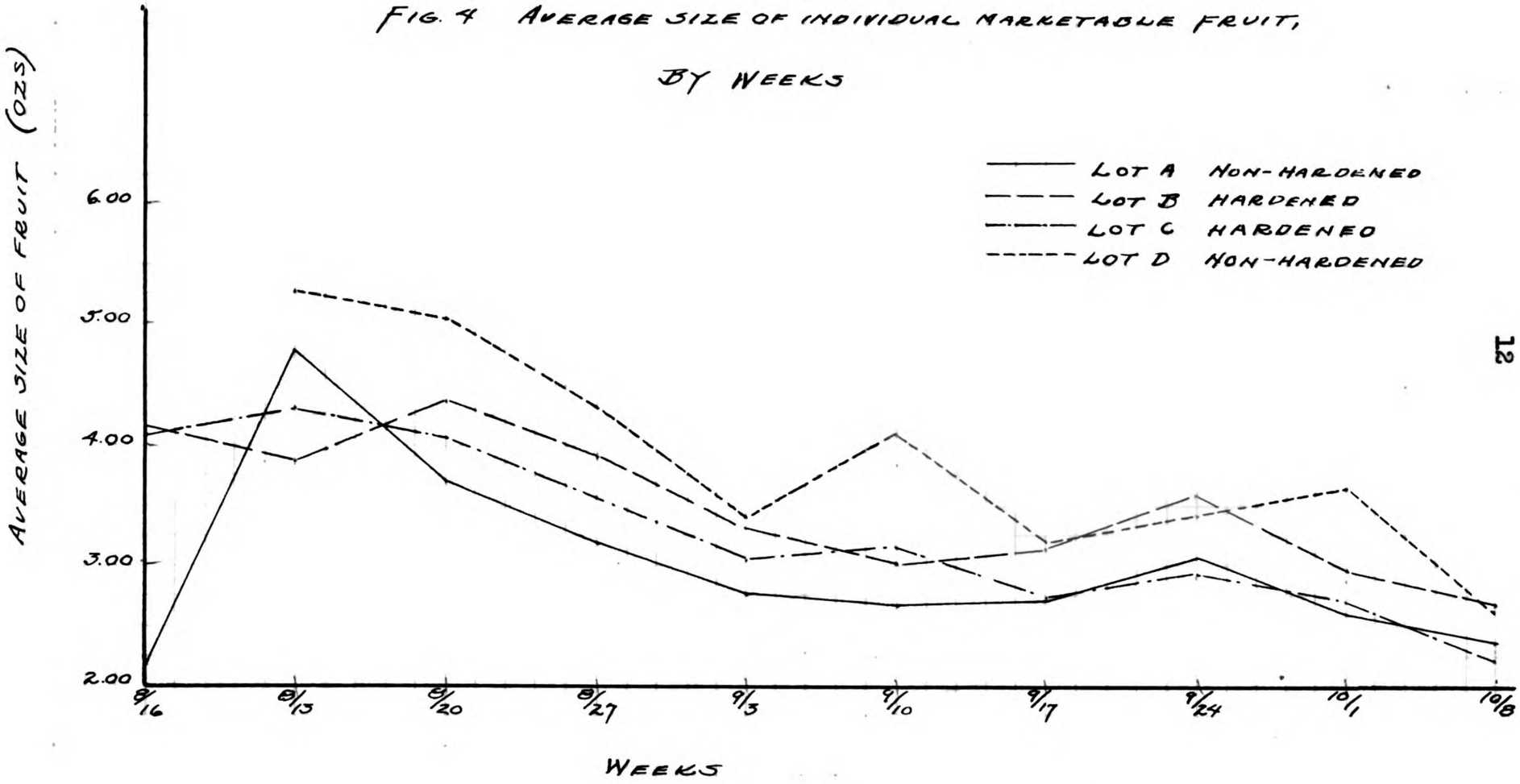


FIG. 3 TOTAL AVERAGE WEIGHT OF MARKETABLE FRUIT, BY WEEKS

FIG. 4 AVERAGE SIZE OF INDIVIDUAL MARKETABLE FRUIT, BY WEEKS



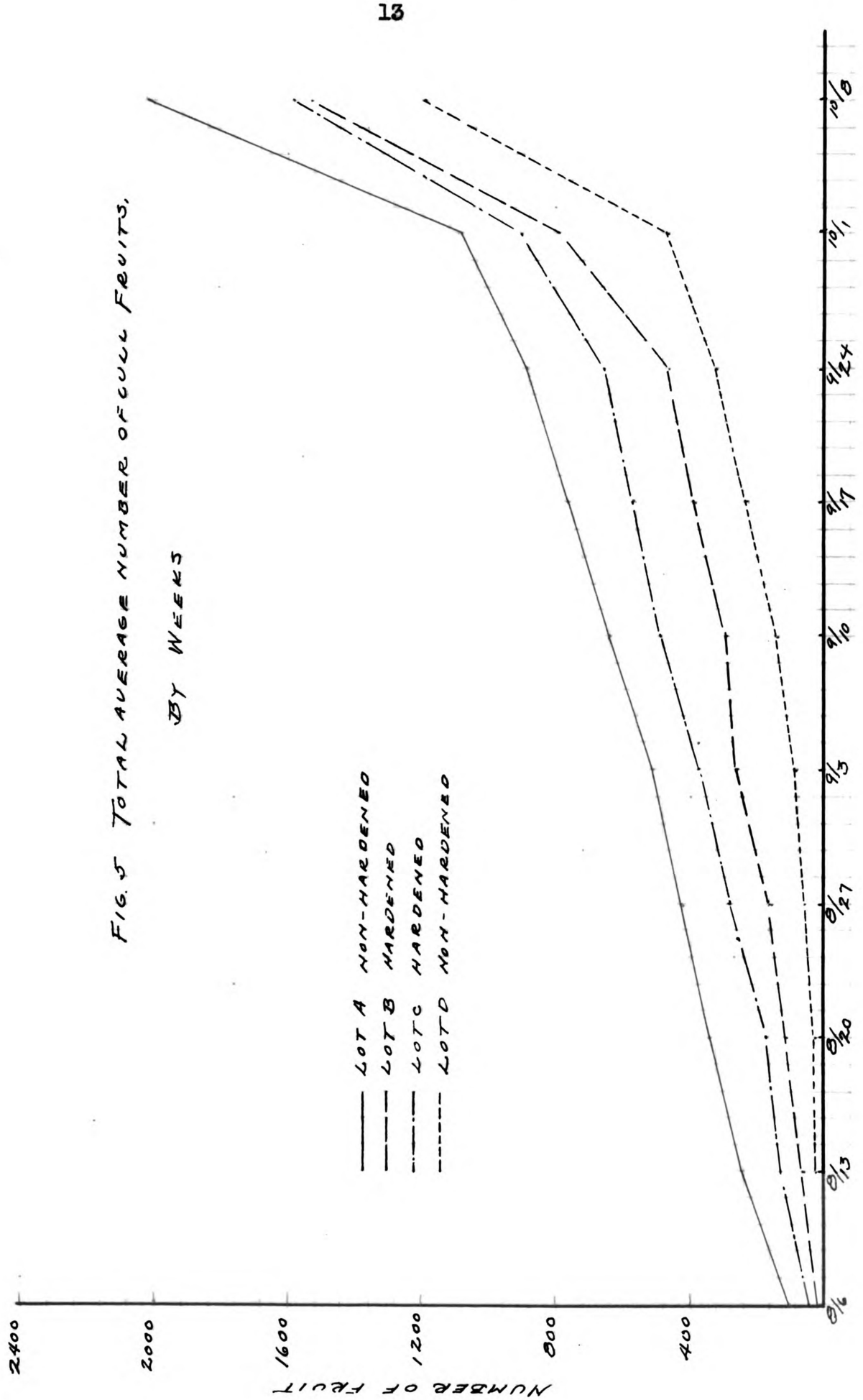


FIG. 5 TOTAL AVERAGE NUMBER OF CULL FRUITS, BY WEEKS

FIG. 6 TOTAL AVERAGE WEIGHT OF CULL FRUITS BY WEEKS

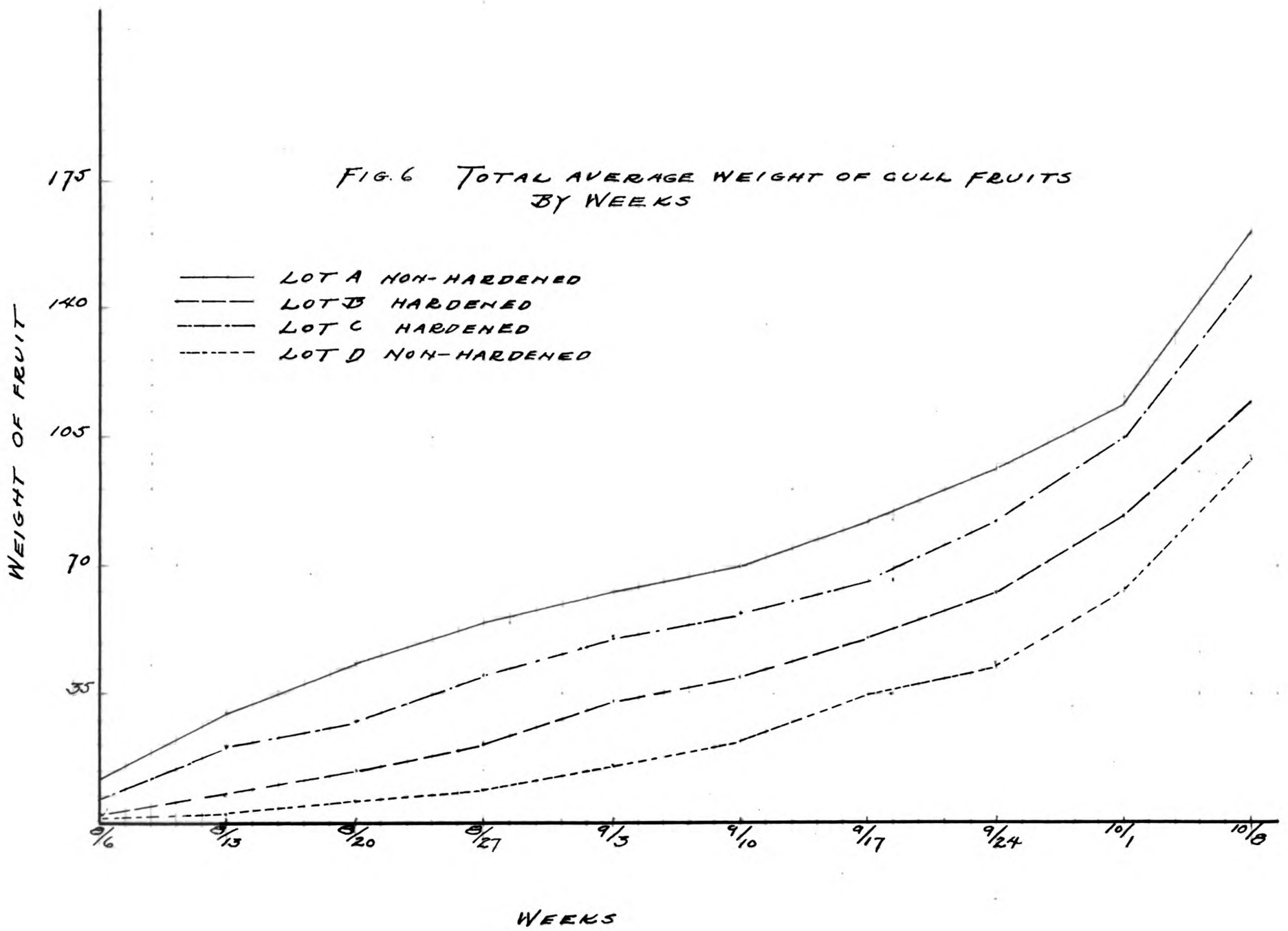
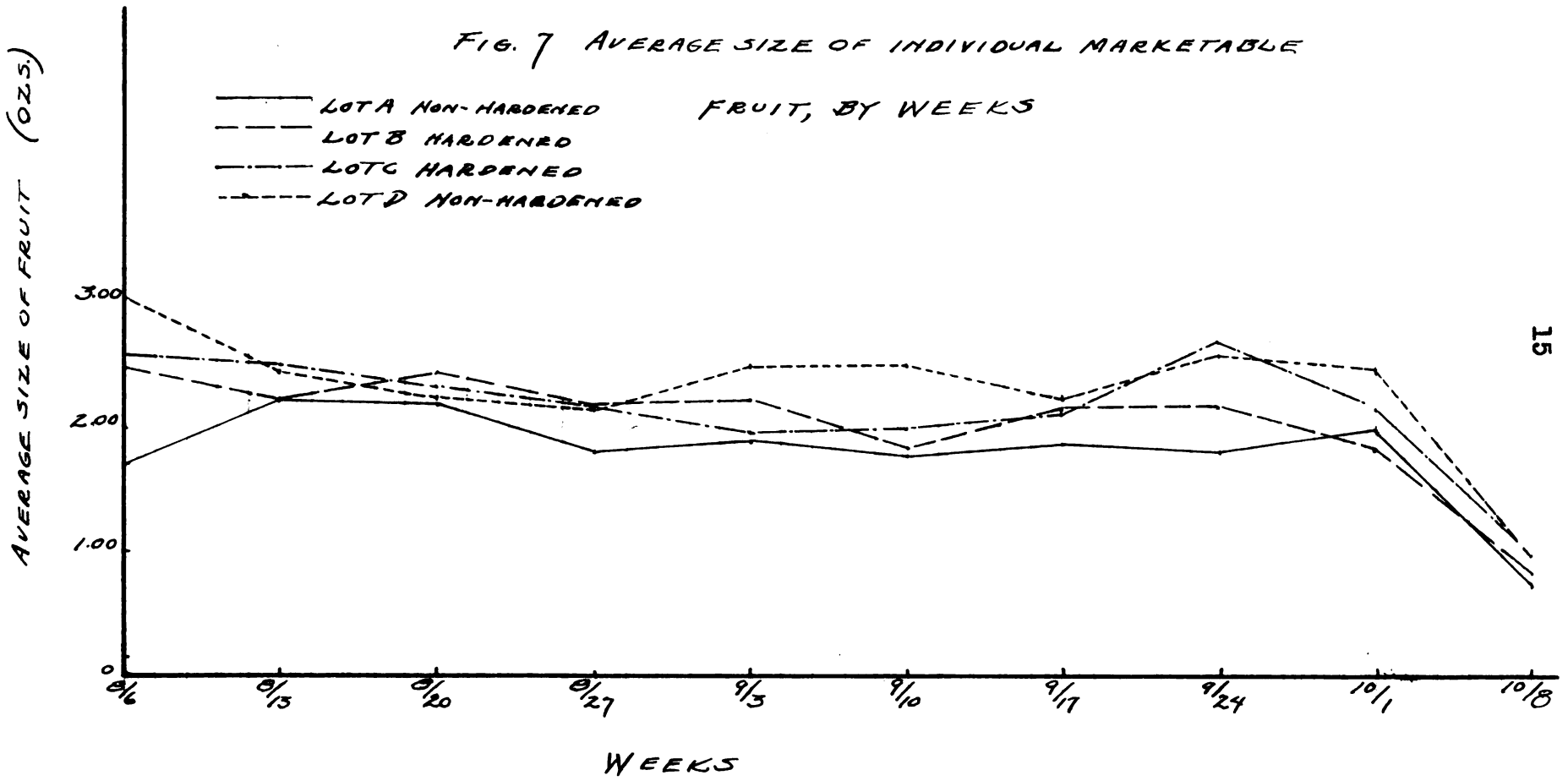


FIG. 7 AVERAGE SIZE OF INDIVIDUAL MARKETABLE FRUIT, BY WEEKS



Figures 2 and 3 show, as regards both number and weight of marketable fruits, that the yields of the plants under the four treatments took the vertical order - A (non-hardened), C (hardened), B (hardened, pricked off at 1.5 by 1.5 inches), and D (non-hardened) - at the first part of the season and remained thus without any change in the order, throughout the season.

The spread between the curves in figures 2 and 3, though slight in the beginning, tended to increase up to about mid-season (some earlier than this with Lots A and C) and then diminished gradually but not completely as the end of the season approached.

Figure 4, presenting average weight of individual marketable fruit, shows that the vertical order of the graphs, especially A and D, is reversed as compared with figures 2 and 3; hence, larger size accompanied the lower numbers of fruits.

Figures 5, 6 and 7, which present graphs of the cull fruits, show the same features as figures 2, 3 and 4, except that in graphs 5 and 6 the spread between the curves of the various lots, instead of diminishing gradually increases to the end of the season.

Besides the data already shown regarding absolute numbers and weights of marketable and of cull fruits, it is interesting to examine the relative production of these two classes of fruits week by week. This is presented in Figs. 8 and 9, which show essentially

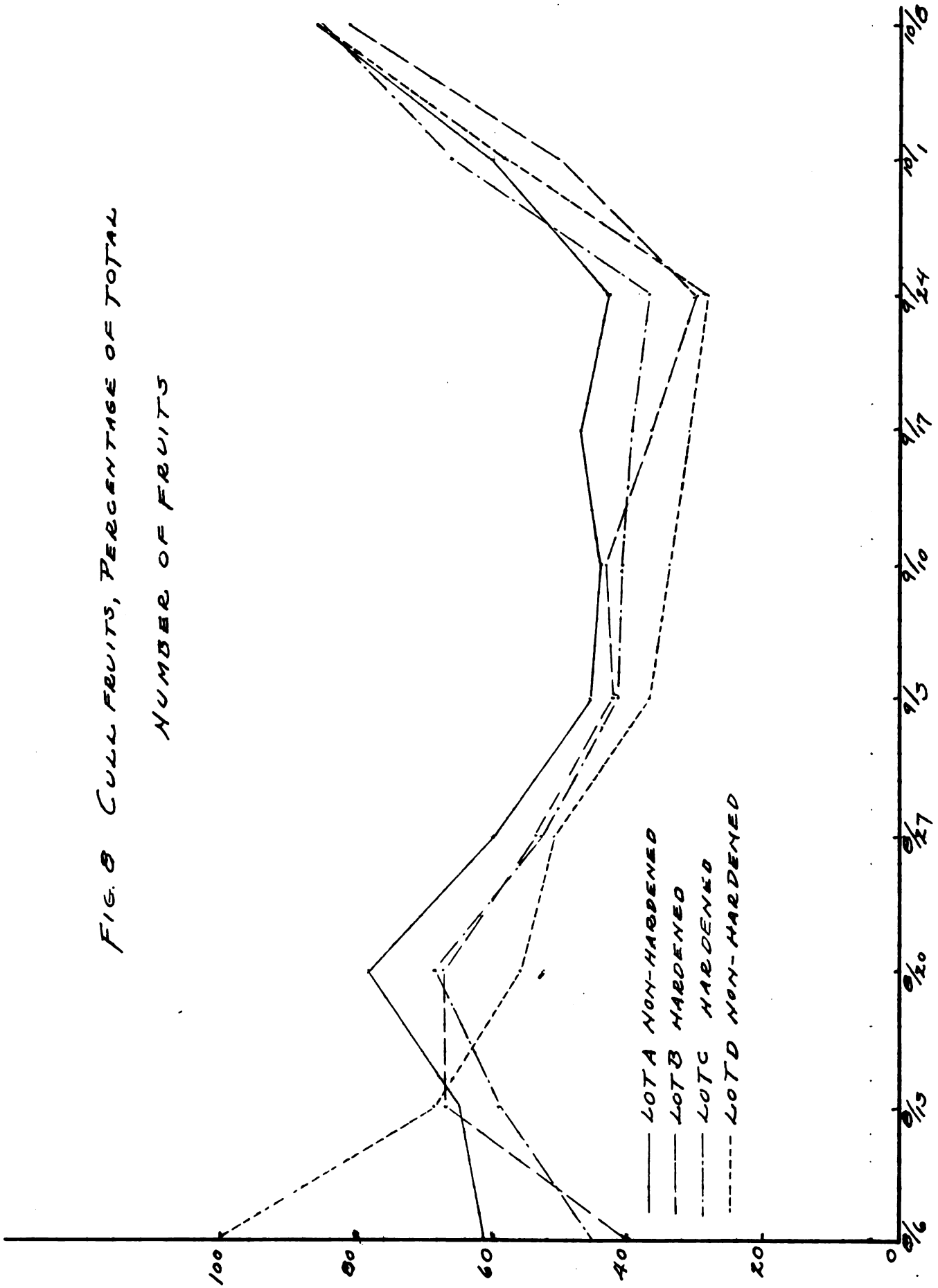
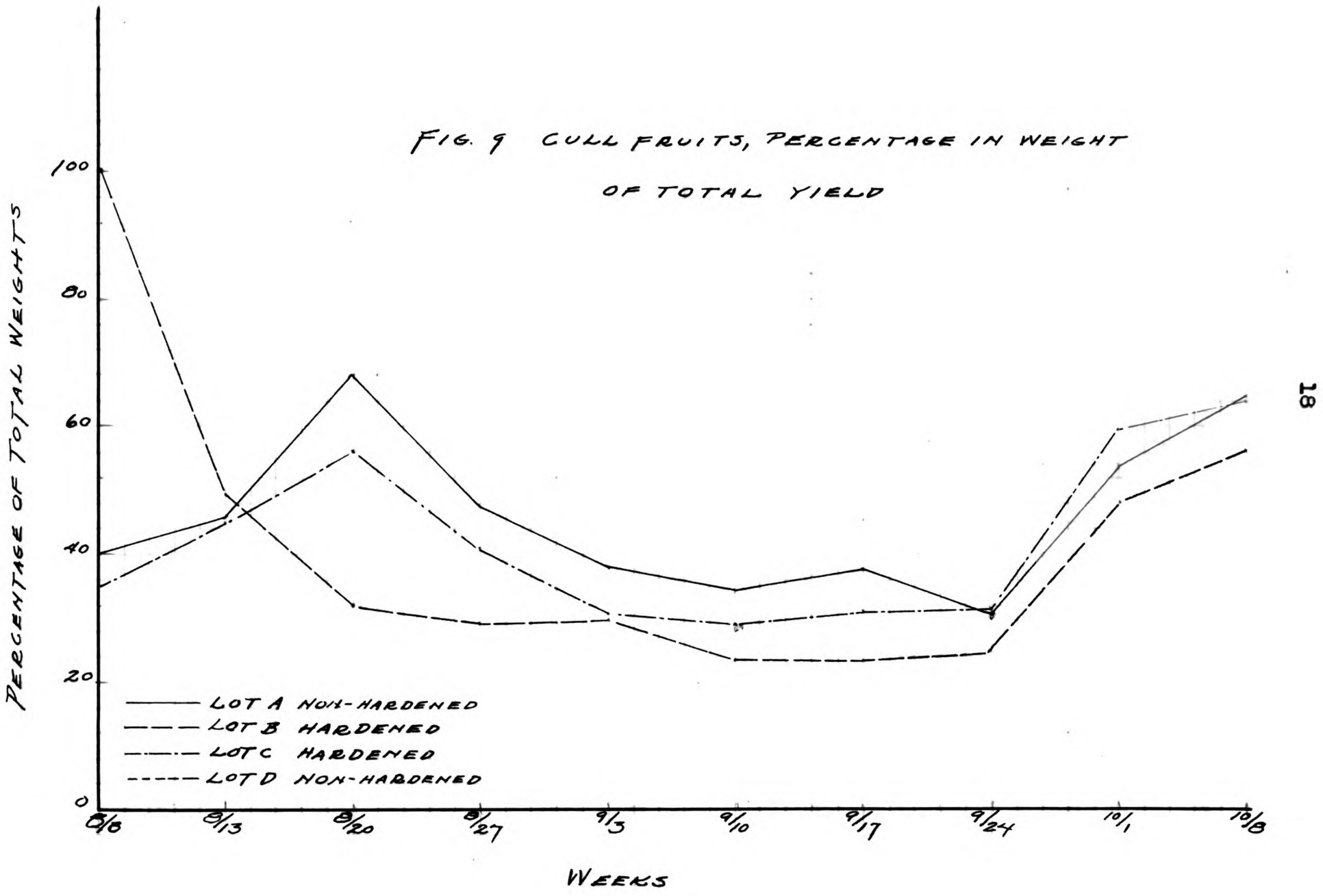


FIG. 8 CULL FRUITS, PERCENTAGE OF TOTAL NUMBER OF FRUITS
PERCENTAGE OF TOTAL NUMBER OF FRUITS
100
80
60
40
20
0
8/6
8/13
8/20
8/27
9/3
9/10
9/17
9/24
10/1
10/8
WEEKS
LOT A NON-HARDENED
LOT B HARDENED
LOT C HARDENED
LOT D NON-HARDENED

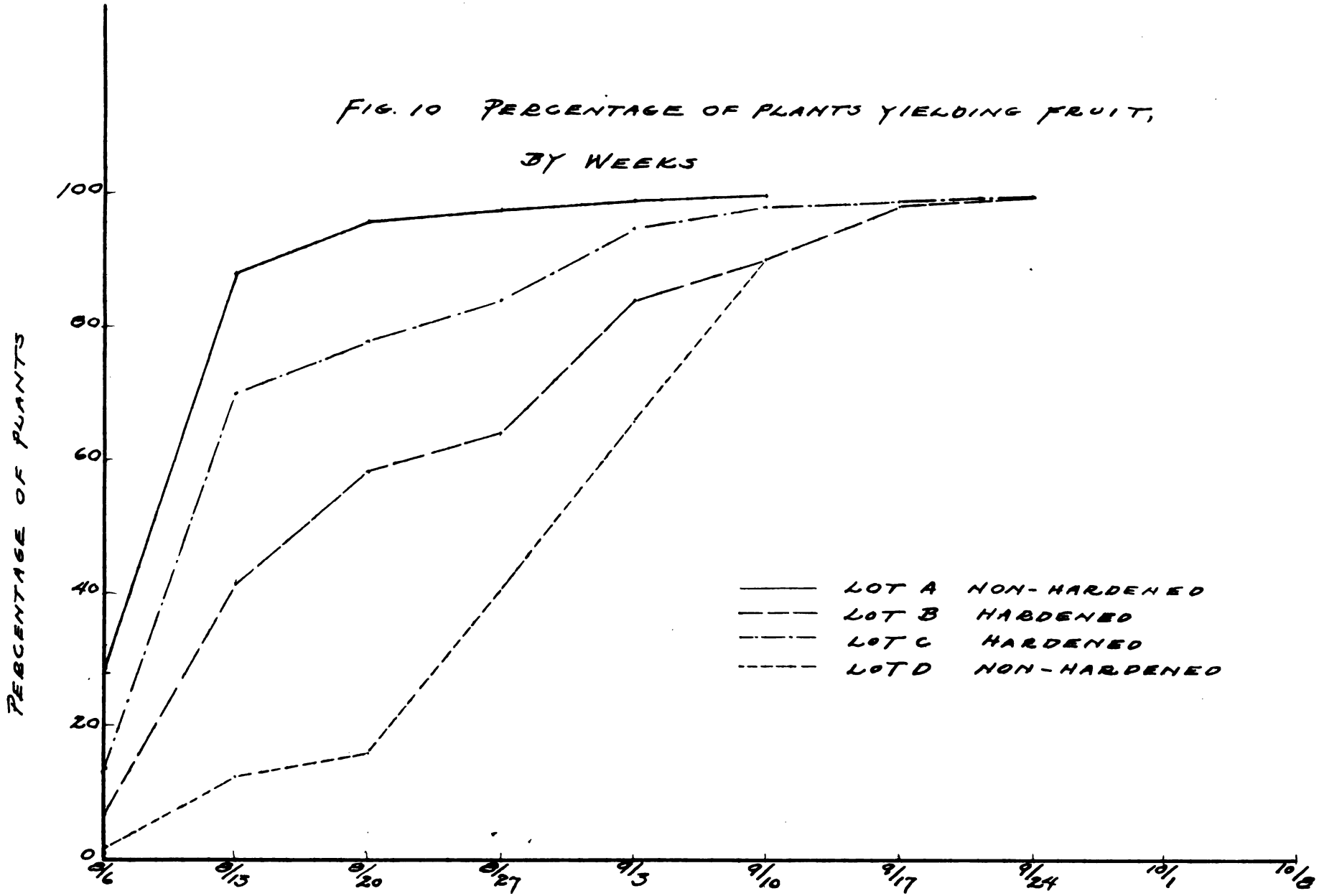
FIG. 9 CULL FRUITS, PERCENTAGE IN WEIGHT OF TOTAL YIELD



the same vertical order as figures 5 and 6; that is, through the major part of the season, the plants of Lot A yielded relatively the most cull fruits, Lot D the least, and Lots B and C were intermediate. At the beginning of the season for a brief period Lot D exceeded all the others, while at the last of the season the four lots showed no significant differences.

Data gathered with respect to the rate at which the plants of the four lots came into production of ripe fruits are presented graphically in Fig. 10. This shows that on the sixth of August 28 percent of the plants of Lot A, 7 percent of Lot B, 14 percent of Lot C, and 10 percent of Lot D were yielding ripe fruits. The spread among them continued to August 20, when 96 percent of the plants of Lot A were bearing ripe fruit as against 58, 78 and 17 percent respectively for Lots B, C, and D. The maximum was reached with Lot A two to four weeks earlier than with the other lots.

FIG. 10 PERCENTAGE OF PLANTS YIELDING FRUIT, BY WEEKS



II. Influence of Hardening on Subsequent Vegetative Growth.

Tomato plants, having been placed in the field, undergo further development. The basis of the future development of the plant which has been hardened is of the nature of a hardened plant, as contrasted with a non-hardened original plant where hardening has not been done. It is important to examine the after effect of this difference in terms of subsequent vegetative growth.

Seventeen plants in each plot were selected for study. Four lateral branches on each plant were tagged and their increase in length measured at intervals of time. The results are presented graphically in Fig. 11.

This figure shows that the plants of Lot D (late sowing and non-hardened) made the greatest gain in terminal growth of branches, Lot A the least, and Lots B and C responded intermediately. In comparison with Figs. 2, 3, 5 and 6, which present the total yield of fruits, the order is plainly the reverse of the response of the plants in yield.

The same condition held relative to increase in diameter of the main stem. Seventeen plants in each plot were labelled and their diameters measured at (a) near surface of soil (b) six inches above the soil surface before the beginning and at the close of the harvest season. The data are presented in Table 3.

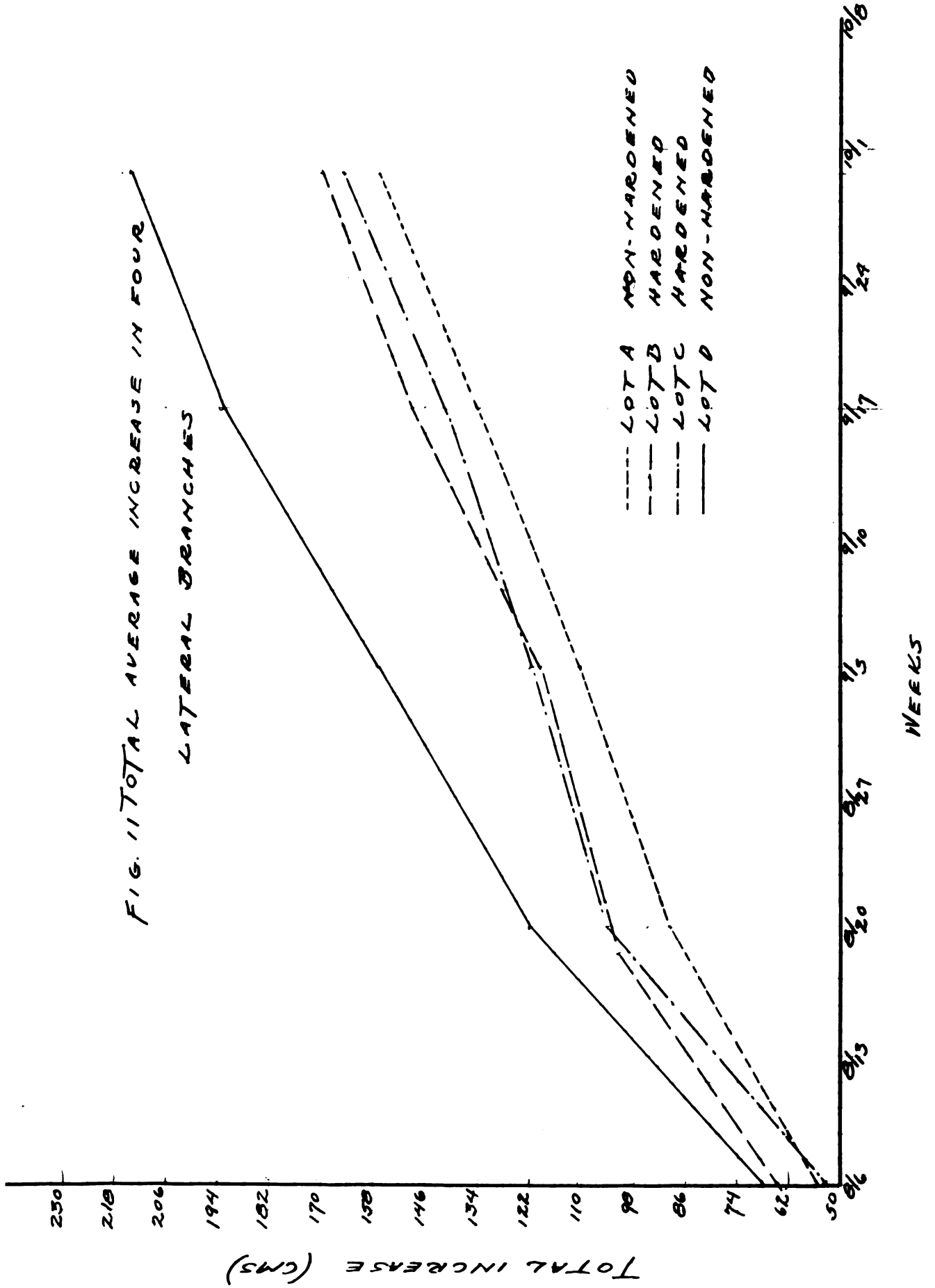


FIG. 11 TOTAL AVERAGE INCREASE IN FOUR LATERAL BRANCHES
TOTAL INCREASE (CMS)
WEEKS
LOT A NON-HARDENED
LOT B HARDENED
LOT C HARDENED
LOT D NON-HARDENED
250
218
206
194
182
170
158
146
134
122
110
98
86
74
62
50
8/6
8/13
8/20
8/27
9/5
9/10
9/17
9/24
10/1
10/8

Table 3. Increase in diameter of main stem, in centimeters.

Lot	Before harvest season		After harvest season		Total increase		Average increase
	Surface	6"above	Surface	6"above	Surface	6"above	
A	1.3	0.97	1.8	1.27	0.50	0.30	0.40
B	1.12	0.80	1.74	1.16	0.62	0.36	0.49
C	1.27	0.85	1.79	1.16	0.52	0.31	0.42
D	1.10	0.81	1.79	1.19	0.68	0.38	0.53

III. Influence of Hardening on Resistance to Adverse Environmental Conditions.

The season of 1930 at East Lansing, Michigan, was notably dry and hot. Actual precipitation and air temperature in comparison with normal are shown in Figs. 12 and 13. Only once during the period from May 24 to October 8 did precipitation reach or exceed the normal. The daily mean temperature ranged below and above the normal about the same over the period from May 24 to July 10, and mostly above the normal over the period from July 10 until late in September. The temperature was rather low at times during the former period and cool winds were strong and very frequent, while during the later period hot drying winds were unusually strong and frequent.

It was, however, in many respects a very favorable season for a study of the sort reported in this paper. Any greater permanent resistance that hardening might be supposed to confer upon tomato plants did not appear in this experiment. Data already presented failed to show any superiority of hardened over non-hardened plants. Lot A (non-hardened) constantly maintained superiority over Lots B and C, practically to the season's end.

Lot D (non-hardened) was lowest in yields but highest in vegetative growth and, due to the peculiarity of its early treatment, really belongs in a special category.

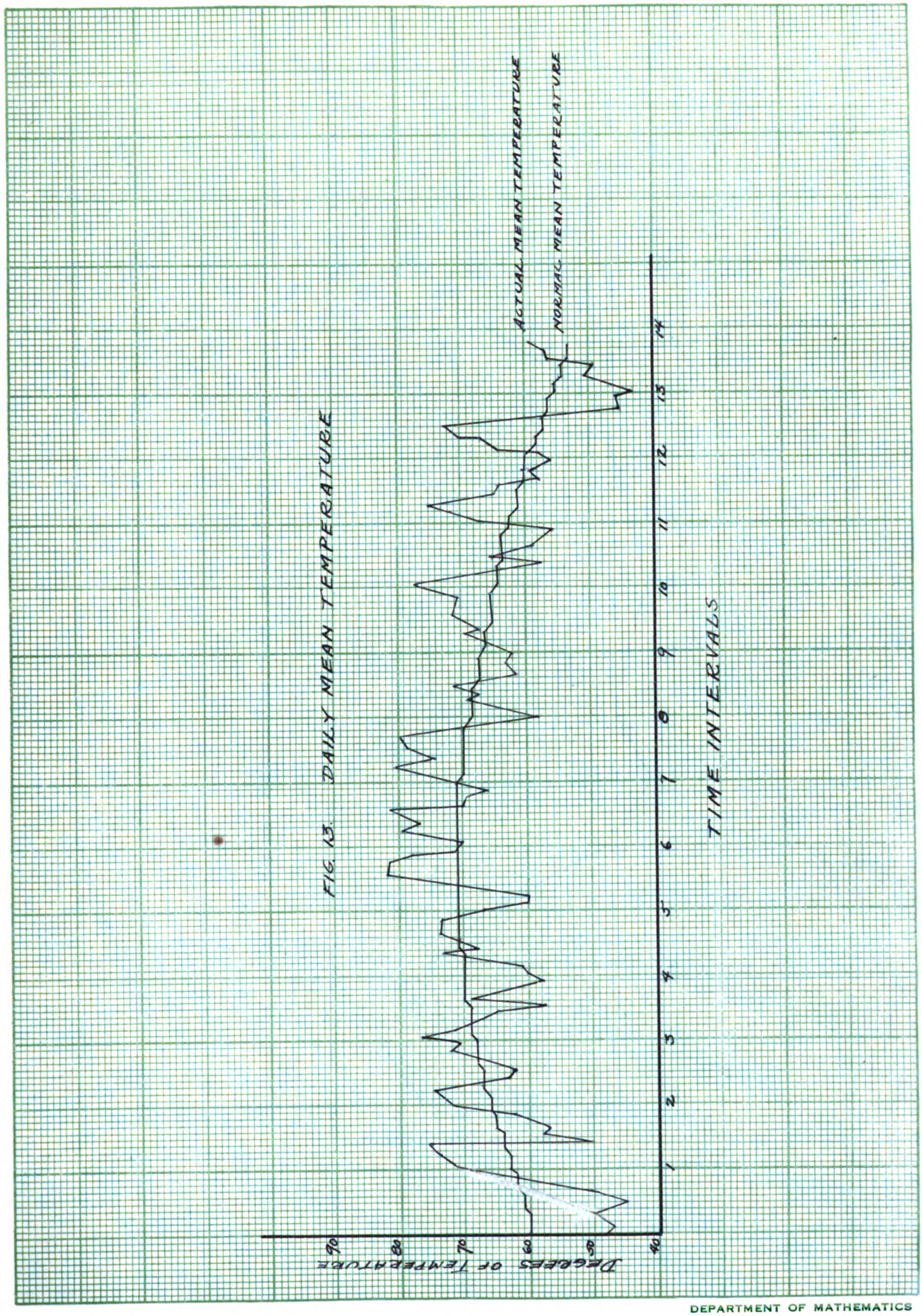


FIG. 13. DAILY MEAN TEMPERATURE

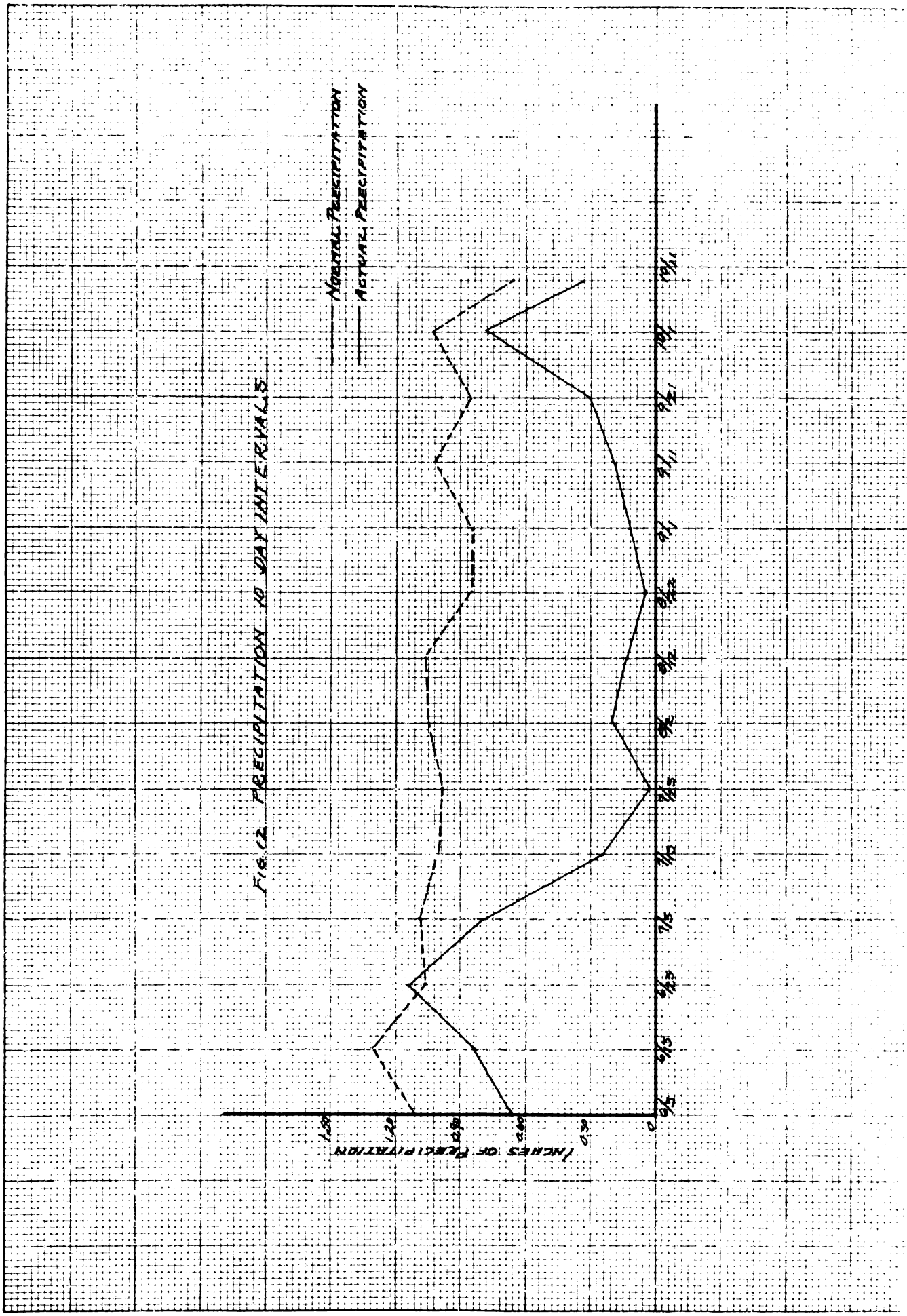


FIG. 12. PRECIPITATION 10 DAY INTERVALS

Not only was Lot A (non-hardened) superior to Lots B and C in yields but it was also superior in resistance to adverse environmental conditions immediately after transplantation in the field. Only 6.5 percent of the plants of Lot A died and were replanted, while for Lots B and C the percentages were 18.0 and 10.6 respectively.

IV. Money Returns from Hardened and Non-hardened Plants.

Having observed differences in the hardened and non-hardened plants as regards growth and yields, it is also important to determine the actual money value of the crop, since from the practical side this is the final criterion for the advisability of hardening tomato plants for growth in the field. The gross returns from the fruit produced in the experiment were calculated and are shown in Table 4. In the computations, the average price for five years in the market at Lansing, Michigan, on the dates shown, was used and the sums lifted to the basis of yields per acre.

Table 4. Gross money returns from marketable fruits. (Dollars per acre)

Date	Lots			
	A	B	C	D
August 6	37.87	2.06	18.06	0
" 13	108.36	7.00	79.52	7.83
" 20	43.32	28.94	48.47	16.36
" 27	27.60	44.32	38.64	28.84
September 3	62.72	73.92	75.04	46.76
" 10	32.64	36.45	35.36	50.86
" 17	38.27	46.59	17.64	66.56
" 24	59.28	74.26	50.17	62.87
October 1	20.59	25.48	19.93	19.80
" 8	34.76	31.86	28.39	29.72
Total	465.41	370.88	411.22	329.60

Table 4 shows that Lot A exceeded all others in money returns. It is interesting to note that the superiority of Lot A is more pronounced during the early part of the season when the prices were higher and at no time during the season did Lot A cease to give greater returns. After August 27, with prices lower, the other lots, especially B and D, gained upon A in yields, but did not overtake it.

Clear recognition should be accorded to the fact that this study concerns the problem of the market gardener and not the problem of the grower for the cannery, which may be quite different. Indeed, the data accumulated in this study show that the total yields for the period August 28 to September 17, assumed arbitrarily as the tomato packing season, were, respectively, as follows: Lot B, 137 lbs.; Lot D, 101 lbs.; Lot C, 92 lbs.; Lot A, 90 lbs. In marketable fruit the yields were: Lot D, 75 lbs.; Lot B, 67 lbs.; Lot C, 62 lbs.; Lot A, 57 lbs. In other words, Lot A had passed its peak production before the canning season opened, and the grower whose sole practicable outlet is the cannery might easily lose by following the procedure most profitable for the market gardener. This study does not, however, concern the canning tomato; with this, the profitable procedure might be that followed with Lot B or that followed with

Lot A, but planting done two weeks later. This is a matter for separate study.

Discussion

The data that have been presented serve to reveal the general fact that the tomato plant is very sensitive to conditions under which it is started and made to exist prior to being set out into the field. These conditions appear to exercise an influence, which amounts to a sort of physiological predetermination, that persists to the end of the plant's cycle of development. In this experiment, the plants of Lot A were not hardened; those of Lot C were hardened by low temperatures; those of Lot B were hardened by low temperatures but were pricked off at 1.5 inches, whereas those of Lot C were pricked off at 3 inches and were less crowded as they grew; those of Lot D were not hardened, but were started 33 days later than the plants of the other three lots, and hence, were not identical with the others from the standpoint of age at the time of transplantation. In accordance with these conditions of early treatment, the order of the lots of plants from the greatest to the least in yield, rate of coming into bearing of mature fruits, resistance to adverse field environmental conditions, and money returns was Lot A - Lot C - Lot B - Lot D. This order was reversed as regards vegetative growth and average size of individual fruits, as might have been expected on the basis of available evidence for negative correlation between yield of fruits and vegetative growth and between number of fruits and

size of fruits.

Lot D, because of the difference in the age of the plants, may be eliminated from strict comparison with respect to the effects of hardening. Though the plants of this lot were not hardened, they failed to develop the superiority shown by Lot A (non-hardened) over the hardened lots. Their behavior may justify a suggestion that tomato plants, to be grown in the field, even if they are not to be hardened, should be started earlier and allowed to attain greater development than these had before being set out. Furthermore, since in Crist's experiments (2) non-hardened plants which were as much as 75 days younger when grown in greenhouse beds and trained to a single stem, it may be conjectured that herein lies a distinction between the effects of indoor and outdoor conditions.

As regards Lots A (non-hardened) and Lots B and C (both hardened), all of equal age when transplanted, and those of A considerably larger than the others, detrimental effect of hardening is made evident beyond any doubt. This effect caused a lag in earliness of bearing, and a relative decrease in production of fruit that persisted through the major part of the season. Consequently, it reduced the money returns considerably because the hardened plants were backward in yields early in the season when the market price for tomatoes was at its highest peak for the season, and, even later in the season, did not overtake the non-hardened plants in yields.

Summary

Field plot tests of tomato plants of the Bonny Best variety, previously hardened in cold frames and also not hardened, gave the following results for the season 1930:

1. Hardened plants were exceeded by non-hardened (same age as hardened) in total yield of fruit (both marketable and cull) during the early part of the season; this superiority persisted through the major part of the season. Consequently the money returns for fruit of the non-hardened plants were considerably greater.
2. Hardening the tomato plant failed to increase its resistance to transplantation and later adverse environmental conditions over non-hardened plants.
3. The vegetative growth and average size of individual fruits of both types (non-hardened and hardened) were more or less reverse in relationship to the amount of fruit production.
4. Non-hardened plants which were started later (33 days) than the other lots (both hardened and non-hardened) exceeded these in vegetative growth but were lowest in yield.
5. The conditions under which tomato plants are started prior to transplantation to the field are of importance since they appear to establish an influence which persists during the remainder of the cycle of development.

Acknowledgments

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