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RESIDUAL EFFECTS OF FORCING AND HARDENING OF TOMATO, CABBAGE, AND
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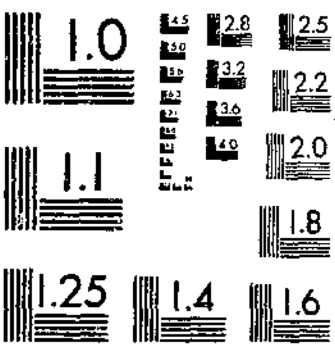

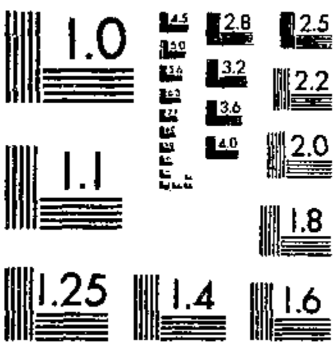

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Residual Effects of Forcing and Hardening of Tomato, Cabbage, and Cauliflower Plants[1,2]

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INTRODUCTION

Textbooks and other horticultural literature dealing with the culture of vegetables make frequent reference to the "hardening" of seedling plants prior to removing them from hotbeds or greenhouses to the more unfavorable conditions of the field. This hardening process is designed to make the plants better able to resist desiccation from hot, drying winds and the direct rays of the sun, less subject to injury from wind-whipping, and more frost-resistant.

Hardening may be accomplished by almost any treatment that will check the growth of the plants. However, it is usually accomplished by gradually subjecting the seedlings to lower temperatures or by watering them sparingly for a period of from 7 to 10 days before they are set into the field. Frequently a combination of these two methods is employed. Other treatments, such as root pruning, frequent transplanting from smaller to larger pots, or watering with N/10 sodium chloride or N/10 sodium bicarbonate solutions have been

[1] Submitted for publication June 18, 1940.

[2] Also submitted as a thesis under the title "Residual Effects of Forcing and Hardening on the Morphology and Physiology of Vegetable Plants" to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of doctor of philosophy. February 1939.

tried but have not met with general acceptance, probably because of the difficulty of standardizing methods of procedure.

The benefits generally expected from hardening are a quicker resumption of growth following transplanting, earlier maturity, and greater yields. To these should be added the saving of the plants from total destruction by one or more of the extremely adverse conditions to which they may be subjected under field conditions.

Plants that have not been hardened are usually designated as "tender." They are more succulent, or less resistant to wind-whipping and desiccation, and have no resistance to frost except what is inherent in the particular species of plant in question.

Having observed many instances where plants that would be classified as tender made greater early growth and reached maturity earlier than hardened plants, the writer conducted preliminary tests in 1931 and 1932 to determine the relative merits of the two types of plants. These tests indicated that the tender plants were equal to, if not better than, the hardened ones. Consequently in 1933, 1934, and 1935 the studies herein reported were conducted at the Cheyenne Horticultural Field Station to establish the most satisfactory method of handling seedling vegetable plants.

These studies have shown that seedlings grown in the greenhouse under optimal conditions of temperature, moisture, and nutrition until they were set in the field were not inferior to hardened plants in their ability to withstand field conditions. For this reason the writer has felt that the term "tender" was not appropriate for the nonhardened plants and has used the term "forced" instead.

LITERATURE REVIEW

Numerous investigations have been conducted in the past to determine the effects of the hardening process on plants. However, with the exception of the investigations of Crist (*4*),[3] Porter (*14*), and Brasher and Westover (*3*), these studies have dealt with the effects induced by the particular treatments given upon the physical characteristics or the chemical composition of the plants or both.

Such studies have contributed much to the knowledge concerning the nature of the response of plants to low temperatures by pointing out several possible methods by which plants can adapt themselves to adverse temperature conditions. Thus Harvey (*7*) has suggested than an increase in the amino-acid content in hardened plants may have been the result of the breaking down of proteins to forms less easily precipitated by the increase in hydrogen-ion and salt concentrations usually accompanying hardening. He also found that plants with the most bloom on their leaves were the most resistant to the formation of ice within their tissues.

Contributing further to knowledge of the nature of the changes effected in plants by hardening, Rosa (*17*) determined that this process was accompanied by a slowing up of the growth rate, an increase in the waxy covering on the leaves, an increase in the percentage of dry matter, a decreased transpiration rate per unit of leaf area, an increased percentage of reducing and total sugars, a decrease in starch, and other changes of a physical or chemical nature

[3] Italic numbers in parentheses refer to Literature Cited, p. 33.

any or all of which may have contributed to the increased resistance of the plants to low temperatures.

As a result of these and other similar studies dealing with the effects of hardening on seedling plants, it has been established that plants may be rather definitely divided into two groups with respect to their potential hardiness. Thus, of the vegetable crops that are commonly grown for a time before field setting in heated plant-growing structures, tomatoes, peppers, and eggplants represent the potentially nonhardy type, or that which acquires but little added resistance to adverse conditions through hardening. Cabbage, cauliflower, and celery, on the other hand, represent the potentially hardy type, or that which acquires considerable resistance to adverse conditions through hardening.

However, the investigations of Starring (*19*), Thompson (*20*), and Platenius (*13*) have shown that exposure to low temperatures, 40° to 50° F., for any considerable period of time is one if not the chief cause of premature seedstalk development in celery.

Boswell (*2*), in his investigation of the causes for premature flower formation in overwintered cabbage, found that exposure to low temperatures was essential and that the effect increased with increasing time of exposure. Miller (*11*) confirmed the findings of Boswell as to the effect of low temperatures on seedstalk formation in cabbage, and both of them stress the fact that the effect of the low-temperature treatment was more pronounced on the older, larger seedlings.

Edmond and Lewis (*5*) state that no bad effects may be expected from extreme hardening of cabbage plants incident to delaying transplanting until weather conditions are favorable, or for the purpose of making them more resistant to frost and drought. However, it appears that all of their plants were subjected to the same temperature, and that the only variable measured was the effect of withholding nutrients during the seedling stage as contrasted with single and double applications of nutrients.

Insofar as is known a relationship between low temperatures and the bolting of cauliflower has not been established experimentally, but this tendency has been reported as common by growers from widely distant sections of the country (Jones and Ernst (*8*), Judson (*9*), and others). That premature heading of cauliflower may be induced by limiting the nitrogenous salts in the nutrient solution supplied to seedlings has been established by Robbins, Nightingale, and Schermerhorn (*16*), and it is of interest to note that they found a relatively high percentage of carbohydrates and a low percentage of assimilated nitrogen in the plants that headed prematurely, as compared with the percentages found in the vigorously vegetative plants.

In a comparison of forced and hardened tomato plants Crist (*4*) found that early yield of marketable fruits from the hardened plants and their total yields were not materially increased over those from the tender plants. As an explanation of this he states:

> 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.

He adds that:

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

This comparison between tender and hardened plants was made by subsequently forcing both types in a greenhouse

In a similar investigation, in which he compared performance in the field of forced and hardened plants, Porter (*14*) arrived at the conclusion that hardening tomato plants reduced early yields of marketable fruits and that this reduction resulted regardless of variety or of when the plants were set into the field. In agreement with Crist, he found that hardening the plants increased total yields but not enough to increase the profits over those from tender plants.

The findings of Brasher and Westover (*3*) are in complete agreement with those of Crist (*4*) and Porter (*14*) as evidenced by their conclusion that even a moderate hardening of tomato seedlings produced a stunting effect, did not make them better able to survive under early spring conditions, and resulted in lower early yields of fruit of lighter weight.

EXPERIMENTAL METHODS

In 1933, 1,440 tomato plants, of the Bonny Best and Penn State Earliana varieties, and 3,000 cabbage plants, of the Golden Acre and Early Jersey Wakefield varieties, were used in the field plot tests. In 1934, 750 plants of Bonny Best tomato and 1,500 plants of the Danish Giant (Dry Weather) cauliflower were used, and in 1935, 3,000 Danish Giant cauliflower plants were set in the field. The change from cabbage to cauliflower as a test crop was made in 1934, because cauliflower has a more definite period of maturity than cabbage, consequently, it is better adapted for a study in which earliness of maturity is an important factor.

All plants were started in the greenhouse. The tomatoes were seeded about March 15 and the cabbage and cauliflower about March 27 each year. With the appearance of the first true leaves the seedlings were transplanted into flats in which they were grown until set in the field. The tomatoes were spaced 4 by 4 inches apart, and the cabbage and cauliflower plants 3 by 3 inches apart in the flats. Normal greenhouse culture was given to all plants until about May 6, at which time one-half of the plants were moved into the coldframes for hardening.

In the first year's study the forced plants were given applications of either nitrogen, or phosphorus, or potassium, or a complete nutrient solution on the assumption that their use would promote better plant growth. The hardened plants were not fertilized.

In 1934 the plan of the work remained the same, except that both the forced and hardened series were subdivided into groups, each of which received a particular nutrient solution. A check or unfertilized group was also added in both the forced and hardened series. This arrangement made possible a study of the differential response of the forced and hardened plants to fertilizers.

In 1935 a further subdivision was made of the nutrient-treated plants whereby one lot received nutrients only during the seedling stage, a second lot during both the seedling stage and after they were set in the field, and a third lot was given nutrients only after the plants were set in the field. Figure 1 shows in diagrammatic form the nature of the forcing and hardening treatments employed each year.

Nutrient solutions used for this work were made by dissolving or leaching commercial fertilizers. The use of pure salts would have facilitated standardizing the solutions but would not have added to the accuracy of the work, because the plants were grown in prairie topsoil to simulate, insofar as possible, the usual method used in growing seedling plants.

The nitrate solution was made by dissolving 2.4948 kg. of nitrate of soda in 40 liters of water, whereas for the solution carrying potash, 1.7282 kg. of muriate of potash was used. The phosphate solution was made by leaching 8.2962 kg. of superphosphate in 40 liters of water for a period of 3 days. The solution was frequently stirred by an electrically driven stirring apparatus to hasten the leaching process.

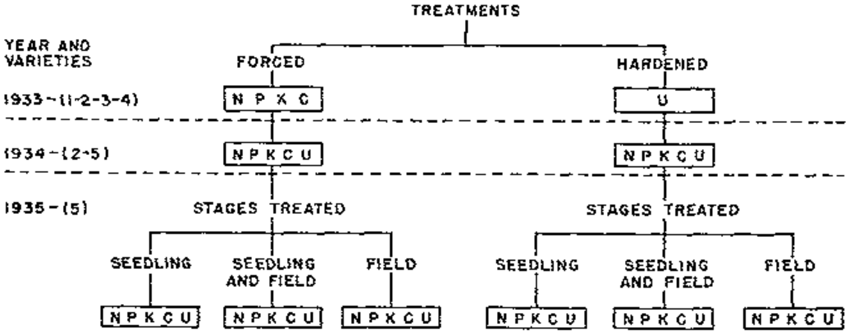

FIGURE 1.—Chart showing nature of forcing and hardening treatments employed. Crops and varieties: 1=Penn State Earliana tomato; 2=Bonny Best tomato; 3=Jersey Wakefield cabbage; 4=Golden Acre cabbage; 5=Danish Giant (Dry Weather) cauliflower. Fertilizers: N=nitrogen; P=phosphorus; K=potassium; c=complete nutrient solution; u=no fertilizer.

The complete nutrient solution was made by mixing equal parts of the three single-element solutions. All stock solutions were diluted with water 1 to 10 before they were applied to the plants. Determinations made by the freezing-point-depression method showed that the osmotic pressures of these solutions averaged about 2.0 atmospheres. This is a somewhat higher concentration than is generally employed, but as the solutions were applied to flats in which the soil was kept moist by daily watering, the actual concentration available to the plants was much less than indicated by the determinations. The nutrient solutions were applied to the plants at intervals of approximately 2 weeks, whether during the seedling stage or after the plants were set into the field.

The number of replications of each treatment group varied from year to year. In 1933 there were six, in 1934 there were three, and in 1935 there were two plots of each subtreatment group. All plots were thoroughly randomized in the field, except in 1933, when two varieties of each crop were used, and the contrasted varieties receiving like treatments were paired. In all 3 years the crops were grown under irrigation.

Data recorded for the tomatoes included the number and weight of the vine-ripened fruits by harvest dates, and at the close of the season the plants were pulled and the number and weight of the green fruits were determined. Root growth studies were also made on the tomato seedlings in 1933 and 1934.

For the cabbage and cauliflower, data were taken at each harvest date on the number of heads and the weight, diameter, and depth of each head. Studies of the rate of transpiration and regeneration were made on the cabbage in 1933, but these were not repeated on the cauliflower in 1934 or 1935.

In 1935 chemical analyses of forced and hardened plants were made a part of the study for the purpose of determining whether or not the chemical composition of the seedlings could be correlated with subsequent performance of the plants. For this purpose typical seedling plants were selected at random from the several treatment groups and preserved in alcohol until required for analysis. Nitrogen determinations were made by the official Kjeldahl method. Starch and hemicelluloses were determined by the recommended methods of the Association of Official Agricultural Chemists (*1*) and the sugars by the Lane-Eynon General Volumetric method as modified by Hildreth and Brown.[1] Separate analyses were made of the stems and leaves and of the roots. All data have been statistically analyzed by Fisher's Method for the Analysis of Variance (*6*). Values for F are taken from those compiled by Snedecor (*18*) from Fisher's tables for t and z.

Reference will frequently be made in this bulletin to the early harvests or to the early harvest period. This period is arbitrarily defined as extending from the date of the first harvest to September 1, inclusive. The date September 1 was chosen as representing the close of the early harvest period, because, for the crops concerned, varieties that do not mature a considerable portion of their ultimate crop before this date may be considered as late. Likewise, treatments that do not materially increase the yields before this date may be considered as of little value in increasing earliness. The data for the entire season include those for both the early and late harvest periods.

EXPERIMENTAL RESULTS

TOMATOES

Table 1 presents the results obtained from forcing and hardening treatments applied to the tomato varieties Penn State Earliana and Bonny Best in 1933 (fig. 2, *A*).

Examination of these data shows that there were no significant differences between the forced plants that were fertilized with phosphorus or potassium and the unfertilized, hardened plants in the number of ripe fruits produced during the early harvest period. Forcing the plants with a complete nutrient solution served to reduce the number of fruits as compared with the effects of phosphorus or potassium; and nitrogen when used alone reduced yields even below those from the unfertilized, hardened plants.

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[1] HILDRETH, A. C., and BROWN, G. B. To be published.

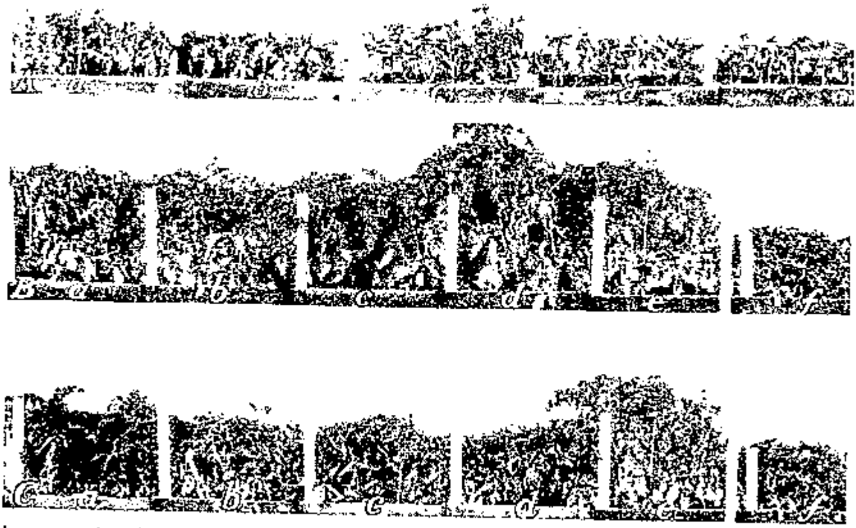

FIGURE 2.—Typical tomato seedlings photographed just prior to field setting. A, Plants grown in 1933 and fertilized with a, a complete nutrient solution; b, nitrogen; c, phosphorus; d, potassium; and e, the unfertilized, hardened plants. B, Forced plants grown in 1934 and fertilized with a, nitrogen; b, phosphorus; c, potassium; d, a complete nutrient solution; e, the unfertilized, forced plants; and f, the unfertilized, hardened plants. C, Hardened plants grown in 1934 and fertilized with a, nitrogen; b, phosphorus; c, potassium; d, a complete nutrient solution; e, the unfertilized, forced plants; and f, the unfertilized, hardened plants.

TABLE [illegible].—*[illegible]*

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hardened plants [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]			[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Standard error	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

In weight of the ripe fruit produced during the early harvest season, the forced plants fertilized with phosphorus or potassium and the unfertilized, hardened plants exceeded those fertilized with nitrogen or a complete nutrient solution. It thus appears that nitrogen served to reduce both the number and the weight of the ripe fruits produced during the early harvest period, but that its depressing effect was somewhat reduced by the addition of phosphorus and potassium in the complete nutrient treatment.

By the close of the harvest season the differences between the forced and hardened plants in number and weight of ripe fruits were not statistically significant, nor were those for total number or weight of both green and ripe fruits.

Bonny Best produced a greater number and weight of ripe fruits than did Penn State Earliana during the early harvest season and exceeded the latter in number produced for the entire season, though it did not exceed it in total weight of both green and ripe fruits. There were no significant differences between the varieties in total set of fruit.

In 1934 only one variety of tomato (Bonny Best) was used for study instead of the two varieties of the preceding year. In this year both the forced and hardened plants were fertilized, and provision was made for a check or unfertilized subseries in each treatment group (fig. 2, *B*, *C*). Table 2 shows the results obtained.

TABLE 2.—*Influence of forcing and hardening treatment upon the mean number and weight of ripe Bonny Best tomato fruits, and the total set of fruits per plot for the season, 1934*

Treatment	Mean number of ripe fruits		Mean weight of ripe fruits		Mean number of green and ripe fruits for entire season	Mean weight of green and ripe fruits for entire season
	Early harvests	Entire season	Early harvests	Entire season		
	Number	*Number*	*Ounces*	*Ounces*	*Number*	*Ounces*
Nitrogen	4.04	43.53	10.88	177.85	420.01	1,032.64
Phosphorus	4.26	41.27	9.09	147.48	379.79	857.87
Potassium	3.60	46.80	6.35	171.41	415.31	1,019.91
Complete nutrient solution	7.26	49.63	21.81	185.86	442.30	1,015.64
Unfertilized	6.69	54.79	14.53	205.67	439.42	1,048.15
Significant difference						
Observed *F*	(1)	(1)	(1)	(1)	(1)	(1)
Treatment:						
Forced	6.57	30.77	11.72	144.83	359.61	868.39
Hardened	3.76	54.63	13.34	210.47	449.15	1,121.30
Significant difference	2.17	7.37		30.54	51.57	136.78
Observed *F*	[2] 6.67	[3] 16.26	(1)	[3] 15.48	[2] 5.33	[3] 13.68
Standard error	2.98	10.09	10.05	41.81	70.61	137.30

[1] Not significant with respect to residual error if odds of 19 to 1 against the differences noted being due to chance are accepted as a criterion.

[2] Odds against the differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.

[3] Odds against the differences noted being due to chance are greater than 99 to 1.

Although in 1933 certain of the fertilizers markedly affected yields an examination of the data in table 2 shows that in 1934 none of them was effective in increasing yields over those of the unfertilized checks.

Regarding the effects of the forcing and hardening treatments, however, it may be seen that the forced plants produced a greater number of ripe fruits than the hardened ones during the early harvest period but not a greater weight of fruit. By the close of the harvest season, however, the retarding effect of the hardening treatment on earliness had disappeared, and the hardened plants are seen to have produced the greater number of ripe fruits.

There was no statistically significant difference in weight of ripe fruits produced by the forced and hardened plants during the early harvest period, though the forced plants produced the greater number; it is evident therefore that forcing increased earliness of maturity at the expense of fruit size. By the close of the harvest season, the hardened plants produced a greater total weight of ripe fruits and they also made a greater total set of fruits, as is evidenced by the total number and weight of green and ripe fruits produced.

CABBAGE

Supplementing the work with tomatoes in 1933, a study was made of the effects of the forcing and hardening treatments on two varieties of cabbage, Early Jersey Wakefield and Golden Acre, a strain of Copenhagen Market (fig. 3). Table 3 shows the results obtained.

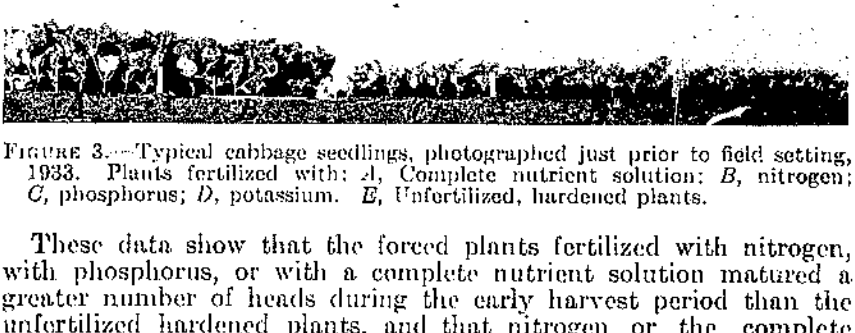

FIGURE 3.—Typical cabbage seedlings, photographed just prior to field setting, 1933. Plants fertilized with: *A*, Complete nutrient solution; *B*, nitrogen; *C*, phosphorus; *D*, potassium. *E*, Unfertilized, hardened plants.

These data show that the forced plants fertilized with nitrogen, with phosphorus, or with a complete nutrient solution matured a greater number of heads during the early harvest period than the unfertilized hardened plants, and that nitrogen or the complete nutrient solution, but not phosphorus, induced significantly greater earliness than potassium. There was no significant difference between phosphorus and potassium in their influence on earliness, and by the close of the growing season the differences between the effects of the other fertilizers and between them and the unfertilized hardened plants had become insignificant.

The plants forced with nitrogen or a complete nutrient solution produced a greater weight of heads during the early harvest period than those that had been forced with potassium or than the unfertilized hardened plants, but there were no significant differences between them for the entire harvest season.

The average weights, average lengths, and average diameters of the heads produced during the early harvest period were not differentially affected by fertilization or by the forcing and hardening treatments. However, toward the latter part of the growing season, though the characteristic of head length remained unchanged, the

TABLE 3.—*Influence of forcing and hardening treatments on yield and on certain morphological characters of 2 varieties of cabbage, 1933*

Treatment and variety	Mean number of heads		Mean yield per plot		Average weight per head		Average length of heads		Average diameter of heads		Density index for heads [1]	
	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season
Forced (fertilized):	*Number*	*Number*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*		
Nitrogen	29.08	49.00	81.42	134.52	2.75	2.74	14.68	14.55	15.18	15.07	5.12	5.06
Phosphorus	26.08	49.50	69.89	131.32	2.63	2.65	14.83	14.80	14.81	14.69	5.28	5.19
Potassium	23.25	49.58	61.70	126.15	2.50	2.54	14.48	14.58	14.68	14.52	5.42	5.30
Complete nutrient solution	28.17	49.17	74.66	124.50	2.56	2.53	14.30	14.34	14.93	14.63	5.32	5.24
Hardened (unfertilized)	22.08	49.25	58.64	124.19	2.61	2.52	14.87	14.68	14.89	14.37	5.34	5.32
Significant difference	3.46		12.19			0.16				0.40	0.19	
Observed *F*	[2] 6.15	(3)	[2] 4.68	(3)	(3)	[4] 2.71	(3)	(3)	(3)	[4] 3.30	[4] 2.72	(3)
Variety:												
Early Jersey Wakefield	12.33	49.10	33.09	127.03	2.57	2.58	15.53	15.57	14.78	14.46		
Golden Acre	30.13	49.50	105.04	129.24	2.65	2.61	13.73	13.61	15.01	14.85		
Significant difference	2.19		7.71				0.28	0.23		0.25		
Observed *F*	[2] 600.61	(3)	[2] 352.24	(3)	(3)	(3)	[2] 164.50	[2] 294.30	(3)	[2] 9.28		
Standard error	4.24	1.15	14.93	10.16	0.24	0.20	0.55	0.44	0.57	0.49	0.23	0.23

[1] Index numbers are inversely proportional to density.
[2] Odds against the differences noted being due to chance are greater than 99 to 1.
[3] Not significant with respect to residual error if odds of 19 to 1 against the differences noted being due to chance are accepted as a criterion.
[4] Odds against the differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.

average weight and average diameter of the heads from the plants forced with nitrogen were greater than were those from plants forced with potassium, or with a complete nutrient solution, or than those from the unfertilized, hardened plants.

The index numbers for density of heads presented in the last two columns of table 3 were computed by multiplying the lengths of the heads by their diameters and dividing the product by their weights. The index numbers so obtained are inversely proportional to the actual density or solidity of the heads.

The objective sought in using two varieties of cabbage in the study was to determine whether or not they would give similar responses to the forcing and hardening treatments. As none of the possible interactions between varieties and treatments was found to be significant, it may be assumed that they did give similar responses in all cases. However, several other characteristics of the two varieties were studied and comparisons between them are shown in the lower part of table 3.

. From these data it may be seen that the Golden Acre variety produced a greater number and total weight of heads during the early harvest season than did Early Jersey Wakefield and that there were no statistically significant differences between them in these respects at the close of the season. The difference noted between them in average length of head is merely an expression of the difference in their varietal characteristics and evidence that this was not measurably altered by any of the treatments given. There was no difference found between them in the average diameter of the heads for the early harvest season, but Golden Acre averaged somewhat larger for the entire season.

Cauliflower

To represent that type of plant which responds to hardening by acquiring added resistance to low temperatures, the variety of cauliflower commonly known as Danish Giant (Dry Weather) was substituted in 1934 (fig. 4) for the two cabbage varieties used in 1933. As

Figure 4.—Field view of cauliflower plots. Taken shortly after first tying of plants.

already stated, this change was made because the stage of maturity of cauliflower can be more definitely determined than that of cabbage, and therefore it is better adapted to a study in which earliness of maturity is an important factor. For this year, too, fertilizers were applied to both the forced and the hardened plants, and unfertilized checks were also provided for in each series. Table 4 shows the results obtained.

TABLE 4.—*Influence of forcing and hardening treatments on yield and on certain morphological characters of Danish Giant cauliflower, 1934*

Treatment	Mean number of heads		Mean yield per plot		Average weight per head		Average depth of heads		Average diameter of heads		Density index for heads[1]	
	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season
	Number	*Number*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*		
Nitrogen	25.67	35.83	351.50	488.00	13.69	13.59	7.82	7.52	11.57	11.22	3.35	3.75
Phosphorus	27.83	39.67	330.17	482.00	11.95	12.20	7.81	7.46	11.20	10.94	2.60	3.26
Potassium	28.17	37.67	375.33	499.50	13.29	13.19	8.09	7.74	11.76	11.34	2.78	3.26
Complete nutrient solution	27.00	36.83	324.50	441.50	12.01	11.96	7.56	7.33	11.14	10.83	2.92	3.32
Unfertilized	26.17	34.83	344.50	435.67	13.06	12.28	7.72	7.31	11.57	11.00	3.00	3.34
Significant difference												
Observed *F*	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Treatment:												
Forced	31.00	39.73	388.47	502.07	12.49	12.59	7.76	7.54	11.34	11.12	2.86	3.26
Hardened	22.93	34.20	301.93	436.60	13.11	12.69	7.83	7.40	11.55	11.01	2.99	3.51
Significant difference	2.89	2.75	57.27									
Observed *F*	[3] 31.21	[3] 16.18	[3] 9.13	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Standard error	3.95	3.77	78.42	94.71	1.66	1.76	.98	.34	.51	.58	.58	.49

[1] Index numbers are inversely proportional to density.
[2] Not significant with respect to residual error if odds of 19 to 1 against the differences noted being due to chance are accepted as a criterion.
[3] Odds against the differences noted being due to chance are greater than 99 to 1.

From the data in table 4 it is evident that there were no significant differences between the effects of different fertilizers nor between the effects of any one of them as compared with the unfertilized checks in their influence on the characteristics studied. Moreover, as the interaction between fertilizers and treatments was found to be nonsignificant, it may be assumed that the effect of the fertilizers was approximately the same on both the forced and hardened plants. Because this is so it is possible to study the effects of the forcing and hardening treatments on the plants independently of fertilizer effects. Such a comparison is made in the lower portion of table 4.

From these data it is evident that the forced plants produced 26.03 percent more heads during the early harvest period than did those that had been hardened, and 13.92 percent more for the entire season. The forced plants likewise produced a greater total weight of heads (22.28 percent) during the early harvest period than did those that had been hardened, but for the entire season no significant difference could be demonstrated between them in weight of heads produced. That the forced plants failed to produce a greater weight of heads than the hardened, though exceeding them in number, is due to the slightly though not significantly greater weight of the heads from the hardened plants during the latter part of the growing season. None of the other characteristics studied was measurably altered by the forcing or hardening treatments.

The work in 1935 was confined to a study of the effects of the forcing and hardening treatments on the Danish Giant (Dry Weather) variety of cauliflower. The design of the experiment remained essentially the same as in 1934, but in order to study the effects of applying fertilizers during various stages in the growth cycle of the plants, each of the fertilized subseries was divided into three groups. To one of these, nutrients were applied only during the seedling stage; to a second, nutrients were applied both while the plants were in the seedling stage and after they were set into the field; the third group was fertilized only after the plants were set into the field (fig. 5). By this design the unfertilized subseries served as appropriate checks for both fertilizers and for the various "stages." Their means, however, are shown in table 5 under fertilizers.

An examination of the data for early yields shows that only potassium increased yields significantly over those of the unfertilized checks, but that phosphorus, potassium, and the complete nutrient solution all served to increase yields over those of the plants fertilized with nitrogen. As neither the interaction between fertilizers and treatments nor that between fertilizers and stages was found to be significant, it may be assumed that the effect of the fertilizers during this early harvest period was essentially the same on both the forced and hardened plants and this was regardless of the stage in the life cycle of the plants during which fertilizers were applied.

In total number of heads for the entire season the plants that had been fertilized with nitrogen were significantly lower than those that had been fertilized with phosphorus, potassium, or a complete nutrient solution, or than the unfertilized checks. Moreover, the depressing effects of nitrogen were still apparent even when used in a complete nutrient solution, for plants so fertilized produced significantly fewer heads than the checks. Potassium did not increase total yield over that of the checks, but it was superior to any of the other fertilizers.

TABLE 5.—*Influence of forcing and hardening treatments on yield and on certain morphological characters of Danish Giant cauliflower, 1935*

Treatment and stage of growth	Mean number of heads		Mean yield per plot		Average weight per head		Average depth of heads		Average diameter of heads		Density index for heads [1]	
	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season	Early harvests	Entire season
	Number	*Number*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*		
Nitrogen	6.33	9.79	89.58	244.29	12.11	18.48	7.93	9.48	10.84	11.67	7.61	7.03
Phosphorus	8.92	15.42	134.23	416.10	14.32	26.13	8.22	10.80	11.82	12.46	7.47	5.48
Potassium	9.38	17.75	145.08	514.42	15.31	28.48	8.65	11.47	12.09	12.62	7.36	5.43
Complete nutrient solution	8.58	13.83	118.00	353.96	13.75	23.33	8.47	10.75	12.07	12.09	8.04	6.14
Unfertilized	6.71	16.71	97.42	530.46	14.24	30.78	8.05	12.05	11.41	12.29	7.00	5.13
Significant difference	2.25	2.06	35.11	89.02		4.66		1.00				.77
Observed F	[2] 2.97	[3] 18.24	[3] 3.60	[3] 14.03	(4)	[3] 8.40	(4)	[3] 7.33	(4)	(4)	(4)	[3] 7.88
Stages of growth cycle:												
Seedling	6.08	11.73	79.88	307.93	12.53	22.99	7.95	10.50	11.11	11.64	7.82	6.16
Seedling and field	7.88	13.53	114.76	364.91	14.25	24.85	8.50	10.79	11.87	12.36	7.65	5.90
Field	10.00	18.85	155.95	562.70	15.05	28.48	8.35	11.44	11.96	12.68	7.01	5.46
Significant difference	1.74	1.59	27.19	68.96	1.85	3.61				0.64		
Observed F	[3] 10.17	[3] 43.13	[3] 15.69	[3] 30.08	[2] 3.87	[2] 4.79	(4)	(4)	(4)	[3] 5.54	(4)	(4)
Treatment:												
Forced	9.68	15.72	116.48	383.33	11.29	22.19	8.04	10.34	10.76	11.43	8.15	5.97
Hardened	6.28	13.68	117.24	440.36	16.60	28.60	8.49	11.48	12.54	13.02	6.84	5.71
Significant difference	1.42	1.30		56.30	1.51	2.95		.63	1.14	.52	.58	
Observed F	[3] 22.85	[3] 9.74	(4)	[2] 4.10	[3] 49.19	[3] 19.47	(4)	[3] 12.73	[3] 9.71	[3] 37.18	[3] 20.41	(4)
Standard error	3.90	3.57	60.81	154.20	4.15	8.07	1.45	1.74	3.12	1.43	1.59	1.33

[1] Index numbers are inversely proportional to density.
[2] Odds against the differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.
[3] Odds against the differences noted being due to chance are greater than 99 to 1.
[4] Not significant with respect to residual error if odds of 19 to 1 against the differences noted being due to chance are accepted as a criterion.

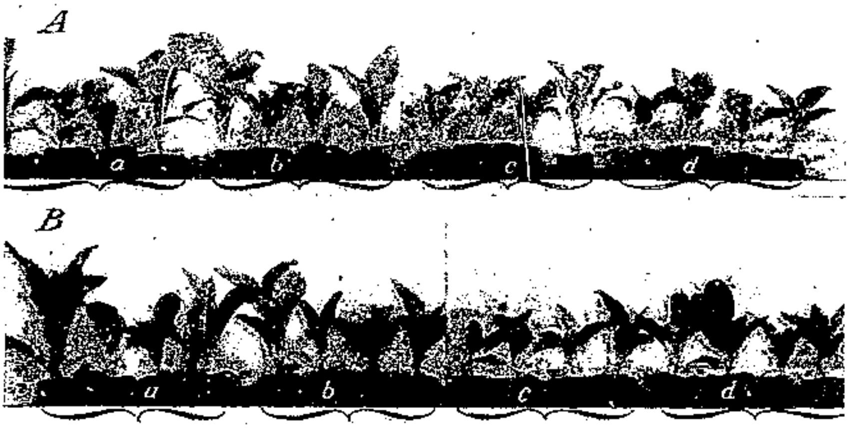

FIGURE 5.—Typical forced and hardened cauliflower plants photographed just prior to field setting, 1935. *A*, Forced plants; *B*, hardened plants. In each series the plants of group *a* were fertilized with (*1*) nitrogen, (*2*) phosphorus, (*3*) potassium, and (*4*) a complete nutrient solution, respectively, and were destined for similar applications in the field: group *b*, plants fertilized like group *a* during the seedling stage but not destined for field applications; group *c*, check plants, unfertilized as seedlings and in the field; group *d*, plants unfertilized during the seedling stage but destined for field applications of (*1*) nitrogen, (*2*) phosphorus, (*3*) potassium, and (*4*) a complete nutrient solution.

Because in this instance the interaction between fertilizers and stages was found to be significant, table 6 is presented to show the differential action of the fertilizers when applied during the various stages of plant growth. It is evident that the poor results obtained from the use of nitrogen were due to its harmful effect when applied during the seedling stage, or both during this stage and after the plants were set in the field plots. When it was applied to the plants only after they were set in the field it did not differ measurably in its effects from the other fertilizers, nor did any of them increase yields over those of the unfertilized plants. The effects of the complete nutrient solution were very similar in tendency to those of nitrogen in that it depressed yields when applied to seedlings. The high value shown in table 5 for the effects of potassium is seen from table 6 to have been due to the relatively high yields secured from its use regardless of when it was applied.

Such results indicate that though potassium may be safely applied during any stage in the growth cycle, nitrogen, either alone or as used in a complete nutrient solution, depresses yields when applied to seedlings. They also show that none of the fertilizer treatments gave results superior to those obtained with the unfertilized plants. In considering these results, it should be borne in mind that conclusions as to the effects of fertilizers on plant behavior can have only local application, because the response of plants to their use depends to a large extent upon the type of soil in which the plants are grown.

In weight of heads produced during the early harvest period the plants fertilized with phosphorus or with potassium outyielded those fertilized with nitrogen as well as the unfertilized checks. Moreover, as the interaction between fertilizers and stages is not significant, the stage means given in table 5 may be accepted as evidence that all of the fertilizers gave better results when applied to plants in the field than when applied during the seedling stage, or during both seedling and field stages.

TABLE 6.—*Differential response for entire season of cauliflower plants to nutrients applied during various stages in their growth cycles, 1935*

[Interaction: Fertilizers × stages]

Fertilizer	Mean number of heads per plot when treated at[1]—			Mean yield per plot when treated at[2]—		
	Seedling stage	Seedling and field stages	Field stage	Seedling stage	Seedling and field stages	Field stage
	Number	*Number*	*Number*	*Ounces*	*Ounces*	*Ounces*
Nitrogen	3.38	6.38	19.63	41.50	150.13	586.25
Phosphorus	12.13	16.25	17.88	335.13	450.44	402.75
Potassium	16.88	17.13	19.25	510.88	400.75	571.03
Complete nutrient solution	10.50	12.00	19.00	184.25	218.75	628.88
Unfertilized	15.75	15.88	18.50	467.88	559.50	564.00

[1] Observed F for interaction, 6.22; 1-percent point, 2.72; value for a significant difference between means, 3.57; between differences, 5.04.
[2] Observed F for interaction, 5.77; 1-percent point, 2.72; value for a significant difference between means, 54.20; between differences, 218.07.

The compound means in table 5 for total weight of heads indicate that the use of nitrogen or a complete nutrient solution depressed yields. However, as the interaction between fertilizers and stages is highly significant, table 6 shows how the various fertilizers affected weight when applied during the seedling stage, during both the seedling and field stages, or only after the plants were set into the field.

Examination of these data shows that nitrogen and the complete nutrient solution depressed yields only when they were applied to seedlings. Applied to plants only after the latter had been set in the field, they gave results not materially different from those obtained from the use of potassium or from the unfertilized plants; and the complete nutrient solution gave results superior to those obtained from the use of phosphorus. None of the fertilizers, however, increased yields over those obtained from the unfertilized checks, with the exception of the complete nutrient solution applied to plants in the field.

Of the other characteristics given in table 5, neither the average weight, nor the average depth, nor the average diameter, nor the average density of the heads produced during the early harvest season was measurably altered by the use of any fertilizer treatment if comparison is made with the unfertilized checks.

By the close of the harvest season, however, the effects of the fertilizers became more pronounced. The table showing the interactions is omitted in the interest of brevity and because it is almost identical in its implications with table 6. Thus, nitrogen used either alone or in a complete nutrient solution served to reduce the average weight of the heads when it was applied to seedlings. When it was applied to the plants only after they had been set into the field it was not measurably different in its effects from the other fertilizers, nor did any of the latter alter the average weights of the heads as compared with those from the unfertilized checks. On the other hand, phosphorus and potassium produced similar results regardless of when they were applied. The interaction implied by these results was found to be significant (observed F, 2.57; 5-percent point, 2.47).

In a similar way nitrogen applied to seedlings either alone or in a complete nutrient solution reduced the average depth and average diameter of the heads produced during the entire season below the values for plants fertilized with potassium or with phosphorus, or for unfertilized plants. Moreover, the interaction between fertilizers and stages was found to be highly significant in each case. The tables for these interactions have also been omitted, as they add but little to the information already gained from a study of table 6.

The density index numbers for the heads produced during the early harvest period (table 5, column 12) indicate that fertilizers did not affect this characteristic significantly and that there were no differential effects from their application at successive stages in the development of the plants. However, these compound means do not differentiate the effects of applying particular fertilizers at successive stages, nor the difference in their effects on the forced and hardened plants. As the second order interaction between these three factors is highly significant, table 7 is presented to show the interactions.

TABLE 7.—*Differential effects of various nutrients when applied to cauliflower plants during successive stages in their growth cycle and the difference in degree of such response by forced and hardened plants during the early harvest period, 1935* [1]

[Interaction: Fertilizers × treatments × stages [2]]

Fertilizer	Density index numbers of forced plants treated at—			Density index numbers of hardened plants treated at—		
	Seedling stage	Seedling and field stages	Field stage	Seedling stage	Seedling and field stages	Field stage
Nitrogen	5.84	9.29	7.78	10.23	7.41	5.19
Phosphorus	8.07	8.97	8.03	6.57	6.82	6.38
Potassium	8.23	8.19	8.50	6.37	6.58	6.27
Complete nutrient solution	10.06	8.19	7.68	9.41	6.70	6.21
Unfertilized	8.73	7.32	7.40	4.72	7.13	6.02

[1] Values in table are inversely proportional to head density.
[2] Observed F for second order interaction, 3.52; 1-percent point, 2.72; value for significance between means, 2.25; for first order interaction, 3.18; for second order interaction, 4.49.

Table 7 shows that the chief cause of the interaction was the differential response to nitrogen by the forced and hardened plants when it was applied during the seedling stage. Thus, when applied to forced plants during this stage, it served to increase the average density of the heads, whereas when applied to hardened plants during this same stage it decreased head density. Moreover, its effect when applied to the forced and hardened plants only after they were set in the field was the reverse of its effect on seedlings. The complete nutrient solution, on the other hand, produced similar effects on both the forced and hardened plants at each stage, but the degree of the effect varied according to the stage in their growth cycles during which it was applied. Thus, heads produced by either the forced or hardened plants that were fertilized only during the seedling stage were significantly less dense than those from plants that were similarly fertilized only after they were set in the field. Corresponding comparisons for phosphorus and potassium show that they produced similar effects on both the forced and hardened plants regardless of the stage in the growth cycle when they were applied. Comparisons other than these may be made by aid of the values for significance appended to table 7, but for the most part they are of little biological importance.

From the above discussion it is evident that the factors most influential in affecting density during the early harvest period were the forcing and hardening treatments. By the close of the harvest season, however, the difference in density of the heads from the forced and hardened plants had largely disappeared, due to the relatively much greater increase in density of the heads from the forced plants during the latter part of the growing season (table 5, column 12).

The difference in the effect of fertilizers on density became more pronounced as the season progressed. Thus the plants to which nitrogen was applied produced heads that were significantly less dense than did plants fertilized with phosphorus, with potassium, with a complete nutrient solution, or the unfertilized plants. Moreover, the effect of the complete nutrient solution was similar to that of nitrogen in that it reduced the density of the heads as compared with those from the unfertilized plants. In this instance, too, the interaction between fertilizers and stages was found to be highly significant because of the differential response of the plants to applications of nitrogen during the seedling stage as compared with field applications. As a similar interaction has already been discussed for total weight of heads (table 6) these data are omitted.

Thus far the discussion of the data secured in 1935 has dealt with the effects of fertilizers and especially with their differential effects when applied during successive stages in the growth cycle of the plants. Turning next to a consideration of the effects of the forcing and the hardening treatments and of the differential effects of fertilizers on forced and on hardened plants (table 5), it will be seen that a larger proportion of heads was produced by the forced plants than by the hardened plants. This increase in yield amounted to 36.12 percent for the early harvest period, and 12.98 percent for the entire season.

The mean yields in pounds per plot for the early harvest period show that there was no measurable difference between the forced and hardened plants, even though the former outyielded the latter in number of heads produced. An explanation of this result is found in the greater average weight of the heads produced during this period by the hardened plants (table 5, column 5). For the entire season the hardened plants produced a greater total weight of heads than did the forced ones. In this case, however, the interaction between treatments and fertilizers was found to be highly significant (table 8).

From these data it is obvious that though phosphorus and potassium served to produce heavier yields than either nitrogen or a complete nutrient solution when applied to the hardened plants, there was no significant difference between fertilizers in their influence on the forced plants. Furthermore, only potassium produced significantly different results on the forced and hardened plants. It was this effect of potassium in increasing the total weight of the heads produced by the hardened plants combined with the nonsignificant but numerically greater yields from the hardened plants supplied with phosphorus and from the unfertilized ones, that accounts for the greater total yield of this series (table 5).

Table 8.—*Differential response for entire season of forced and hardened cauliflower plants to nutrients, 1935*

[Interaction: Fertilizers × treatments]

Fertilizer	Mean yield per plot [1]		Average weight of heads [2]	
	Forced	Hardened	Forced	Hardened
	Ounces	*Ounces*	*Ounces*	*Ounces*
Nitrogen	289.58	190.00	18.44	18.52
Phosphorus	359.33	472.88	22.84	29.43
Potassium	388.83	640.00	21.22	35.74
Complete nutrient solution	391.25	316.07	21.27	25.39
Unfertilized	487.67	573.25	27.18	34.38

[1] Observed *F* for interaction, 5.30; 1-percent point, 3.53; value for a significant difference between means, 125.00; between differences, 178.05.

[2] Observed *F* for interaction, 2.57; 5-percent point, 2.47; value for a significant difference between means, 6.59; between differences, 9.32.

As has already been pointed out, the average weight of the heads produced by the hardened plants during the early harvest period was greater than that of the heads from the forced plants, indicating that earliness of maturity was achieved at the expense of weight. Furthermore, this reduction in weight of the heads from the forced plants was persistent for the entire season. However, as the interaction between treatments and fertilizers was found to be significant, these data are presented in table 8 to show the interactions.

This tabulation shows that the heads from the hardened plants fertilized with phosphorus or potassium and also those from the unfertilized plants were significantly heavier than those from similar groups of forced plants. On the other hand, the differences in weight between the heads from forced and from hardened plants fertilized with nitrogen or a complete nutrient solution were not significant.

No difference was found between the depth of the heads from the forced and hardened plants during the early harvest period, but for the entire season the heads from the hardened plants averaged somewhat greater in depth.

Forcing the plants reduced the average diameter of the heads both during the early harvest period and for the entire season. Forcing likewise reduced the density of the heads produced during the early harvest period, but for the entire season there was no difference in the density of the heads from the two treatment groups.

ROOT GROWTH AND ROOT REGENERATION STUDIES

Tomatoes

Supplementing the field tests in 1933, which compared the effects of forcing and hardening treatments on the subsequent performance of the tomato varieties Penn State Earliana and Bonny Best, studies were also made to determine whether there was a difference between the forced and hardened plants, or between the two varieties in root growth, or in their ability to regenerate roots after transplanting. For this purpose 15 plants were selected at random from each variety and treatment group and set in washed bar sand in earthenware crocks where they were allowed to grow for a period of 13 days. Before they were set in the crocks, however, the plants from each treatment group were further subdivided into 3 subseries of 5 plants each. One of these subseries was transplanted with roots intact; a second subseries had all of the roots trimmed to 1 inch from the point on the stem where the topmost root originated; the third had all lateral roots removed from the plants with a sharp scalpel. The size or volume of the roots was determined by measuring the cubic centimeters of water displaced when they were submerged in a Landsiedl extraction tube of the incomplete siphon type. The delimitation of the roots was done to simulate as nearly as possible the loss of roots that occurs in transplanting. Table 9 presents the results obtained.

TABLE 9.—*The effects of forcing and hardening treatments on root growth and root replacement of tomato, 1933*

Treatment and variety	Mean initial root volume	Mean volume after 13 days	Mean increase in root volume	Mean ratio of increase to initial volume
	Cubic centimeters	*Cubic centimeters*	*Cubic centimeters*	*Cubic centimeters*
Forced (fertilized):				
Nitrogen	3.87	10.37	6.50	2.07
Phosphorus	3.46	11.08	7.51	2.49
Potassium	2.86	9.91	7.05	2.76
Complete nutrient solution	4.65	9.95	5.30	1.50
Hardened (unfertilized)	2.45	7.77	5.32	2.37
Significant difference	0.82			.68
Observed *F*	[1] 8.84	(2)	(2)	[1] 4.06
Variety:				
Penn State Earliana	3.03	8.51	5.48	2.27
Bonny Best	3.88	11.09	7.21	2.21
Significant difference	0.52	1.53	1.26	
Observed *F*	[1] 10.82	[1] 11.37	[1] 7.45	(2)
Root treatment:				
No roots	2.28	9.33	7.05	3.31
1-inch roots	3.84	10.80	6.96	1.99
Entire roots	4.26	9.27	5.01	1.42
Significant difference	0.63		1.55	.52
Observed *F*	[1] 21.71	(2)	[3] 4.46	[1] 27.14
Standard error	1.42	1.18	3.46	1.18

[1] Odds against the differences noted being due to chance are greater than 99 to 1.
[2] Not significant with respect to residual error if odds of 19 to 1 against the differences noted being due to chance are accepted as a criterion.
[3] Odds against the differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.

Data on the initial volume of the roots are presented to show the influence of the forcing and hardening treatments on root growth up to the time the seedlings were ready for transplanting in the field.

Analysis of the data in table 9 shows that the initial root volumes of the forced plants that had been fertilized with either nitrogen, phosphorus, or a complete nutrient solution were significantly larger than those of the unfertilized hardened plants, but that there was no significant difference between the plants that had been fertilized with potassium and those that had been hardened. Moreover, the seedlings that had received a complete nutrient solution had larger root volumes than those that received either phosphorus or potassium.

The difference between the complete nutrient and the nitrogen treatments was not quite significant.

Of the three root treatments it is evident that the plants whose roots were left entire and those whose roots were limited to 1 inch were both greater in initial volume than those of the "no-root" subseries, but that there was no significant difference between the two former. Perhaps it should be explained that the value 2.28, given as the initial volume of the "no-root" subseries, represents the average volume of the main roots of the plants from which the lateral roots had been trimmed.

Root measurements at the close of the 13-day period show that initial differences in root volume of the plants from the several fertilizer treatment groups had largely disappeared. Of even less magnitude were the differences remaining between the root treatment subseries. Unfortunately, no measurements were made on the tops of these plants during the experimental period, so it is not known whether or not root growth during this period was made at the expense of top growth. Of the two varieties, Bonny Best still maintained its lead over Penn State Earliana in root volume.

There was no significant difference between the fertilizers in their influence on the amount of root growth made during the 13-day period. However, a comparison of the ratios of increase to initial size shows that the plants fertilized with phosphorus or potassium and the unfertilized hardened plants made significantly greater root growth than those fertilized with a complete nutrient solution. The greatest growth in proportion to initial volume was made by the plants fertilized with potassium, and this significantly exceeded that made by the plants fertilized with nitrogen and those fertilized with a complete fertilizer. Of the root-treatment series it is evident that the no-root plants made proportionately greater growth than those of the 1-inch subseries during the 13-day period, and these in turn made greater growth than those whose roots were not pruned. It may also be seen that Bonny Best made greater root growth than Earliana, but not a proportionately greater growth in relation to the initial size of its roots. It thus appears that the rate of root replacement and growth was inversely proportional to the initial size of the root systems at transplanting time. Approximately the same relationship also exists in the fertilizer series.

In 1934, studies on the rate of root growth of the forced and hardened tomato seedlings were conducted in very much the same manner as for the preceding year. Five seedlings were selected at random from each of the forced and hardened treatment groups and transplanted into washed bar sand in earthenware crocks. All plants were set with their roots intact, and the tests were extended from 13 to 35 days. Prior to setting them in the crocks, the plants were treated in all respects like those employed in the field studies. Thus, both the forced and hardened series were represented by subseries of five plants that had been fertilized with nitrogen, with phosphorus, with potassium, or with a complete nutrient solution. Unfertilized, or check plants, were also provided for in each series. Table 10 presents a general summary of the results obtained.

TABLE 10.—*The effects of forcing and hardening treatments on root growth and root displacement of tomatoes, 1934*

Treatment	Mean initial root volume	Mean volume after 35 days	Mean increase in root volume	Mean ratio of final volume to initial volume
	Cubic centimeters	*Cubic centimeters*	*Cubic centimeters*	*Cubic centimeters*
Nitrogen	3.12	16.56	13.44	5.59
Phosphorus	3.61	13.47	9.86	3.93
Potassium	3.39	14.13	10.75	4.19
Complete nutrient solution	3.32	18.93	15.61	5.86
Unfertilized	3.08	15.47	12.39	5.11
Significant difference		3.57	3.55	1.21
Observed F	[1]	[2] 2.92	[2] 3.25	[3] 3.78
Treatments:				
Forced	3.03	16.29	13.27	5.52
Hardened	3.58	15.13	11.55	4.34
Significant difference	.31			.78
Observed F	[3] 10.06	(1)	(1)	[3] 9.99
Standard error	.60	3.99	3.97	1.39

[1] Not significant with respect to residual error if odds of 19 to 1 are accepted as a criterion.
[2] Odds against differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.
[3] Odds against differences noted being due to change are greater than 99 to 1.

Contrary to the results of the preceding year, these data show that there were no measurable differences in the effects of the fertilizers on root growth up to the time the seedlings were large enough to be set in the field, and that the root systems of the hardened plants averaged somewhat larger than those of the forced plants.

By the close of the 35-day period any significant difference in root volume between the forced and hardened plants had disappeared. Between the fertilizers, however, though their influence during this period was purely residual, it may be seen that the root systems of the plants fertilized with a complete nutrient solution were significantly larger than those of the plants forced with either phosphorus or potassium. None of the other comparisons are significant.

Because in this instance the interaction between the effects of the fertilizers and those of the forcing and hardening treatments was found to be significant, table 11 is presented to show more clearly the differential effects of the fertilizers on the forced and hardened plants.

TABLE 11.—*Differential response of forced and hardened tomato plants to nutrients, 1934*

[Interaction, Fertilizers × treatments]

Fertilizer	Final volume of roots [1]	
	Forced	Hardened
	Cubic centimeters	*Cubic centimeters*
Nitrogen	20.92	12.20
Phosphorus	14.63	12.31
Potassium	13.54	14.73
Complete nutrient solution	17.20	20.65
Unfertilized	15.18	15.76

[1] Observed F for interaction, 3.46; 1-percent point, 3.91; 5-percent point, 2.64; value for significance between means, 5.05; between differences, 7.14.

A study of these interacting means shows that fertilizing the forced plants with nitrogen, or the hardened plants with a complete nutrient solution, resulted in significantly greater root growth than that made by either the forced or hardened plants fertilized with phosphorus or potassium. Moreover, the forced plants fertilized with nitrogen made significantly greater root growth than either the forced or hardened unfertilized plants, or than the hardened plants supplied with nitrogen, though not more than the hardened plants that were given a complete nutrient solution. Other comparisons are made possible by aid of the values required for significance appended to the table.

The increase in root volume made during the 35-day period by the plants fertilized with either nitrogen or a complete nutrient solution was significantly greater than that of those fertilized with phosphorus; and those fertilized with a complete nutrient solution made significantly greater root growth than those fertilized with potassium (table 10).

No significant difference was found between the two treatments in their influence on the increase in root size made during the 35-day period, but the interaction between fertilizers and treatments was found to be significant. The table for this interaction is omitted, however, as it is identical in its implications with findings shown in table 11.

In proportion to their initial volume and irrespective of the forcing and hardening treatments, the plants fertilized with nitrogen or a complete nutrient solution made greater gains in root volume than those fertilized with either phosphorus or potassium, but not significantly greater than those of the unfertilized subseries. Moreover, the mean gains of the forced plants were greater than those of the hardened plants (table 10).

Cabbage

The 1933 investigation of the effects of the forcing and hardening treatments on the root growth of cabbage seedlings was conducted in the same manner as that on tomatoes, except that in this case all seedlings were transplanted with their roots intact. Table 12 presents a summary of the results obtained.

Table 12.—*The effects of forcing and hardening treatments on root growth and root displacement of 2 varieties of cabbage, 1933*

Treatment and variety	Mean initial root volume	Mean volume after 13 days	Mean increase in root volume	Mean ratio of final volume to initial volume
	Cubic centimeters	*Cubic centimeters*	*Cubic centimeters*	
Forced (fertilized):				
Nitrogen	3.57	16.59	13.02	7.05
Phosphorus	6.49	22.63	16.14	4.11
Potassium	5.26	20.58	15.33	4.39
Complete nutrient solution	5.31	23.81	18.46	6.83
Hardened (unfertilized)	4.63	11.11	9.19	3.01
Significant difference			5.80	2.32
Observed F	(1)	(1)	[2] 2.75	[3] 4.65
Variety:				
Early Jersey Wakefield	6.52	23.31	16.80	4.21
Golden Acre	3.58	15.78	12.18	5.90
Significant difference	1.46	4.66	3.67	1.47
Observed F	[3] 12.33	[3] 10.47	[2] 6.33	[3] 5.71
Standard error	2.91	8.23	6.58	2.60

[1] Not significant with respect to residual error if odds of 19 to 1 are accepted as a criterion.
[2] Odds against the differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.
[3] Odds against the differences noted being due to chance are greater than 99 to 1.

A comparison of these data indicates there were no significant differences between the effects of the fertilizers on root growth up to the time the seedlings were large enough to be set in the field, or between the average root volumes of the seedlings at the close of the 13-day growth period. However, a comparison of the actual increases made during this period shows that the forced plants fertilized with phosphorus, with potassium, or with a complete nutrient solution made significantly greater root growth than the unfertilized, hardened plants. There was no significant difference between the plants fertilized with phosphorus and potassium or between the plants fertilized with nitrogen and the hardened plants in the amount of root growth made. In proportion to their initial volumes, the plants fertilized with nitrogen or with a complete nutrient solution made significantly greater root growth than did those fertilized with phosphorus, or with potassium, or the hardened plants.

Early Jersey Wakefield seedlings had larger root systems than Golden Acre both at the beginning and at the end of the 13-day period, but in proportion to their initial size those of Golden Acre made the greater gains.

A general summary of the results obtained from these root-growth studies with tomato and cabbage plants shows that there was but little uniformity in the effects of the fertilizers on root growth either before the seedlings were transplanted or afterwards. A similar lack of consistency also appears in the effects of the forcing and hardening treatments on root growth. Nevertheless, as in the case of the data showing the differences in the relative root size of the Early Jersey Wakefield and Golden Acre cabbage varieties in 1933 and between the forced and hardened tomato seedlings in 1934, it is evident that the seedlings having the smaller root systems when they were transplanted made greater gains in proportion to their initial size than those having larger root systems. A comparison of these results with the subsequent performance of similar plants in the field shows that earliness of maturity was associated with rapidity of root growth after transplanting.

This same tendency is to be found elsewhere in the data, as in the case of the relative root size of the Penn State Earliana and Bonny Best seedlings in 1933. In this instance, however, the differences in the ratios of increase in root volume to initial volume were not significant and so no definite conclusions can be drawn from them.

TRANSPIRATION STUDIES

Cabbage

Transpiration studies were conducted in 1933 with cabbage seedlings that, prior to their selection for this purpose, had been treated in all respects like those used for the field studies. Five plants of each variety, selected at random from each of the forced groups and from those that had been hardened, were transplanted into moist prairie soil in tin containers of about 1-gallon capacity. A wax seal was used to prevent loss of water from the soil by evaporation, and provision was made for the replacement of water lost by transpiration. The quantity of water lost was determined by weighing. Leaf areas were measured by the use of a polar planimeter. The duration of the experimental period was 5 days.

Measurements of the leaf areas of seedlings at the time they were transplanted show (table 13) that those fertilized with a complete nutrient solution were larger than those from the other fertilized groups, and that, with the exception of the seedlings fertilized with potassium, all of the forced seedlings were significantly larger than the hardened ones.

As might be expected from their larger sizes, the plants fertilized with a complete nutrient solution lost a greater quantity of water by transpiration than those from any other treatment group. Likewise, the forced plants, regardless of the type of fertilization, lost more than the hardened plants.

In this connection it is of interest to note that though the plants fertilized with potassium were not significantly larger than the hardened plants, they lost a greater quantity of water by transpiration.

TABLE 13.—*Rate of transpiration of cabbage seedlings of 2 varieties as affected by forcing and hardening treatments, 1939*

Treatment, and variety	Initial leaf area; mean values	Transpiration per plant; mean values for 5-day period	Transpiration per 100 sq. cm. leaf area; mean values for 5-day period
	Square centimeters	*Grams*	*Grams*
Forced (fertilized):			
Nitrogen	112.16	143.21	146.03
Phosphorus	92.96	141.74	156.02
Potassium	79.65	109.50	116.73
Complete nutrient solution	131.95	200.95	146.15
Hardened (unfertilized)	47.63	48.51	103.84
Significant difference	36.02	40.61	
Observed *F*	[1] 9.25	[1] 15.11	(2)
Variety:			
Early Jersey Wakefield	98.58	120.28	130.72
Golden Acre	95.16	138.48	148.79
Significant difference			
Observed *F*	(2)	(2)	(2)
Standard error	40.28	45.41	48.00

[1] Odds against the differences noted being due to chance are greater than 99 to 1.
[2] Not significant with respect to residual error if odds of 19 to 1 are accepted as a criterion.

There were no significant differences between the two varieties in their initial leaf sizes, transpiration per plant, or transpiration per 100 square centimeters of leaf area.

CHEMICAL STUDIES

CAULIFLOWER

Table 14 presents the results of analyses for organic and for total nitrogen in forced and hardened cauliflower seedlings selected at random from groups fertilized with nitrogen, with phosphorus, with potassium, with a complete nutrient solution, and from the unfertilized checks.

TABLE 14.—*Organic and total nitrogen contents of stem and leaf tissues (dry weight) of forced and of hardened cauliflower seedlings, 1935*

Treatment	Organic nitrogen			Total nitrogen		
	Forced	Hardened	Fertilizer means	Forced	Hardened	Fertilizer means
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nitrogen	2.7200	1.6295	2.1783	2.8830	1.7310	2.3070
Phosphorus	1.2485	.0705	1.1695	1.2550	1.0325	1.1437
Potassium	1.1505	.9125	1.0465	1.1140	1.0200	1.0820
Complete nutrient solution	1.5740	1.4630	1.5185	1.5810	1.5595	1.57[illegible]
Unfertilized	1.4975	1.1085	1.3030	1.5045	1.1205	1.3125
Treatment means	1.6399	1.2228		1.6735	1.2927	
Significant difference	0.1176		0.1860	0.0917		0.1150
Observed *F*	[1] 50.28		[1] 48.27	[1] 60.06		[1] 91.13
Standard error	0.1315			0.1025		

[1] Odds against the differences noted being due to chance are greater than 99 to 1.

A comparison of the means for fertilizers shows that the percentages of organic and of total nitrogen were practically identical in magnitude. This indicates that the nitrate content of the seedlings was extremely low; in fact, its presence could not be detected in some instances by the methods of analysis employed.

Furthermore, an analysis of the data in table 14 shows that the effects of the fertilizers were practically identical on both the organic and the total nitrogen content of the seedlings. Thus the plants fertilized with nitrogen or a complete nutrient solution contained significantly higher percentages of both organic and total nitrogen than those fertilized with phosphorus, or with potassium, or than the unfertilized checks. Both phosphorus and potassium, on the contrary, appear to have actually decreased the percentages of organic and total nitrogen, as the plants fertilized with them were significantly lower in these constituents than the unfertilized checks; and those given a complete nutrient solution were lower than those given only nitrogen.

A critical examination of the two sets of nitrogen data will disclose the fact that in each case the interaction between fertilizers and forcing and hardening treatments is highly significant. The observed F for the interaction in the organic nitrogen data was 7.56 and the 1-percent point 6.42; in the data for total nitrogen the observed F was 19.40 and the 1-percent point 6.42. In each case the interaction is significant because the forced plants fertilized with nitrogen or with phosphorus and the unfertilized, forced seedlings contained significantly higher percentages of nitrogen than the corresponding groups of hardened seedlings, whereas the differences in nitrogen content of the forced and hardened seedlings fertilized with potassium or a complete nutrient solution were not significant. As these interactions appear to have but little biological importance, the tables for them have been omitted.

The two sets of nitrogen data also agree in showing that the forced plants contained significantly higher percentages of organic and total nitrogen than the hardened.

The effects of the forcing and hardening treatments and of fertilization on the percentage of dry substances and of carbohydrates in cauliflower seedling is shown in table 15.

TABLE 15.—*Dry-matter and carbohydrate contents of the stem and leaf tissues (dry weight) of cauliflower seedlings as affected by forcing, fertilization, and hardening, 1935*

Treatment	Dry substances			Hemicelluloses			Starch			Total sugars			Total carbohydrates		
	Forced	Hardened	Fertilizer means	Forced	Hardened	Fertilizer means	Forced	Hardened	Fertilizer means	Forced	Hardened	Fertilizer means	Forced	Hardened	Fertilizer means
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nitrogen	14. 2105	15. 6580	14. 9343	7. 7670	13. 3000	10. 5335	4. 6150	1. 8610	3. 2380	17. 7750	17. 0895	17. 4323	30. 8940	32. 4118	31. 6529
Phosphorus	18. 1240	20. 4830	19. 3035	23. 0915	17. 4800	20. 2857	3. 6700	6. 4055	5. 0378	11. 2980	10. 1390	10. 7185	36. 6923	31. 4835	35. 0879
Potassium	19. 6070	21. 1925	20. 3998	24. 0465	17. 3100	20. 6783	3. 4525	4. 1560	3. 8543	15. 1540	11. 8150	13. 4845	37. 4685	33. 3823	35. 4254
Complete nutrient solution	16. 8480	17. 8120	17. 3300	23. 4070	12. 3795	17. 8933	4. 1925	5. 2365	4. 7145	12. 5240	14. 8250	13. 6745	40. 1340	32. 4425	36. 2883
Unfertilized	17. 7845	20. 5270	19. 1558	17. 8610	23. 0390	20. 4500	5. 8770	5. 9400	5. 9085	14. 3600	12. 6370	13. 4985	39. 0873	41. 6158	40. 3515
Treatment means	17. 3148	19. 1345		19. 2346	16. 7017		4. 3614	4. 7398		14. 2222	13. 3011		37. 2552	34. 2672	
Significant difference	0. 7566		1. 2963			6. 3102						3. 2654			
Observed F	[1] 23. 14		[1] 25. 70	([2])		[3] 3. 88	([2])		([2])	([2])		[3] 4. 29	([2])		([2])
Standard error	0. 8459			4. 4620			2. 7992			2. 3090			4. 6271		

[1] Odds against the differences noted being due to chance are greater than 99 to 1.
[2] Not significant with respect to residual error if odds of 19 to 1 against the differences noted being due to chance are accepted as a criterion.
[3] Odds against the differences noted being due to chance are greater than 19 to 1, but less than 99 to 1.

Reference to table 15 shows that the percentages of dry substances and of hemicelluloses were higher in the plants fertilized with phosphorus, with potassium, with a complete nutrient solution, and in the unfertilized checks than in those fertilized with nitrogen. It thus appears that nitrogen served to reduce the percentages of these constituents, as the percentages in the nitrogen-fertilized seedlings are lower than those in the unfertilized checks. In the case of the dry substances, however, phosphorus and potassium appear to have slightly offset the depressing effects of nitrogen, as plants fertilized with them contained higher percentages than the plants fertilized with a complete nutrient solution and the latter were not significantly different from the unfertilized checks. This effect of phosphorus and potassium in reducing the depressing effects of nitrogen on the percentage of dry substances is also to be found in the data for hemicelluloses, but the values are not of significant proportions.

The effects of the fertilizers on the percentage of total sugars in the seedlings were in direct contrast with their effects on dry substances and hemicelluloses, in that the plants fertilized with nitrogen were significantly higher in sugar content than those fertilized with phosphorus, with potassium, with a complete nutrient solution, or the unfertilized checks.

No significant differences were found between the effects of the fertilizers on the percentages of starch or total carbohydrates in the seedlings. In the case of the total carbohydrates this failure of the fertilizers to show significantly differential effects is probably due to their contrasting effects on the hemicellulose and total sugar content of the seedlings.

Though the percentage of dry substances was significantly higher in the hardened than in the forced seedlings, there were no measurable differences in the effects of the two treatments in the percentages of hemicelluloses, starch, sugars, or total carbohydrates.

Similar analyses of the root tissues show that there were no significant differences between the forcing and hardening treatments or between the fertilizers in their effects on chemical composition. Table 16 is presented to show the percentages of organic nitrogen, total nitrogen, dry substances, and carbohydrates found.

A similar stability of roots toward the effects of treatments that materially affected the chemical composition of the tops has been reported by Robbins, Nightingale, and Schermerhorn (*16*), Reid (*15*), and other investigators.

Comparisons between the chemical composition of the seedling plants and the performance of similarly treated plants after they were set in the field indicate that the high percentages of nitrogen and total sugar in the seedlings fertilized with nitrogen or with a complete nutrient solution were associated with retarded earliness of maturity. Accompanying this relatively high nitrogen content, there was a decrease in the percentages of dry matter and of hemicelluloses as compared with those found in the plants fertilized with phosphorus or with potassium.

As no significant differences were found between their effects on the starch and total carbohydrate content of the seedlings, no valid comparisons can be drawn between the proportions of these constituents and subsequent plant performance. For the same reason, this comparison cannot be made between the chemical composition of the roots and the subsequent performance of the plants.

TABLE 16.—*Nitrogen, dry matter, and carbohydrate content of the root tissues of cauliflower seedlings as affected by forcing and hardening, 1935*

[Based on dry weights]

Treatment	Organic nitrogen		Total nitrogen		Dry substances		Hemicelluloses and starch		Total sugars		Total carbohydrates	
	Forced	Hardened	Forced	Hardened	Forced	Hardened	Forced	Hardened	Forced	Hardened	Forced	Hardened
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nitrogen	1. 514	1. 565	2. 196	1. 588	66. 186	56. 700	16. 208	19. 913	2. 271	3. 200	18. 479	23. 113
Phosphorus	1. 123	1. 081	1. 295	1. 076	62. 826	65. 110	8. 868	14. 112	6. 976	3. 136	15. 844	17. 248
Potassium	. 936	. 963	. 998	1. 010	45. 776	58. 778	10. 305	15. 174	7. 377	3. 678	17. 682	18. 852
Complete nutrient solution	1. 047	1. 331	1. 068	1. 334	64. 439	65. 530	12. 677	18. 837	3. 461	2. 274	16. 138	21. 111
Unfertilized	. 940	1. 047	. 959	1. 058	62. 713	74. 809	20. 013	18. 559	7. 440	3. 667	27. 453	22. 226

Although the carbohydrate/total-nitrogen and total-sugar/total-nitrogen ratios are not presented, they were calculated and their relationship to subsequent plant behavior examined.

Neither the carbohydrate/total-nitrogen ratios in the stem and leaf tissues nor those in the roots were differentially affected by fertilization or by the forcing and hardening treatments, and so no valid comparisons can be made between their relative magnitudes and subsequent plant performance. It is also true that the total-sugar/total-nitrogen ratios did not show the influence of the forcing and hardening treatments. However, significant differences were found between fertilizers in their effects on the total-sugar/total-nitrogen ratios in the stem and leaf tissues, and these may be compared with subsequent plant performance.

By such a comparison, it appears that the relatively high ratios of total sugars to total nitrogen found in the plants fertilized with phosphorus or with potassium were associated with greater early and total yields, whereas the relatively low total-sugar/total-nitrogen ratios of the plants fertilized with nitrogen or with a complete nutrient solution appear to be associated with reduced early and total yields.

These results differ from those obtained by Miller (*11*), who found no relationship between subsequent performance and the ratios of sugars to insoluble, to soluble, to amine, or to total nitrogen. However, the belief that such a relationship does exist has been expressed by Kraus and Kraybill (*10*), Walster (*21*), Nightingale (*12*), Platenius (*13*), and many others. In some of the studies referred to, the chemical changes in the plants were the results of temperature treatments; in others they were the results of differential fertilization, but regardless of how they were induced their effects appear to have been more or less persistent throughout the life of the plants.

SUMMARY AND CONCLUSIONS

Studies of the effects of forcing and hardening treatments applied to tomatoes in 1933 at Cheyenne, Wyo., showed that there were no significant differences between the two treatments in their effects on either the number or the weight of ripe fruits produced during the early harvest season or during the entire season.

The use of nitrogen or of a complete nutrient solution on the seedlings reduced both the number and total weight of ripe fruits produced during the early harvest season, but there were no significant differences between fertilizers in their effects on total yield.

In 1934, the forced tomato plants produced a greater number of ripe fruits than the hardened ones during the early harvest period, but there was no significant difference between treatments in their effects on the weight of the fruits produced. For the entire season, the hardened plants produced the greater number and total weight of ripe fruits. Fertilizers were without effect in altering earliness of maturity or total yields.

Similar studies of the effects of the forcing and hardening treatments on cabbages showed that forced plants fertilized with nitrogen or with a complete nutrient solution produced a greater number and weight of heads during the early harvest period than unfertilized, hardened plants. The plants fertilized with phosphorus also produced a greater number of heads during the early harvest season, but these did not exceed in weight those produced by the unfertilized, hardened plants during this same period. For the entire season, there was no significant difference between the forced and hardened plants in either number or total weight of heads produced.

Tests with cauliflower in 1934 showed that the forced plants produced 26.03 percent more heads during the early harvest season than did the hardened plants, and 13.92 percent more for the entire season. The increase in total weight of heads from the forced plants during the early harvest period was 22.28 percent, but for the entire season there was no significant difference between the two treatments in this respect. Fertilizers produced no measurable effects on number or total weight of heads during the early harvest period or during the entire season.

In 1935, forced cauliflower plants produced 35.12 percent more heads than the hardened plants during the early harvest period, and 12.98 percent more for the entire season. However, the heads produced by the forced plants during the early harvest period averaged lighter in weight than those from the hardened plants, and there was no significant difference between treatments in their effect on total weight of heads during this period; and for the entire season the hardened plants produced the greater total yield as measured by weight.

Of the fertilizers, phosphorus, potassium, and the complete nutrient solution increased early yields as compared with nitrogen, but only the plants fertilized with potassium produced a greater number of heads than the unfertilized checks. For the entire season, however, even the unfertilized checks exceeded the plants fertilized with nitrogen in the number of heads produced.

The effects of the fertilizers on the weight of heads were similar to their effects on number, except that both phosphorus and potassium increased production over that of the checks during the early harvest season, and for the entire season both nitrogen and the complete nutrient solution decreased yields.

Analysis of interactions between fertilizers and stages of growth showed that this depressing effect of nitrogen was due to its harmful effects when it was applied to seedlings. When it was applied to the plants only after they were set in the field, its effects were not significantly different from those of the other fertilizers. The complete nutrient solution, probably because of its nitrogen content, produced effects similar to those of nitrogen but not so pronounced. Phosphorus and potassium, on the other hand, produced approximately the same effects whether they were applied to the plants during the seedling stage of growth, after the plants were set in the field, or during both of these stages.

Root-growth studies on the tomato and cabbage seedlings at the time they were set in the field showed that there were no consistent differences between the forcing and hardening treatments or between fertilizers in their effects on root growth up to that time. Thus, in 1933, the forced tomato seedlings fertilized with nitrogen, phosphorus, or a complete nutrient solution had larger root systems than the unfertilized, hardened checks, but the forced plants fertilized with potassium were not significantly different in size from the latter. In 1934 there were no significant differences either between the forcing and hardening treatments or between fertilizers in their influence on root growth up to the time the tomato plants were transplanted; and this was also true for the cabbage seedlings in 1933.

Studies on the rate of root growth made by the seedlings after transplanting showed that where significant differences in initial size existed the subsequent growth was inversely proportional to initial size, and that the subsequent rate of growth, rather than large initial size, was most closely associated with earliness of maturity. A similar tendency was also found to exist in those cases where initial differences in root size were not significant, but obviously no valid comparisons can be made between these and subsequent plant performance.

A study of the transpiration of newly transplanted cabbage seedlings in 1933 shows that the quantity of water lost was approximately proportional to the size of the seedlings, except that the forced seedlings fertilized with potassium lost more than the unfertilized, hardened plants though not differing from the latter in initial size. When these differences were calculated as loss per 100 $cm.^2$ of leaf area they failed to reach statistically significant proportions. For this reason, mathematical comparison between them and subsequent plant performance cannot be made, but an inspection of the means showing relative earliness of maturity and of those for transpiration indicates that the rate of water loss per unit area of leaf surface was not an important factor in affecting early yields.

Chemical analyses of cauliflower seedlings in 1935 show that the forced plants contained in their stem and leaf tissues higher percentages of organic nitrogen and of total nitrogen than the hardened seedlings, but that the hardened seedlings contained higher percentages of dry substances. There were no measurable differences between the two treatments in their effects on the percentages of hemicelluloses, of starch, of sugars, or of total carbohydrates.

Fertilizing the seedlings with nitrogen or with a complete nutrient solution served to increase the percentages of organic nitrogen, of total nitrogen, and of total sugars in the stem and leaf tissues, whereas fertilizing with phosphorus or with potassium served to decrease them. On the other hand, the nitrogen-fertilized seedlings were lower in dry substances and hemicelluloses, whereas phosphorus and potassium produced increases. The percentages of starch and of total carbohydrates in the stem and leaf tissues were not significantly affected by fertilization.

The chemical composition of the root tissues was not measurably affected either by the forcing and hardening treatments or by fertilization.

Comparisons of the chemical composition of the seedlings with the subsequent performance of similarly treated seedlings after they were set in the field indicate that the relatively high percentages of total nitrogen and of sugars in the plants fertilized with nitrogen or with a complete nutrient solution were associated with retarded earliness of maturity; whereas the relatively high percentages of dry matter and of hemicelluloses in the plants fertilized with phosphorus or potassium were associated with increased earliness of maturity.

Comparisons of the carbohydrate/total-nitrogen ratios in the stem and leaf tissues or in the roots of the seedlings with subsequent performance cannot be made, because neither fertilizers nor the forcing and hardening treatments differentially affected these ratios. This is also true of the total-sugar/total-nitrogen ratios in the roots of the seedlings. However, the total-sugar/total-nitrogen ratios in the stem and leaf tissues were measurably affected by fertilization, and a comparison of these with subsequent performance indicates that the relatively high ratios in the plants fertilized with phosphorus or potassium were associated with greater early and total yields; whereas the relatively low ratios in the plants fertilized with nitrogen or a complete nutrient solution appear to have been associated with reduced early and total yields.

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