Improvement of the Sugar Beet

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SUGARCANE and sugar beet are the important sources of sugar. This foodstuff, which today is one of the purest and cheapest in our dietary, two centuries ago was a luxury available only to the rich. The story of the rise of sugar production to meet an ever-increasing demand is a romance of agriculture and chemistry. The accomplishments of the plant breeder and the chemical engineer in making this contribution to the world’s food supply rank in significance with such important contributions to human welfare as the introduction of the potato or the invention of the cotton gin. Today sugar is a part of the diet of everyone, and the per-capita consumption is associated with the standard of living of a nation.

It is a common statement in this series of articles on breeding and genetics that the wild progenitors of our crop plants are not known; there are diverse opinions, in many cases, even about the places of their origin. Primitive peoples wrested these plants from nature, improved, and conserved them. They come to us as the heritage of the past, the steps in their development being matters of surmise or conjecture. We can reconstruct the course of their development only on the basis of our own experience or from the theories of plant and animal evolution and dispersal.

In the article on sugarcane a glimpse is afforded of the probable course of development of this plant. The observations by Brandes (6) on the nurture of sugarcane among the primitive tribes of New Guinea supply a pattern of the course which the aborigines at a similar stage of development may have followed with their food plants. The tribal beliefs and practices reported by Brandes throw light on primitive methods of selection and husbandry, and they indicate what mankind at the dawn of history probably did with various plant forms on which he was dependent.

In sharp contrast to this reconstruction of the past and inference concerning it, we deal in the case of the sugar beet with a development reaching back not more than 150 years. The winning of this sugar plant from the common stock of beets used chiefly as feed for animals was done by known historical figures who left some written record of
their accomplishments. It is a story of man’s success, through a
century and a half of endeavor, in adapting a plant to highly
specialized use.

The consideration of other crop plants turns our glance backwards
to the unknown and legendary “plant improvers” as man emerged
from savagery. We must postulate enormous stretches of time for
improved varieties to evolve. The story of the sugar beet, on the
other hand, is a record of scientific achievement. A brief span of
time is involved. It is an epic of modern science.

The History of the Sugar Beet—One of the Few Plants
Developed in Modern Times

THE sugar beet as we know it today and the great industry which
has been built up about this plant date back to the work of two
men—Marggraf, who made an epochal scientific discovery, and
Achard, his student, who applied this discovery with zeal and genius.

In 1747 Andreas Sigmund Marggraf, a German chemist, found in
two cultivated species of the beet family a sugar identical with the
sugar then known as “cane sugar.” In his scientific report, the
chemical methods of extraction were described, the proportions
found in the plants tested were given, and he stated that the crystals
of sugar could be recognized under the microscope in the dried slices
of beet (18).1 There is little doubt that Marggraf was aware of the
significance of his discovery, but apparently he made no attempts
to apply it.

The application of the finding and the gigantic task of developing
technological methods and creating an agriculture on which to base
an industry were the contributions of Achard (1). In 1786 Achard
began his classic researches on the extraction of sugar from fodder
beets. The kinds of beets existing at the time were probably a com-
plex mixture of which the predominating types were those akin to
what we know today as mangel-wurzels. In the closing years of the
eighteenth century, Achard’s experiments were successful. A fac-
tory project, underwritten by funds granted by Frederick Wilhelm III
of Prussia, was launched at Cunern in Silesia, Germany. The report
referred to was written at the close of the first year’s campaign of
this factory.

Achard coined the term “beet-sugar,” and in the press “sugar beet”
began to be used to designate the beets he favored for fabrication of
sugar. As may be determined from Achard’s writings and the seed
lists of the period, these beets were mixed stocks of red or white
mangel-wurzels, undoubtedly hybrids—some having red flesh, some
white flesh. These were in common use by the farmers around
Magdeburg, Germany, where Achard carried on his early work and
obtained his seed supplies. Although they were chiefly grown for
the feeding of livestock, it appears that the peasants of this section
also used beets to make a table sirup. This use may, perhaps, have

1 Italic figures in parentheses refer to Literature Cited, p. 650.
played a significant role in conserving the sweeter types which otherwise might have been dropped from culture.

NEED FOR BREEDING WORK RECOGNIZED IN 1809

When the small factory was started, although he was beset with technological difficulties in manufacturing sugar from the low-quality beets available, Achard gave much attention to the agronomic and economic problems involved in the production of beet roots suitable for the factory. In his early writings he listed the existing types of beets and evaluated them from the standpoint of purity and sugar concentration. From the beginning of the small factory at Cunern, he was groping among the conglomeration of types in the mangel-wurzel complex to find those most suitable for fabrication, saving the better sorts and raising seed from them. By 1809, Achard clearly recognized that the future of the industry depended on securing suitable varieties and that they could come only as a result of breeding work. The little factory made sugar from beets whose average sucrose percentage was far less than half that of present-day sugar beets.

Achard did not achieve commercial success in his venture nor complete his plans for beet improvement. His factory failed, and he died a disappointed man. But he had contributed an idea to the world and opened a new field for human endeavor.

In these early years of development, the name of Freiherr von Koppy is linked with that of Achard. Shortly after the first success in obtaining sugar from beets in Silesia, Koppy erected a factory at Krayn, Germany, and interested himself in the selection of improved types. The record seems clear that Achard generously aided Koppy by supplying seed and technical assistance for what some might have considered a rival enterprise. Achard’s factory operations ended in 1810, but Koppy continued his attempts to maintain a factory until about 1820, and even after it closed he kept on with his selection work with improved strains of beets. From this work came the White Silesian beet, which the historian Lippmann (1.7) denominates “the mother stock of all the sugar beets in the world.”

On the foundation laid by these pioneer efforts, the sugar industry arose. The succeeding steps can only be mentioned briefly to bring out the events of the last century that have a direct bearing on the theme of this article. The histories of sugar and of the sugar beet by Lippmann or Vilmorin (26) should be consulted for a complete account.

The attempts to establish factories were abandoned in Germany for the period from 1815 to 1830. Activities in sugar production centered in France under the impetus given by Napoleon’s Decree of March 25, 1811. In order to strike a blow at the trade in sugar from British colonies, the French Emperor subsidized factories and ordered the growing of large acreages of sugar beets. It may be said that the French industry grew out of the experiences of Achard, and the White Silesian beet was introduced for factory use and for improvement by seedsmen. Breeding work with sugar beets was begun early in this period of development in France.

In 1820 Philippe André de Vilmorin reported results of his selections based on morphological characters. His work was carried forward by his brilliant son, Louis. The science of plant breeding credits Louis
de Vilmorin with formulating the principle according to which the breeding value of the mother plant was determined by the quality and characteristics of its progeny (13). Vilmorin applied this principle in sugar-beet breeding, evaluating the progenies according to dry substance as determined from density values (silver-ingot method). In 1853 these values were checked by sucrose determinations obtained by use of the polariscope. In the hands of Vilmorin the improvement of the sugar beet was definite and rapid. In his Notes on Some Varieties of White Sugar Beets, published in 1861, Vilmorin states that in the strain then in process of development by his method, certain lots contained from 16 to 17 percent of sucrose, in comparison with the Imperial beet—produced by German breeders—which contained only 9.8 to 11 percent. Both of these forms showed great superiority over the ordinary white sugar beet in common use, which tested only 7.5 percent.

**IMPROVED METHOD OF TESTING MAKES SELECTION MORE CERTAIN**

Between 1860 and 1875 polariscopic analysis of the juice as a guide to selection came into use in various beet-breeding establishments. The radical improvement in sugar-beet quality may be said to date from the introduction of this technique and its application to the breeding principle established by Vilmorin.
In root shape, color characters, and foliage, the sugar beets worked by Achard and Koppy probably resembled the sugar beet as we know it today. We must infer that the White Silesian variety was a population containing high- and low-testing individuals, together with their hybrids, and that as a whole these gave a low percentage of sucrose. Schribaux (22) is the authority for the statement that in the period from 1838 to 1868 when morphological selection prevailed, the average richness in sucrose progressed from 8.8 to 10.1 percent. From 1868 to 1888 it mounted to 13.7 percent and from 1888 to 1912 to 18.5 percent. Other tabulations, based chiefly on computations from statistics of sucrose production, are prone to indicate that each decade following the general use of the polariscope by breeding establishments in Europe has shown a steady and mounting gain in sucrose and yield. It seems probable that in such summarizations the improvement in factory methods which took place at the same time has not been fully taken into account.

In 1880 Ware (27) described the varieties or commercial brands then existing. These descriptions clearly show the improvement that had taken place to this date. His statements as to sucrose percentage for the various brands and their yields per acre indicate that sugar-beet types rather closely approaching those of the present time in quality and yield had been separated from the mother stock. The data taken from the experimental plantings of sugar beets in the United States under the direction of Harvey W. Wiley, of the Department of Agriculture, in the period from 1885 to 1908 (28), also bring into question the common opinion that there was a steady and continuous improvement. In Wiley's tests standard European brands were used in many localities, as well as home-grown seed derived from local selections, and the tests gave data fairly consistent with results obtained in American beet districts in the last decade. From 1900 (21) various other tests with European brands were made along the line of Wiley's early work. These too approximate the results with present-day tests. Records of factories started in 1900 or slightly later reveal that the sugar beets used were not strikingly different from those of the present day.

It seems important to call attention to this evidence as to the quality of sugar beets at a period during which it is common to assume that the quality was much lower. For one thing, the accepted belief that the sugar beet has shown steady and increasing gains in quality and yield each decade since 1880 is difficult to harmonize with the genetic considerations involved. If this were true, it would seem perhaps to make marked departure from present methods unwarranted. It is suggested that each period of development made its contribution to the technique of selection, and as the new factor entered, its effects were rather promptly secured. In the interim periods, the work of the breeder may have been to hold the advance gained and to maintain the stocks free from outside contamination.

This rapid review brings out certain points significant to the sugar-beet-improvement program. In the early work the less desirable portions of the mixed population were separated out and discarded by slow degrees. There was an advance with each development in method whereby reliable selections could be made. Most significant of these was the development and application of the progeny test. Its full effects could come only with the discovery of an efficient and
accurate means of determining richness in sucrose. Hence marked progress followed the introduction of the polariscope to test individual beets and composite samples. From this time on, it was possible accurately to compare individuals through the behavior of their progenies, and to retain a population in which hybrids of desirable types predominated.

This brief account has also stressed the point that sugar-beet varieties as we know them today trace back to the White Silesian beet of Achard and Korary. Since they come from this common source, the potentialities for development in the present varieties lie within the genetic limits of the basic material. With each successive step in selection, we may conceive that the previous gene complement may have been reduced. These considerations are significant when the problems of further development are faced. We may surmise, for example, that desirable potentialities have been dropped by the way and must be found again. This opens a broad field to be explored.

We do not know what additional desirable characters there are within the varieties as they exist today until work proceeds in new directions to separate forms adapted to special conditions of soil or climate, or resistant to disease. The achievements of the past forecast future possibilities for new and useful discoveries.

**THE METHODS USED IN EUROPEAN SUGAR-BEET BREEDING**

From the preceding outline, it is clear that from the very beginning of the industry, plant breeders in Europe concerned themselves with beet improvement. As the industry grew in size, the efforts increased, and seed firms which at first used only simple methods developed into highly specialized beet-breeding establishments seeking to secure improved strains and to furnish a trustworthy product.

The methods of sugar-beet breeding followed by European firms producing seed for American use are similar in their essential features. The product is marketed under brand designations, usually consisting of the name of the firm and a letter, name, or symbol to indicate the type, that is, whether a high-sucrose strain, a high-yield producer, or a "compromise" or intermediate type. It is the common experience that the types analyzing highest in sucrose produce lower tonnages than the high-yield types, while the latter in turn commonly show a lower sucrose percentage. The so-called compromise types are expected to take an intermediate position.

The firms with which contact has been established apparently follow a system that may be designated as "mother-line breeding." As will be clear from table 6 on page 655 in the appendix and figures 1 and 2, which show commonly used methods, it is meant by this that the pedigree starts with a mother beet, often selected as a result of polariscope tests of many beets. Seed is obtained from this mother beet, more or less effort being made to eliminate out-pollination of the mother plant. A progeny is grown from a portion of this seed, and the performance of the progeny is compared with the performance of progenies similarly produced from other mothers. Selection is based on the performance of the progeny. If a progeny is satisfactory, the reserve seed arising from the mother plant is used to give stocklings from which to secure a considerable quantity of
seed and roots to continue the "line." Usually tests are made of the progenies arising from this increase before the best are pooled together to give an "elite stock" from which to produce commercial seed.

Since the performance of the progenies is reasonably well known from the tests, it is possible to make the poolings to produce brands of the general types desired.

European Breeding Retains Many Diverse Characters

The method of seed production followed in Europe is from the stecklings, produced by growers to whom the elite seed is furnished for this purpose. An attempt is made to have the seed fields reasonably isolated from fields of sugar beets of different type or brand, and from mangel-wurzels grown for seed. The sugar-beet seed is cleaned, then blended to produce a product of uniform grade conforming to the trade standards. The use of the designation "original" is in some countries restricted by law to seed produced by direct increase from an elite stock furnished the grower by the company selling the seed under its brand designation.

The practices in sugar-beet breeding followed by the various companies deviate in various ways from the schemes outlined, but do not depart from the general principle involved. In its essential features the method commonly used corresponds to the ear-to-row method used with corn to secure selected ears from which to plant a seed plot. The number of years devoted to test of beet progenies may vary, and the emphasis given to certain features may differ. It is to be noted that only 1 year of inbreeding is employed. The most salient variation probably occurs in the method of isolating the mother beets.

The statement is commonly made that sugar beets are the product of mass selection. From the methods followed, it is evident that beet seed is not produced by mass selection of the roots that are to furnish the commercial seed. The mass selection is based on progeny performance, and the seed of selected progenies are pooled. This in turn produces the commercial seed. The great divergence of types which show up in every field indicates clearly that the methods followed do not lead to uniformity in foliage or root characters, except as these may be correlated with quantitative characters such as sucrose percentage, yield tendencies, and the like, on which selection is based.

Information is not complete for all firms, but judging from published statements and information furnished, the methods used follow three main lines. Certain firms produce seed of a given type by securing a large number of progenies of satisfactory performance and massing them. Other firms seek a smaller number, one firm using about a dozen lines, each tracing back to a selected mother. Still others use a smaller number than this. It must be borne in mind that these lines are seldom pure lines as the term is used by the geneticist. They are collections of hybrids which may be said to have a satisfactory uniformity in certain physiological characteristics, for example, sucrose percentage. Thus, when they are massed, many more diverse elements are included than might be expected from the limited number of initial progenies.

2 The stecklings are small beet roots produced by close spacing of the plants. These are stored (siloed) over the winter and replanted to produce seed the following year.

3 A method is also illustrated in which an attempt is made to determine the best combinations of "lines" to use in production of commercial seed.
METHOD COMMONLY EMPLOYED IN PRODUCING SUGAR-BEET SEED.

1935 Mother beets selected on basis of morphology and analysis.

1936 Seed produced with more or less isolation of individuals. Low seed producers eliminated.

1937 Duplicate plantings made of seed of individual mothers: (A) for progeny test; (B) as source of roots, if mother line is selected for increase.

1938 Seed production from provisional elites in small, more-or-less, isolated parcels.

1939 Agronomic evaluation test of seed lots of 1938, liberal remnants saved.

1940

1941

1942 Remnant seed lots of selected lines pooled and used to produce stocklings on seed farms.

1943 Commercial seed produced.

1944 Seed used for production of commercial sugar beets.

FIGURE 1.—Diagrammatic representation of European method of producing sugar-beet seed. At some establishments the evaluation tests are made with seed from original mother roots, and seed production shown for 1938 follows these tests.
The methods employed for seed production in the Union of Soviet Socialist Republics (20) are not at present distinctly different from those employed in other European countries. According to the Russian prospectus, an ingenious use is made of fall plantings, presumably in small isolated parcels, which should permit testing of progenies 1 year in advance of the main production contemplated. It was stated to the writer that the inbred lines produced by the intensive breeding investigations at Belaya Cerkov and Kiev, Union of Soviet Socialist Republics (2), were not as yet used to produce commercial seed.

With the majority of European firms, selections of mother beets are made each year to start the series over again and produce seed for the next commercial crop. The new mothers are usually taken from breeding plots, and their lineage on the mother's side can be traced. Hence in the records of the various firms, pedigrees of the mothers can be followed, going back perhaps many generations to a single ancestral beet.

Possibilities for Securing Special Characters Are Limited

In animal breeding, line breeding would be expected to result in remarkable intensification of certain characters arising from the sire. But it must be understood that the cases are not parallel. Whereas with animals the matings are controllable, in the case of the sugar-beet mothers, with the methods usually employed, the situation is one of polyandry. It seems probable that even though the mother line is traceable at each generation, the chance is strong that pollen of a diverse line entered to modify to a large extent the intensification expected. A factor which undoubtedly operates to favor selecting cross-pollinated individuals as against those largely self-pollinated is the choice of mothers that are heavy seed producers. As is well known from breeding experience, the yields from selfed beets are often extremely low and, though not always, the higher yields come from out-pollination.

It must be conceded that if selections were always made among beets that had the same grandmother, great-grandmother, great-great-grandmother, and so on, it would be expected that the cross pollinations would become more and more narrowed to those coming from the ancestral mother stock. But the generally insufficient isolation and the selection of mother beets for high seed yield mentioned above operate to nullify the effects of the attempts at lining and may even result in diverse lines being established within a pedigree that, on paper, apparently precludes such a contingency.

Thus the common observation that a sugar-beet field, no matter what the brand, presents a conglomeration of types serves to show that there is little approach to the intensification of certain characters that might be expected from the pedigrees of the beets.

Critical analysis of the method, therefore, explains the apparent contradictions between the pedigree showing and the actual results. It seems evident that the method serves to sort the progenies of the mother roots into certain grades according to physiological performance—as sucrose percentage—and that this sorting may be accomplished rapidly. Then, as the limits set by inheritance are approached, further improvement is probably slow. It also seems clear that the method cannot be expected to give progenies with special characters,
METHOD FOR PRODUCTION OF SUGAR-BEET SEED WHICH INCLUDES TESTS OF COMBINING CAPACITY OF "LINES"

1935 Mother beets selected for seed bearing.

1936 Seed produced with more or less isolation of mother beets. Elimination based on quantity of seed produced.

1937 Preliminary test with portion of seed. Elimination of poorer progenies.

1938 (A) Chief test of better performers in 1937 trial. (B) Increase plots to supply mother roots as desired. Additional eliminations made alter harvest, retaining best performers (provisional elites).

1939 Seed bearers used in two ways:
(A) Seed increase by progenies a,b,c,n.
(B) Crossings in all combinations between progenies a×b, a×c, a×n, b×c---etc.

1940 Tests in trial fields of A and B lots of 1939.

1941 Seed of lots shown by trial crossings to be satisfactory are mixed in pairs, as: a and f, to produce a×f or b and n, to produce b×n. This seed sent to contract seed growers to produce commercial seed bearers.

1942 Seed year (seed produced assumed to be chiefly hybrid).

1943 Commercial beet seed for use in growing sugar beets for factories. Brands or commercial varieties made by purposeful mixing of a number of the hybrid combinations, as: a,b,e,f,d,g, etc.

FIGURE 2.—The method of producing sugar-beet seed coming into use in certain European seed establishments. It offers the advantage of tests of combining capacity of lines prior to final large-scale making of combinations.
such as resistance to disease, unless provision can be made for rigid selection for the desired character. It would appear also that massing of many progenies would tend to nullify any advance made with a limited number. The method is apparently adequate to hold the progress made by narrowing the population to the types that possess certain characters in common and to get rid of any serious admixture of chard, mangel-wurzel, or red garden beet. But the performance of the variety or brand obtained in this manner may be expected to be the average of its many components and to show little change as one series follows in the steps of its predecessor.

**Breeding Sugar Beets to Meet the Special Needs of Growers in the United States**

THE system followed in Europe, then, is a mass-selection scheme based on progeny performance—the Vilmorin method—coupled with attempts to maintain certain mother-beet lineages. That noteworthy progress has been attained by this method is evident. The results may be judged from the performance of European beet seed in the United States, which shows that seed purchased from a reliable firm is commonly true to its brand characterization and almost always free from serious admixture with red garden beets, mangel-wurzels, and Swiss chard. Farmers may use this seed with a high

THE sugar beet as we have it today may have lost important factors in the course of its development, or there may be exceedingly valuable new genes which might be introduced. Two avenues are open for experimental exploration in the search for new genes—the cultivated plants with which the beet readily hybridizes, and the wild species of the genus. Also of exceeding interest in practical breeding work is the reaction which follows hybridization of inbred lines. The general average of 41 hybrids was an increase in yield of 39½ percent over the commercial variety used as a check, the highest yielder showed an increase of 65.7 percent.
degree of assurance that crop yields will be satisfactory under favorable conditions for growth and development. But American conditions for growth and development are not always favorable, nor do they parallel the soil and climatic conditions under which the seed was developed. In developing his various brands of sugar beets—the so-called sugar type, the intermediate type, or the tonnage type—the European seed producer sorts out the hereditary combinations as well as possible to conform to these categories. Because it is a complex mixture of potentialities, the same brand of seed may suffice for the eastern United States, the Rocky Mountain region, and the Pacific coast. Under such diverse conditions, one portion or another of the population thrives—but conversely certain portions may be totally unsuited to the conditions. It is clear that a variety adapted to a given area should perform better than one whose performance is an average of good, mediocre, and poor producers. This point has long been recognized, and home production of seed has been urged by the United States Department of Agriculture and various experiment stations as a logical step for improvement of sugar-beet crops.

In table 1 (p. 652) are listed the important projects in sugar-beet breeding undertaken in the United States. The list is of interest for its record of efforts that did not persist as well as those that show present trends. The small number of commercial firms engaged in these efforts is significant. In many areas, European sources are depended on entirely for seed supplies. So long as the policy of purchasing seed abroad is continued, the general level of performance in these districts probably will not be greatly altered.

With other crops, even those that are cross-pollinated and comparable to the sugar beet, no such system of importing seed supplies from a distance prevails. In the case of the corn crop, for example, increasing attention is given to securing varieties adapted to the soil and climatic conditions in a given area. The superiority of the product from home-grown seed is generally accepted. With full recognition of the good average performance of the high-grade brands of sugar-beet seed now imported for American use, it must be frankly pointed out that the European methods have their inherent limitations which make it essential that breeding work with new aims be carried on if adequate attention is to be given to some very definite requirements of the American beet grower.

The importance of this to American agriculture can probably best be brought out by considering the part played by epidemic plant diseases in recent years. These disease hazards to our crops are as much a part of growing conditions as the general factors included in soil and climatic effects. In the western United States, curly top is the limiting factor in sugar-beet production; in the areas east of the Rocky Mountains, Cercospora leaf spot or "blight" is a problem of major importance.

Since 1900 western growers and operators have been asking the European producers of seed for varieties resistant to curly top. The losses in the period from 1900 to date from curly top have been enormous; crop failures have been frequent because of this disease. For an equally long period there has been a demand for strains resistant to Cercospora. Since curly top does not occur in Europe and since Cercospora leaf spot very rarely reaches serious proportions in the seed-breeding areas of northern Europe, little or no progress has been
made in meeting the American demand. Tests of the leading brands of European seed have shown that without exception they lack, as brands, resistance to these diseases. But it is noteworthy that within these brands individuals have been found more resistant than their fellows. The sorting out of these resistant individuals can be done only under conditions in which the disease occurs as a severe outbreak (9).

The heavy losses and the occasional crop failures in certain districts from sugar-beet diseases, which may be conservatively stated as amounting to many millions of dollars a year, show clearly that the development of resistant sorts is a most pressing need of the American industry. The magnitude of the losses gives some indication of the return to be expected from successful efforts in this direction. Resistant varieties will not only mean increased income for the farmers; the control of these epidemic diseases will also have a stabilizing effect on production (3). The importance of investigations looking to the development of varieties of sugar beets safe from disease has in the last 13 years been fully recognized by the Division of Sugar Plant Investigations (5).

Resistance to Curly Top

The history of the experimental work looking to the development of curly-top-resistant varieties dates from 1902. Carsner (8) has reviewed these early experiments and appraised their contribution. Although they did not result in the development of strains suitable for use, these attempts demonstrated that from the complex of hereditary combinations existing in commercial brands of sugar beets, highly resistant components could be separated. It may be remarked that this finding, which today is accepted without question, was strikingly at variance with a rather pessimistic belief on the part of many European breeders as to such a possibility.

The first curly-top-resistant variety furnished growers for commercial use was produced by Eubanks Carsner and D. A. Pack in 1929 and came into extensive use in 1934. It was released under the designation U. S. 1 (8) (fig. 3). After intensive test in the western United States in 1930, 1931, and 1932 by members of the Division of Sugar Plant Investigations, steps were taken to make this variety available as the means of combatting the destructive course of curly top. The details of the development of this variety, the results of the tests, and an outline of the methods used in securing rapid multiplication of seed to commercial proportions are given in the publication cited.

The variety was produced by growing for seed production the highly resistant individual roots taken from progenies of mother roots that had been selected from fields and experimental plots in which curly top exposure had been severe. Table 2 (p. 652) gives the data concerning seed production for this variety and an estimate of the acreage on which it has been used. Its prompt acceptance and the expansion of its use to the limits of the seed supply is evidence both of the need and of the performance of the variety under curly top conditions.

Detailed account of tests with this variety in 1932, 1933, and 1934 has been published (24). These tests have shown a general superior-

\[4\] Acknowledgment is made to H. A. Klock, sugar-beet seed committee, P. S. Ingalls, Utah-Idaho Sugar Co., and the Farrar-Loomis Seed Co. for data as to commercial sugar-beet seed production in the United States.
ity over commercial brands amounting to at least 2 tons per acre under moderate curly top exposure, and reaching 5 tons or more per acre, as indicated by the preliminary tests, when curly top was severe. The sucrose percentage of the variety has always been high, in many cases exceeding that of the commercial brand with which it was compared.

Because of the emergency, the variety was released before it was perfected in curly top resistance or with respect to certain other characters. For example, it has a tendency to bolt, which precludes its utilization for winter plantings in California. Effort has been concentrated on improving and stabilizing the variety, and as improvement has been accomplished new foundation stocks have been furnished for increase, looking to their use by growers. In tables 2 and 3 (pp. 652, 653) details are given of two new releases, designated as U. S. 33 and U. S. 34, which were obtained as mass selections from U. S. 1. These selections were made by F. V. Owen and F. A. Abegg in 1931 from fields in Idaho in which curly top was extremely severe.

The data on the performance of U. S. 33 and U. S. 34 have not been fully evaluated, but these two varieties represent a decided improvement in curly top resistance over U. S. 1. In some experiments, the superiority of U. S. 34 over U. S. 1 seemed almost as striking as that of U. S. 1 over commercial brands with which it was compared. Under conditions of severe curly top exposure, U. S. 34 has produced upwards of 10 tons per acre, U. S. 1 about 7 tons, and commercial brands from 2 to 3 tons. The sucrose percentage has been maintained at a high level. As will be noted from the tables, seed of U. S. 34 has been increased in greater amount, and this variety will replace U. S. 1 in the production of sugar beets for fac-

![Figure 3](image-url)
tory use in the curly top areas beginning with 1936. Present indica-
tions are that this curly-top-resistant variety will be used almost
exclusively in some districts. U. S. 33, which produces a slightly
higher sucrose percentage and has less bolting tendency, will probably
come into large-scale use in 1937.

Breeding work to secure curly-top-resistant strains of sugar beets
is being continued. It is expected that from time to time new
improved material can be furnished as foundation stocks to replace
existing material. As illustrative of the program, table 4 (p. 653) has
been compiled to furnish a partial list of promising varieties and strains
being submitted to intensive agronomic tests in the curly top area to
determine their suitability for future commercial use. It will be
noted that, in addition to curly top resistance, the strains are being
tested as to bolting tendency in order to secure varieties adapted to
the present program of sugar-beet planting followed in California.
As will be seen from the sources of material listed, some trace directly
to U. S. 1 and arise from small groups of selected mother beets
chosen for outstanding curly top resistance; others trace back to the
original strains utilized by Eubanks Carsner and D. A. Pack in pro-
ducing U. S. 1; one variety is listed from selections made for curly
top resistance at State College, N. Mex. The progenies from single
mother beets of exceptional resistance, which are the starting point
in the development of pure lines, cannot be evaluated as yet because
they have not progressed far enough toward a homozygous condition.

Resistance to Cercospora Leaf Spot

The problem of securing strains of sugar beets resistant to leaf spot
has received attention since 1925. At the outset of this work, no
varieties outstanding in resistance from which to make selections
and to serve as a starting point for improvement existed, with the
exception of the Leaf Spot Resistant variety developed by Skuderna
(23) from an early selection made by W. W. Spencer.

The methods followed in breeding for Cercospora leaf spot resistance
have been reported from time to time (3) and statements given of
results. Selections made under severe leaf spot epidemic have been
tested, and the results show that some progress can be made in this
way. The nature of the disease and the absence of immune or
strikingly resistant individuals in present commercial brands have
made it practically impossible to select on the basis of the degree
to which leaves are affected. However, by use of the criteria of weight
development and high sucrose percentage under leaf spot conditions,
strains have been obtained that are strongly improved in their reaction
to leaf spot. The advance made, however, has not been so marked
as to warrant belief that simple field selection will meet the difficult
problem presented.

The attack, therefore, has centered chiefly on the use of selection
and inbreeding to secure lines of beets stabilized in leaf spot resistance
to serve as a basis for production of hybrids or synthetic varieties.
It has been found that as inbreeding has continued, the lines under
study have lost vigor but maintained their capacity for sucrose
storage. The lines secured to date, while high in leaf spot resistance,
are not heavy enough producers to be suitable for use in commercial
sugar-beet production.
The problem then has resolved itself into the accumulation of leaf-spot-resistant lines and the use of these lines in various combinations to find those that prove to be superior upon hybridization, either as a single or a double cross, or as a synthetic variety—a combination of several desirable inbreds (fig. 4). Because of the sporadic nature of leaf spot outbreaks, the performance of the varieties must be satisfactory not only under Cercospora leaf spot conditions but also when the disease is not a factor.

In securing these resistant inbred lines, use has been made of the results painstakingly secured by W. W. Tracy, Jr. Beginning in 1915, he carried on a series of inbreedings with sugar beets for the purpose of isolating as many types as possible from the complex. Continued until 1929, Tracy's work gave source material from which strains outstanding in resistance were chosen. Selections were also made from the Leaf Spot Resistant variety developed by Skuderna.
Table 7 (p. 656) lists outstanding inbred lines that have come from this research. In all cases, these inbred lines have been increased in isolated plots to secure supplies of seed for use in large-scale production when the results of intensive tests determine which combinations of lines are the most desirable.

The first large-scale use of leaf-spot-resistant lines will be possible in 1937 with two synthetic varieties at present known by their field designations, accession 217 and accession 220. Using five inbred lines 40299–0 (a), 5–734–0 (b), 5–297–0 (c), 40293–0 (d), 5–735–0 (e), hybrids have been made by pairing a × b, b × c, d × e, in three isolated fields. The seed from these fields has been mixed in approximately equal proportions to supply the stock seed for planting commercial seed fields. Accession 220 contains the same inbred lines as accession 217, but the method of incorporating the lines in the final synthetic variety is slightly different. Seed will be produced in the summer of 1936 on approximately 150 acres. The seed stocks of the inbred lines are being maintained, and from these, new poolings can be made to continue the production of the synthetic varieties as long as their performance justifies it.

In the plan followed, preliminary tests of the varieties should be far enough along before the large-scale commercial increases (second commercial increases) are made to give information as to the performance to be expected from the synthetic variety.

OTHER BEET-BREEDING ACTIVITIES IN THE UNITED STATES AND CANADA

Cooperative work of the Michigan Agricultural Experiment Station with the United States Department of Agriculture is closely following the plan of securing pure lines by inbreeding, testing combinations of these lines for effects of heterosis or hybrid vigor, and testing the strains so produced for performance under humid-area conditions. These plans look toward laying the foundation for the production of a stable, improved variety of sugar beets that can be reproduced again and again as needed. A report from this experimental work in 1935 indicates that many inbred strains are being compared, 5 of them having been inbred for 6 generations, 90 for 5, 112 for 4, and 44 for 3 generations. These strains, which were started from selected roots taken from commercial brands, are beginning to become uniform in appearance with continued inbreeding, and crossing between inbred trains is projected.

Breeding investigations of the Department of Agriculture in cooperation with the Colorado Agricultural Experiment Station in Colorado have been concerned with the technique to be employed in securing isolation (?); inheritance of certain genetic characters; and the development of inbred lines suitable for studying the inheritance of quantitative characters such as sucrose percentage and size and shape of root. Selections have been made for resistance to drought and cold. Tests of progenies from these selections have shown that cold resistance in the seedling stage is a hereditary character and capable of purification. Inbred lines from red garden beets and from sugar and red garden beet crosses are being carried for use in genetic investigations.

The California Agricultural Experiment Station, Davis, Calif., has conducted sugar-beet breeding investigations chiefly for curly top 5 See table 7.
resistance and to secure nonbolting lines. The work was begun in 1928 when some curly-top-resistant material was turned over to the station by the Spreckels Sugar Co. This material and the results obtained with it have been described (12). The work with the resistant variety was continued by the experiment station on a very limited scale until 1933 and then was practically dropped because it seemed inadvisable to duplicate similar work being done by the Department of Agriculture. None of the seed developed in Davis was ready for commercial distribution, but some of it, considered valuable for hybridization, was sent to the Federal station at Salt Lake City, Utah.

Breeding for nonbolting was begun in 1929 on a small scale and results do not yet permit any definite conclusions. The first generation of the beets selected for nonbolting showed marked decrease in the tendency to bolt, but in the second generation certain lines showed a high degree of bolting while others maintained a lower degree.

In cooperation with the Department of Agriculture, breeding investigations are being conducted to attempt to secure strains of beets resistant to root rot caused by Sclerotium rolfsii. This work, begun in 1932 with beets selected from badly affected fields, shows some promise that resistant material may be obtained.

Breeding Work of Commercial Organizations

The Canada & Dominion Sugar Co., Chatham, Ontario, has conducted mass-selection work since 1912 to produce an improved strain. Several hundred pounds of this seed were used for steckling production in 1934. The strain is known as Home Grown (Canada). Other lines are being developed.

The research department of the American Crystal Sugar Co.—formerly the American Beet Sugar Co.—Rocky Ford, Colo., conducted mass-selection work from 1920 to 1929 and developed the Flat Foliage variety, a high-sugar type, for use under leaf spot conditions prevalent in southeastern Colorado. The strain is used on a considerable scale, seed being produced annually from elite stocks.

By repeated selections, beginning with a beet selected under epidemic conditions, a strain was produced designated as Leaf Spot Resistant. This strain, which possesses high leaf spot resistance, was too low in sucrose percentage to be used commercially. It has been a valuable source of inbred strains possessing high resistance to Cercospora leaf spot.

The research division of the Great Western Sugar Co., Denver, Colo., has conducted extensive beet-breeding operations since 1915, growing many hundreds of acres of beet seed annually from its elite stocks. Until recently the methods followed have been similar to those used in European beet breeding. Announcement has been made of the development, by "family" or tested-progeny breeding, of a type tolerant to Cercospora leaf spot (10). This variety is being widely used in company operations under the name Great Western.

The Amalgamated Sugar Co., Ogden, Utah, has conducted selection work for curly top resistance and developed a variety called 600, which possesses strong curly top resistance, by crossing a hybrid, P 19 (Spreckels Sugar Co.) × 905a2 (Carsner), with primary selections from commercial fields. In 1936, a considerable quantity of this variety will be used in commercial acreages.
New Industry Based on Plant Breeding—Production of Sugar-Beet Seed in the United States

As has been stated, the United States has imported the greater part of its sugar-beet seed supply except during the World War period. The costs of seed production under the conventional system in which stocklings are siloed over winter and replanted in a seed field were much greater in the United States than abroad. In the absence of specially adapted varieties in the United States, the urge for domestic seed production was in part lacking. Certain companies having breeding work in progress have maintained seed production by the conventional method. The data as to seed imported from year to year into the United States have been compiled from United States Department of Commerce reports. In general, about 15,000,000 pounds were brought in annually in the period from 1920 to 1933. American production prior to 1932 furnished a very small percentage of the sugar-beet seed used.

Cooperative investigations by the New Mexico Agricultural Experiment Station, State College, N. Mex., and the United States Department of Agriculture demonstrated the possibility of producing sugar-beet seed under the mild winter conditions in the southwestern United States by overwintering the plants in the field. This method eliminates the expensive handling costs involved in lifting stocklings.
in the fall, siloing, and replanting. The losses of stecklings in the silo due to freezing and rotting are also avoided.6

In the method as developed, some of the steps of which are illustrated in figures 5, 6, and 7, beet seed is planted in early September, exactly as one would plant sugar beets for ordinary crop production. The beets are left unthinned and given enough irrigation to maintain them alive over winter. The next summer, seed is produced on the overwintered plants. Cultural operations, except hand hoeing which may be necessary in weedy or grassy fields, are carried on by machine. The seed may be cut by machine (mower or reaper) or by hand. The seedstalks are shocked in cobs to dry, and the seed is threshed, either from the field or from stacks, with standard threshing equipment adapted for this purpose. By care in giving light irrigations at weekly intervals during the setting period, seed of high viability has been obtained. In certain years, clean seed, graded to remove the small, immature seed, has shown from 85 to 90 percent germination.

The development of the sugar-beet seed industry in New Mexico, Utah, Nevada, California, and recently in Arizona, has been rapid. For the years 1933, 1934, and 1935 the seed produced by this method was largely the U. S. 1 and U. S. 34 varieties.7 In the 3 years mentioned 5,283,000 pounds of the curly-top-resistant varieties were

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6 Because it illustrates the turning to advantage of some otherwise fruitless efforts, the history of this important development has unusual interest. Experiments begun in 1922 by C. O. Townsend and Fabian Garcia with a view to determining the best time to plant for beet production led to observations encouraging the belief that seed production by overwintering the plants in the field was practicable. The experiments originally planned demonstrated the futility of attempting to grow beets for the factory in that area on account of unusually severe curly top. However, the tests served a useful purpose because fall plantings were included and these proved the clue to the seed-production method. Several investigators contributed to the method, including G. R. Quesenberry and W. T. Conway, who directed attention to the fact that September plantings uniformly produced seed stalks. E. W. Brandes, who succeeded Dr. Townsend in charge of the Division of Sugar Plant Investigations, observing that, in great contrast to the earlier plantings, the September plantings were singularly free from curly top and therefore definitely more promising, shifted the local interest of the Division to seed production exclusively. Under the direction of J. C. Overpeck the cooperative seed experiments were vigorously pushed, with results that vindicated belief in the new industry.

7 See tables 2 and 4, pp. 602 and 603.
produced on 2,400 acres, the average yield per acre being 2,200 pounds.

In the fall of 1934 nearly 500 additional acres were planted with American varieties other than the curly-top-resistant sorts, for use outside of the curly top area. The indications for 1936 are that on a total of 5,350 acres planted in the fall of 1935 the United States will produce approximately 30 percent or more of its 1937 seed requirements. Details of this interesting development are given in the literature cited (11, 19).

Domestic seed production and breeding are definitely interlocking activities. Prompt introduction of improved varieties can best be accomplished if facilities are available for the economical production of seed true to designation and of good quality. Domestic seed production requires a constant source of elite seed to use for increase. We may expect steady expansion of domestic seed production and with it greater developments in breeding to provide improved and tested supplies of foundation stocks.

Recent Advances in Genetics Promise Further Possibilities for the Breeder

As is generally recognized, the sugar beet presents certain difficulties in genetical investigations. It is commonly biennial and normally sets seed as a result of wind or insect pollination. It is readily out-pollinated by red beet, chard, or mangel-wurzel. The
small, perfect flowers, borne in a common cluster of from one to five or more, make hand pollination extremely difficult, especially as the progressive opening of the flowers on the seedstalk increases the likelihood of contamination. These factors make breeding experiments with the sugar beet time-consuming and arduous.

Earlier work depended largely on space isolation to secure selfing of plants. Many investigators have reported securing set of seed under cages of cloth or of glass. The cloth used for cages was believed to be close-meshed enough to prevent entry of foreign pollen. Successful results have also been obtained by use of parchment or kraft paper bags. Extensive tests of this method have been reported by Browbaker (7), who refers to earlier use of the bagging method with beets. Other advances in technique may be noted, such as the use of vegetative clons of beet roots to continue the stock and to permit hybridizing plants with a comparable genetic make-up. Fruiting has been controlled in greenhouse plantings by means of temperature control and the use of artificial light to increase length of day. By the use of the bagging technique in these greenhouse plantings, selfing of individuals and controlled crosses have been readily secured. Vernalization of germinating seed has been used to induce early fruting in greenhouse tests and has also afforded a reliable means of judging tendencies toward early bolting. These methods are in common use at the United States Sugar Plant Field Station at Salt Lake City, Utah, and have been of distinct service in genetic investigations.

With any type of isolation the possibility of undesired crossing must be recognized. Space isolation cannot be adequate to assure absence of wind-blown or insect-carried pollen in all cases. Sugar-beet pollen has been caught by airplanes high in the air, and preliminary tests indicate that pollen grains caught at elevations of 1,000 feet apparently were viable. The caging of plants requires meticulous care that the cages be set before any flowers open. The bagging requires faithful examination to assure that no flowers on the branch have opened.

Several investigators have reported the existence of sterile, partially sterile, and self-sterile individuals in the sugar-beet complex. Inbreeding obviously sorts out self-sterile individuals at once, so that inbreeding is restricted to the strains that produce seed under these conditions (15). There is a pressing need in sugar-beet breeding for more information on the self-sterility and self-fertility factors. Improvement of breeding methods and efficient utilization of the material now available is dependent on the findings that may come from such research.

A similar statement might be made concerning other heritable characters of the sugar beet. Only a start has been made on the problem involved in color inheritance, the early investigations by Lindhard and Iverson (16) having given information on the characters involved in red, yellow, and white coloration, with a hint at linkages. Recently Keller (14) has listed nine color characters and given evidence as to their inheritance. In this study the cross-over value between the factor \(B\) for red color of the hypocotyl (the portion of the stem below the first seed leaves) and the basic pigment factor \(Y\)

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3Vernalization as employed with sugar beets denotes exposure of germinating seeds to temperatures near the freezing point for approximately 1 month. The effects of such treatment are the shortening of the vegetative period and the prompt occurrence of the fruiting phase.
was found to be approximately 7.5 percent. Evidence has been secured by F. A. Abegg and is now in course of publication on a linkage relation between annualism (bolting the first year) and red hypocotyl color, $R$. A linkage between a major factor for curly top resistance and this hypocotyl color has also been shown. These two studies give the first definite information on a linkage group in sugar beets\(^9\) \(13\). Advances in our knowledge in this direction have prompt and valuable applications. Characters such as color are of great service to the plant breeder because they may serve as markers to identify a hybrid and permit its separation in experimental crossings.

The reports of recent work from foreign laboratories are extremely interesting. Russian investigators and those in other countries are engaged in a thorough cytological study of the chromosomes in the sugar beet and of chromosome variation. To the previous knowledge of the chromosome numbers of *Beta vulgaris*, *B. maritima*, and *B. trigyna* has been added the information for various other wild species. It is probably of considerable significance that the $2n$ chromosome number in all species of *Beta* studied, except *trigyna*, is 18. *B. trigyna* has 36 as the $2n$ number, and a strain of this species with a variant number has been found in the Crimea. The Russian workers also report polyploidy as occurring and state that the polyploid individuals show increased value for use.\(^10\)

### EXPLORING NEW SOURCES OF GENES

With the renewed interest in such scientific attacks on sugar-beet genetics, the problem of the gene content of the beet becomes of salient importance. As has been brought out earlier, the sugar beet as we have it today, with variations that seem so numerous as to confound analysis, may have lost important factors in the course of its development or there may be exceedingly valuable new genes which might be introduced (5). It is clear that the source of new genes must be outside of the sugar-beet brands now available, because these seem largely, if not entirely, to trace back to a common source. Two avenues seem open in this experimental exploration. The cultivated plants with which the beet readily hybridizes—the red garden beet, the Swiss chard, and the mangel-wurzel—may be sources of new factors for the geneticist. Savitsky,\(^11\) for example, has produced evidence concerning inheritance of quantitative characters. He believes that sucrose production may be governed by four factors which he denominates $SS SS SS SS$, of which three exist in the sugar beet and a fourth in the mangold (Swiss chard). Similarly, he suggests that factors which govern size may reside in the mangel-wurzel, which, while it can make no contribution to the sucrose factors, may contribute size factors to the sugar beet.

The other source of new genes may be the wild species of *Beta*. It has commonly been accepted that *B. maritima* was the wild progenitor of the sugar beet. The ready crossing of *B. maritima* with all types of

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\(^9\) Abegg, F. A. A Genetic Factor for the Annual Habit in Beets (*Beta vulgaris* L.) and Linkage Relations. (In preparation.)

\(^{10}\) For a brief resume of Russian investigations, the summary by Kagan in the Institut International de Recherches Betteravières for 1934 may be consulted. More complete accounts have been published in the various reports from the Sugar Research Institute, Kiev, Union of Soviet Socialist Republics.

\(^{11}\) See footnote 15, above.
beets, the similarity of chromosome numbers and the apparent (not explored) identity in hereditary characters gave color to this assumption. Recently the studies of Zosimovich (29) on the species of Beta occurring in Transcaucasia and Asia Minor have focussed attention on this area as one of the main centers of formation of the genus.

Table 8 (p. 656) gives a list of the wild species of the genus Beta and the general geographic areas in which they are found. For additional information the monograph by Ulbrich (25) may be consulted. Those which are known to cross with sugar beet are indicated in the table. During the summer of 1935, seeds of many of these species were secured for use in experimental work in the United States.

**HYBRIDIZATION OF INBRED LINES**

Of exceeding interest in practical breeding work and in genetic investigations is the reaction which follows hybridization. On the basis of the results in corn investigations and certain general observations, such as the response when Beta vulgaris and B. maritima are crossed (9), heterosis effects have been predicated as occurring in the F₁ or first hybrid generation of sugar beets. Evidence secured with 22 inbred lines developed in the course of the Cercospora leaf spot investigations ¹² clearly indicates the significance of heterosis phenomena in sugar beets. The general average for the 41 hybrids produced by various combinations of these inbred lines showed the yield of the hybrids to be 43 percent greater than the mean yield of both parents, and 39.5 percent greater than the yield of the commercial variety used as a check. Considering individual results from the replicated tests, the lowest hybrid yielded 9.8 percent more than the commercial check, and the highest, 65.7 percent more. No hybrid lot was significantly lower in yield than the check, 12 of the 41 tested were not significantly different, and 29 were significantly better. The comparisons based on mean yields of both parents are approximately the same as those given in terms of the commercial brand. Sucrose percentages in hybrids, with a few exceptions, seemed to approach the mean of the parents chosen.

The placing of heterosis in sugar beets on a factual basis is extremely significant in its bearings on the future breeding program. Since strong responses in yield came in a fairly large percentage of the crosses, and the yields of the hybrids were often strikingly better than the mean of the parents, and often exceeded that of the commercial brand used as a check, it may be expected that beet-breeding methods will seek to utilize inbred lines in purposeful combinations as has been profitably done with corn.

Not all hybridizations result in a more vigorous F₁ generation. Hence the problem requires the development of many desirable inbred lines and the determination of their qualities and behavior in various hybrid combinations.

Since the production of inbred strains seems to be desirable in breeding efforts, a direct and logical corollary of the findings made on heterosis may be pointed out as a guide in such attempts. Drawing from our experience, it may be stated that mere continuous selfing of plants, especially on the limited scale possible with sugar beets, does not necessarily lead to the results commonly connoted in the term "inbreeding." In selection work, it is entirely natural to choose

¹² From unpublished data obtained in investigations by Stewart, Lavis, and Coons, U. S. Department of Agriculture.
sugar beets on the basis of size and sucrose percentage. Since the sugar beets with which breeding operations would start are essentially hybrids, and the breeding plan hitherto followed seeks to insure this, the large beets in the field most likely is large because of its hybrid nature. As this beet is inbred, the large beets in its progeny would be the ones most nearly reproducing the parental F1, or hybrid condition. Hence it is conceivable that continued inbreeding might deal always with the heterozygous portions of the progeny and make little progress, the material under study never reaching a stage of homozygosity such that there could be rapid progress in purification. As one reads various statements about the selection of beets on the basis of size and sucrose content, it is clear that the potency of heterosis, although accepted in theory, has often been disregarded in practice.

The sugar-beet breeding projects of the Department of Agriculture, as shown in preceding sections, have followed two lines of development: (1) For immediate production of varieties showing adaptation to the disease factor or some other special condition, the standard selection methods have been followed, and when desirable varieties have been obtained in this way, these have been made available for general use, and (2) increasing emphasis is being placed on the development of desirable inbred lines as the basis for beet improvement. The securing and testing of such lines and the determination, among companion lines, of those that are compatible and complementary require much effort. The process is slower in attaining desired results than is the case with certain other plants.

As vigor seems to become less with continued inbreeding—although this may not invariably be the case—the task in such a problem as breeding for Cercospora leaf spot resistance is complicated by the necessity of finding many lines instead of a single one. As lines are developed, one is always confronted with the fact that the sugar beet is a highly specialized crop, and inbred lines must be severely culled to retain only those of satisfactory commercial quality.

Given inbred lines suitable in quality and stabilized, for example, for leaf spot resistance, there is still the problem of securing the desired intercrossing between lines on a commercial scale. In any large-scale attempts at hybridization, a certain percentage of the plants are the result of self-fertilization, which perpetuates the original inbred lines. Such selfed plants probably will yield less than those arising from cross pollination between the lines paired. Various methods of counteracting the effects of selfing in the development of the final product are under test. One method used is the scheme described in connection with the two synthetic varieties being increased for use in leaf spot areas.

These steps in the development of a technique in beet breeding may take a considerable time to perfect. Genetic research is now giving information that can be applied to the very practical problem of securing improved varieties for the farmer. The performance of such hybrid combinations as have been made so far is exceedingly encouraging. Once the desired combinations are found, the results should be noteworthy. Since the foundation inbred lines may be maintained by proper isolation, or made more homozygous by additional generations of inbreeding, the recreating of the desired combination may readily be accomplished. The increased efficiency possible with this simplification of the work of producing foundation or elite
stocks of sugar-beet varieties will in itself do much to offset the expense and effort necessary to secure the basic inbred lines with which to work.

The interest that is being aroused in the whole subject of sugar-beet improvement is extremely encouraging. As the problems are understood and the needs are properly visualized, there is little doubt that the American industry will take up the challenge.

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### Table 1.—Record of seed production and utilization of the curly-top resistant variety U. S. 1, 1929–35

<table>
<thead>
<tr>
<th>Year of seed production</th>
<th>Description</th>
<th>Place</th>
<th>Area planted for seed production</th>
<th>Quantity</th>
<th>Commercial beet acreage planted in curly top area</th>
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<tr>
<td>1929</td>
<td>Original or foundation stock.²</td>
<td>Twin Falls, Idaho</td>
<td>70-100</td>
<td>972</td>
<td>600</td>
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<tr>
<td>1930</td>
<td>First direct multiplication</td>
<td>State College, N. Mex, St. George, Utah</td>
<td>600</td>
<td>660</td>
<td>660</td>
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<tr>
<td>1931</td>
<td>Second direct multiplication</td>
<td>State College, N. Mex, Hemet, Calif</td>
<td>1,500</td>
<td>1,657</td>
<td>1,500</td>
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<tr>
<td>1932</td>
<td>Second direct multiplication (called also first commercial increase)</td>
<td>Mesilla Valley, N. Mex, St. George, Utah, Hemet, Calif</td>
<td>6,774</td>
<td>8,324</td>
<td>5,960</td>
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<tr>
<td>1933</td>
<td>Third direct multiplication (called also second commercial increase)</td>
<td>Mesilla Valley, N. Mex, St. George, Utah district ¹, Hemet, Calif</td>
<td>390,000</td>
<td>341,308</td>
<td>146,061</td>
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<tr>
<td>1934</td>
<td>Third direct multiplication (called also second commercial increase)</td>
<td>Mesilla Valley, N. Mex, St. George, Utah district ¹, Pecos Valley, N. Mex</td>
<td>823,971</td>
<td>918,529</td>
<td>140,667</td>
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<td>1935</td>
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</table>

¹ Estimated, seed used in year shown was mostly produced the preceding season.
² Carman (8).
³ Seed produced by commercial companies.
⁴ Includes acreage in Moapa Valley, Nev.

### Table 2.—Record of seed production and utilization of the curly-top-resistant variety U. S. 33, 1932–36

<table>
<thead>
<tr>
<th>Year of seed production</th>
<th>Description</th>
<th>Place</th>
<th>Area planted for seed production</th>
<th>Quantity</th>
<th>Commercial beet acreage planted in curly top area</th>
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</tr>
<tr>
<td>1932</td>
<td>Reselection from U. S. 1 (selection based on refractometer and polariscope readings, 100 roots chosen)</td>
<td>Twin Falls, Idaho and Salt Lake City, Utah</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>Seed increase</td>
<td>Salt Lake City, Utah</td>
<td>230</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1934</td>
<td>First multiplication</td>
<td>State College, N. Mex</td>
<td>5,646</td>
<td>5,646</td>
<td>5,646</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1935</td>
<td>Second multiplication (called also first commercial increase)</td>
<td>State College, N. Mex, Pecos Valley, N. Mex, Hemet, Calif</td>
<td>30,000</td>
<td>30,000</td>
<td>30,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1936</td>
<td>Third multiplication (called also second commercial increase)</td>
<td>Mesilla Valley, N. Mex, Salt River Valley, Ariz, Moapa Valley, Nev, Hemet, Calif</td>
<td>371</td>
<td>371</td>
<td>371</td>
</tr>
</tbody>
</table>

¹ Estimated, seed used in year shown was mostly produced the preceding season.
² Carman (8).
³ Seed produced by commercial companies.
⁴ Includes acreage in Moapa Valley, Nev.
Table 3.—Record of seed production and utilization of the curly-top-resistant variety, U. S. 34

<table>
<thead>
<tr>
<th>Year of seed production</th>
<th>Description</th>
<th>Place</th>
<th>Area planted for seed production</th>
<th>Quantity</th>
<th>Commercial beet acreage planted in curly top area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932</td>
<td>Reselection from U. S. 1 (1,000 roots chosen from 10,000 picked for curly top resistance, selection based on refractometer reading).</td>
<td>Twin Falls, Idaho, and Salt Lake City, Utah.</td>
<td>1.38 Acres</td>
<td>857 Pounds</td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>First multiplication (called also first commercial increase).</td>
<td>State College, N. Mex.</td>
<td>5 Acres</td>
<td>10,770 Pounds</td>
<td>Experimental acreage.</td>
</tr>
<tr>
<td>1934</td>
<td>Second multiplication (called also first commercial increase).</td>
<td>Mesilla Valley, N. Mex.</td>
<td>10 Acres</td>
<td>22,496 Pounds</td>
<td>Do.</td>
</tr>
<tr>
<td>1935</td>
<td>Third multiplication (called also second commercial increase).</td>
<td>St. George, Utah.</td>
<td>34.25 Acres</td>
<td>27,411 Pounds</td>
<td></td>
</tr>
<tr>
<td>1936</td>
<td>do.</td>
<td>St. George, Utah.</td>
<td>5 Acres</td>
<td>1,281,881 Pounds</td>
<td>90,000-100,000 acres.</td>
</tr>
</tbody>
</table>

1 Estimated.

Table 4.—Source list of material available in 1936 as possible foundation stocks to replace U. S. 34

[List given is a partial one and subject to drastic revision following evaluation tests]

<table>
<thead>
<tr>
<th>Designation</th>
<th>Source</th>
<th>By whom selected</th>
<th>Years tested</th>
<th>Outstanding character</th>
<th>Suggested utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. S. 13</td>
<td>5001 (Carsner and Pack) California increase.</td>
<td>do</td>
<td>2</td>
<td>Curly top resistance; good yield under curly top conditions.</td>
<td>First commercial increase.</td>
</tr>
<tr>
<td>U. S. 14</td>
<td>5001 (Carsner and Pack) Utah increase.</td>
<td>do</td>
<td>2</td>
<td>do</td>
<td>Do.</td>
</tr>
<tr>
<td>2167</td>
<td>U. S. 1</td>
<td>F. V. Owen and F. A. Abegg.</td>
<td>2</td>
<td>Curly top resistance; nonbolting and high sugar.</td>
<td>Seed supply being increased.</td>
</tr>
<tr>
<td>536</td>
<td>Hybrid, U. S. 1 selection X “600” (Amalgamated Sugar Co.).</td>
<td>F. V. Owen, R. A. Abegg, R. H. Cotrell, and V. Jensen.</td>
<td>1</td>
<td>Curly top resistance; extremely nonbolting.</td>
<td>Selection and increase.</td>
</tr>
<tr>
<td>Period</td>
<td>By whom carried on</td>
<td>Place</td>
<td>Methods employed</td>
<td>Purpose</td>
<td>Varieties produced</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------</td>
<td>-------------------</td>
<td>-----------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1888-1917</td>
<td>South Dakota Agricultural Experiment Station (J. A. Shepherd)</td>
<td>Fargo, S. Dak.</td>
<td>…..</td>
<td>…..</td>
<td>…..</td>
</tr>
<tr>
<td>1910-22</td>
<td>U. S. Department of Agriculture (C. O. Townsent)</td>
<td>U. S. Department of Agriculture, Utah, California</td>
<td>Mass selection from mother lines.</td>
<td>…..</td>
<td>…..</td>
</tr>
<tr>
<td>1915 to July 1, 1936</td>
<td>Great Western Sugar Co.</td>
<td>Longmont, Colo.</td>
<td>Mass selection from mother-line breeding.</td>
<td>(1) Curly-top resistance; (2) single-germ seed.</td>
<td>…..</td>
</tr>
<tr>
<td>1920 to July 1, 1936</td>
<td>American Crystal Sugar Co.</td>
<td>Rocky Ford, Colo.</td>
<td>Mass selection from mother-line breeding.</td>
<td>Improvement; leaf spot resistance.</td>
<td>…..</td>
</tr>
<tr>
<td>1912 to July 1, 1936</td>
<td>Canada &amp; Dominion Sugar Co. (Henry Stokes)</td>
<td>Chatham, Ontario.</td>
<td>Mass selection and mother-line breeding.</td>
<td>High sugar under leaf spot conditions; leaf spot resistance.</td>
<td>…..</td>
</tr>
<tr>
<td>1919-28</td>
<td>Spreckels Sugar Co.</td>
<td>Spreckels, Calif.</td>
<td>Mass selection</td>
<td>…..</td>
<td>…..</td>
</tr>
<tr>
<td>1920 to July 1, 1936</td>
<td>California Agricultural Experiment Station and U. S. Department of Agriculture, cooperative.</td>
<td>Davis, Calif.</td>
<td>Mass selection and pure-line breeding.</td>
<td>…..</td>
<td>…..</td>
</tr>
<tr>
<td>1915 to July 1, 1936</td>
<td>U. S. Department of Agriculture.</td>
<td>Arlington Experiment Farm, Va.; Fort Collins, Colo.; Rocky Ford, Colo.; and State College, N. Mex.</td>
<td>Pure-line breeding.</td>
<td>Leaf spot resistance; curly top resistance; genetic investigations (cooperative with Colorado Agricultural Experiment Station).</td>
<td>…..</td>
</tr>
<tr>
<td>1918 to July 1, 1936</td>
<td>do..</td>
<td>Riverside, Calif.; Salt Lake City, Utah; and Twin Falls, Idaho.</td>
<td>Mass selection and pure-line breeding.</td>
<td>Curly top resistance; genetic investigations; nematode resistance.</td>
<td>…..</td>
</tr>
<tr>
<td>1922 to July 1, 1936</td>
<td>Michigan Agricultural Experiment Station and U. S. Department of Agriculture, cooperative.</td>
<td>East Lansing, Mich.</td>
<td>Pure-line breeding.</td>
<td>…..</td>
<td>…..</td>
</tr>
<tr>
<td>1927 to July 1, 1936</td>
<td>Amalgamated Sugar Co.</td>
<td>Ogden, Utah</td>
<td>Mass selection</td>
<td>…..</td>
<td>…..</td>
</tr>
<tr>
<td>1930 to Sept. 1935</td>
<td>Minnesota Agricultural Experiment Station and U. S. Department of Agriculture, cooperative.</td>
<td>Pure-line breeding.</td>
<td>…..</td>
<td>…..</td>
<td>…..</td>
</tr>
</tbody>
</table>

**Place**
- Schuyler, Nebr.
- Fargo, S. Dak.
- Longmont, Colo.
- Chatham, Ontario.
- Spreckels, Calif.
- Davis, Calif.
- Arlington Experiment Farm, Va.; Fort Collins, Colo.; Rocky Ford, Colo.; and State College, N. Mex.
- Riverside, Calif.; Salt Lake City, Utah; and Twin Falls, Idaho.
- East Lansing, Mich.
- Ogden, Utah
- Pure-line breeding.
- Mass selection and pure-line breeding.
- Mass selection from mother lines.
- Mass selection from mother-line breeding.
- Mass selection and mother-line breeding.
- Pure-line breeding.
- Pure-line breeding.
- Mass selection.

**Methods employed**
- Mass selection
- Mass selection from mother lines
- Mass selection from mother-line breeding
- Mass selection and mother-line breeding
- Pure-line breeding
- Mass selection and pure-line breeding
- Pure-line breeding

**Purpose**
- Improvement
- Leaf spot resistance; curly top resistance; genetic investigations (cooperative with Colorado Agricultural Experiment Station).
- Leaf spot resistance; curly top resistance; genetic investigations; nematode resistance.
- Improvement
- Curly top resistance; genetic investigations; nematode resistance.
- Curly top resistance; genetic investigations.
- Genetic investigations

**Varieties produced**
- South Dakota 1 (not introduced commercially).
- Great Western (used commercially).
- Flat Foliage (used commercially); Leaf Spot Resistant.
- Home grown (Canadian) (to be used commercially 1936); Stokes (Canadian grown).
- P 19 (not used commercially).
- Various inbred lines being tested in various combinations.
- U. S. 1, U. S. 33, U. S. 34 (used commercially) in bred lines and selections under tests.
- Various inbred lines being tested in various combinations.
- Crosses of resistant inbred lines under test.

**Present staff**
- H. A. Dahlberg, Asa Maxson.
- A. W. Skuderna, 1920-29; 1935-.
- E. E. Down, H. L. Kohls.
- F. R. Immer.
<table>
<thead>
<tr>
<th>First year, fall</th>
<th>Second year</th>
<th>Third year</th>
<th>Fourth year</th>
<th>Fifth year</th>
<th>Sixth year</th>
<th>Seventh year</th>
<th>Eighth year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Choice of:</strong></td>
<td><strong>Super-elite (roots).</strong></td>
<td><strong>Super-elite (seed).</strong></td>
<td>Roots</td>
<td>1st multipl. (seed).</td>
<td>Yield test (roots)</td>
<td>Stecklings (roots)</td>
<td>Selected seed (sale)</td>
</tr>
<tr>
<td>Cl. I</td>
<td>Good elite (roots).</td>
<td>Elite (roots).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl. II-III (roots)</td>
<td>New choice of:</td>
<td><strong>Super-elite (roots).</strong></td>
<td>Roots</td>
<td>1st multipl. (seed).</td>
<td>Yield test (roots)</td>
<td>Stecklings (roots)</td>
<td>Selection seed (sale).</td>
</tr>
<tr>
<td>Cl. I</td>
<td>Good elite (roots).</td>
<td>Elite (roots).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
</tr>
<tr>
<td>Cl. I</td>
<td>Good elite (roots).</td>
<td>Elite (roots).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
</tr>
<tr>
<td>Cl. II-III (roots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Copied from: “Improving the Sugar Beet”, by V. Lathouwers. La Sucrerie Belge. Organe de la Société Générale des Fabricants de Sucre de Belgique et de la Société Technique et Chimique de Sucrerie de Belgique. Numéro du Centenaire. 50° Année. (Translation by H. A. Kuyper.)
### Table 7.—Inbred lines of sugar beets starting from roots selected from commercial fields, produced by the Division of Sugar Plant Investigations in connection with breeding for leaf spot resistance

<table>
<thead>
<tr>
<th>Current designation</th>
<th>Generations</th>
<th>Number</th>
<th>Number</th>
<th>Number</th>
<th>Outstanding characters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selfed</td>
<td>Group</td>
<td>Increase</td>
<td>tested</td>
<td></td>
</tr>
<tr>
<td>30296-0</td>
<td></td>
<td>10742-27</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>40293-0</td>
<td></td>
<td>5488-29</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>40299-0</td>
<td></td>
<td>4588-25</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>5-207-0</td>
<td>3444-29</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>Cercospora leaf spot resistance; very high sucrose percentage.</td>
</tr>
<tr>
<td>5-298-0</td>
<td>00475-0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>Strong Cercospora leaf spot resistance; high sucrose percentage.</td>
</tr>
<tr>
<td>5-532-0</td>
<td>4516-29</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>Strong Cercospora leaf spot resistance.</td>
</tr>
<tr>
<td>5-546-0</td>
<td>4874-29</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>Do.</td>
</tr>
<tr>
<td>5-550-0</td>
<td>1294-29</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>Cercospora leaf spot resistance.</td>
</tr>
<tr>
<td>5-580-0</td>
<td>6571-29</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>Cercospora leaf spot resistance; very high sucrose percentage.</td>
</tr>
<tr>
<td>5-734-0</td>
<td>Acc. 215</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>Cercospora leaf spot resistance.</td>
</tr>
<tr>
<td>5-735-0</td>
<td>6484-29</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>Strong Cercospora leaf spot resistance.</td>
</tr>
<tr>
<td>5-801-0</td>
<td>5885-29</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>Cercospora leaf spot resistance.</td>
</tr>
</tbody>
</table>

1 Selected from Leaf Spot Resistant variety (Skuderna).

### Table 8.—Wild 1 species of beets and their general geographic location

<table>
<thead>
<tr>
<th>Species</th>
<th>Geographical distribution</th>
<th>Hybridization with <em>B. vulgaris</em> reported by—</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Beta maritima</em> L.</td>
<td>Mediterranean and Atlantic coasts</td>
<td>Munenerati, Vilmorin, Schneider, Coons.</td>
</tr>
<tr>
<td><em>Beta trijgyna</em> W. and K.</td>
<td>Slavonia, Crimea, Transcaucasia, Turkey, and eastward.</td>
<td>Tschermak, Schneider, Savitsky, <em>et al.</em></td>
</tr>
<tr>
<td><em>Beta intermedia</em> Bunge</td>
<td>Asia Minor and eastward</td>
<td></td>
</tr>
<tr>
<td><em>Beta tomatogona</em> F. and M.</td>
<td>do</td>
<td></td>
</tr>
<tr>
<td><em>Beta procumbens</em> Chr. Sm.</td>
<td>Canary Islands</td>
<td>Schneider.</td>
</tr>
<tr>
<td><em>Beta patellaris</em> Moq.</td>
<td>Mediterranean coast</td>
<td></td>
</tr>
<tr>
<td><em>Beta patula</em> Soland</td>
<td>Madeira Islands</td>
<td>Rimpau (?).</td>
</tr>
<tr>
<td><em>Beta marocarpa</em> Gross</td>
<td>Portugal, Canary Islands, etc.</td>
<td></td>
</tr>
<tr>
<td><em>Beta macrorhiza</em> Stev.</td>
<td>Transcaucasia and southward</td>
<td></td>
</tr>
<tr>
<td><em>Beta nana</em> Boiss. and Hold.</td>
<td>Greece</td>
<td></td>
</tr>
<tr>
<td><em>Beta atriplicifolia</em> Rony</td>
<td>Spain</td>
<td></td>
</tr>
<tr>
<td><em>Beta webbiana</em> Moq.</td>
<td>Canary Islands</td>
<td></td>
</tr>
</tbody>
</table>

1 The sugar beet, red garden beet, Swiss chard, and mangel-wurzel are commonly classified as varieties of *Beta vulgaris* L.