METHODS OF BREEDING THE SUGAR BEET

THESIS FOR DEGREE OF M. S.

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1921

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Respectfully submitted in partial fulfillment
for a Master of Science degree at the
Michigan Agricultural College

Hugh B. Smith

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THESIS

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A - INTRODUCTION.

1-Need for Study of Methods.

Plant Breeders have very slowly increased the quality and yield of the sugar beet (Beta maritima L. or Beta Vulgaris; var. maritima, Koch, Deutsch, Gunter, Proskowetz, Rimpau.) The sugar content of the beet has been increased several fold, yet one must hesitate to state that sugar beet breeding is a triumph of scientific method. Shepard (1909) writes, "in spite of years of domestication the sugar beet is still a wild and erratic creation always tending to lapse back into numerous wild and primitive forms and creations". The lack of science is emphasized by the statement of DeVries, confirmed by Castle (1914), that there has been no permanent effect in raising the sugar content of the beet. Surely there is a need for a study of methods of breeding the sugar beet. Various methods will be described and compared.

2-Sources of Data.

The source of the literature reviewed is given in the bibliography. Hundreds of pages of literature written on the subject in the English language were studied, and the facts learned are properly referred to in this thesis. Nearly one hundred pages of Fruwirth's textbook "Die Buchtung der Landwirtschaftlichen Kulturpflanzen" were translated. Important points were discovered from the translation. Because Fruwirth is considered an authority on the subject, his textbook is referred to quite often.

The working out of problems dealing with self-fertilization of the sugar beet compose the experimental research accomplished. The experiments conducted are described in section (C) of this thesis as indicated in the table of contents. The methods of breeding under self-fertilization, which are described in section (D) of this thesis, are especially important methods.

B - BASIS OF METHODS.

1-The Beet Flower.

Pritchard (1916) states that "the introduction of economic methods based upon correlated characters, upon a better acquaintance with scientific principles, and upon a better knowledge of the plant, would aid materially in the improvement of the beet". A study of the beet flower is fundamental. The perianth of the beet flower is composed of five green sepals. Before the flower opens; that is, in the early stages, the five sepals completely enclose the stamens and pistil. They are united with one another only at the base. When the

flowers open they form a five pointed star which is very pronounced in the ripe seed. There are five stamens, one opposite each sepal. The pistil consists of a three parted stigma protruding from an ovary partially imbedded in the flesh of the receptacle.

The flowering period varies with the section of the country and with the year. At the Michigan Experiment Station in 1920 it began about the fourteenth of June and lasted practically three weeks. The pollen grains are ripe as soon as the flower opens and are so numerous that their pungent odor can be detected for quite a distance from the field. The stigma is receptive for at least three days and may be receptive nine days after the flower opens. This was shown to be true in 1920 at the Michigan Experiment Station. (Plate I, figures 1 and 2). Flowers at about equal stages of development were emasculated. These flowers were covered with paper bags and later hand pollinated. Some flowers were pollinated on the third day after they had been emasculated, others were pollinated on the fourth day, others on the fifth, and so on till the ninth day inclusive. In every case the pollination was effective. In a control experiment the flowers were emasculated and covered with paper bags, but they were not pollinated. In every case there was no seed formed. In other cases only a few flowers on the stem were sacked and not emasculated, yet in every case there was no seed formed. An experiment by Shaw (1916) shows

-PLATE I-

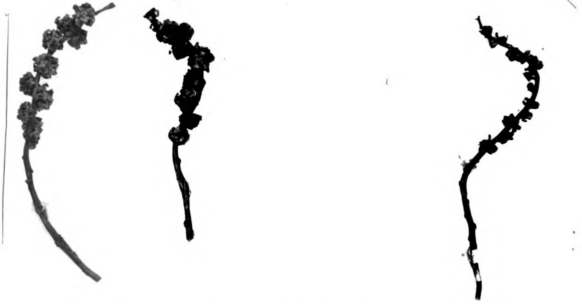

Fig. 1.- Pollinated and unpollinated flowers.

Fig. 2.- The emasculation operation.

that the beet flower is protandrous; hence it is impossible for the pollen of a flower to fertilize the stigma of that flower. The facts presented in these last two paragraphs show that the beet flower is naturally cross pollinated; therefore, allogamy is the normal form of mating.

2-Habit of Plant.

The habit of the plant must be considered. There are many intermediate habits of development, ranging from an annual to a perennial foliage plant. However, the plant desired for cultivation must be a biennial or a perennial. The normal type of beet produces seed the second year from a root stored over winter. Plants which fail to bloom the second year and which may or may not erect seed stems are spoken of as "trotzers". Variations from foliage plants to normal seed beets have been recorded according to Shaw (1917) by Rimpau, Slesin, Trzebinski, and Wasiliziew. Shaw (1917) in agreement with others (Briem, Deutsch, Stift, Gredinger) writes that any factor which retards or checks the growth of beet seedlings will cause them to behave as annuals.

The root is the desirable product in the first year of growth. Hence, it is imperative that the cultivated beet behave as a biennial or a perennial seed beet. This behavior is brought about by the proper

storage of roots. Improper storage will cause a large percentage of trotzers. Shaw (1918) writes that "a relatively prolonged period of restrained growth in the growing point of bud rudiments of beets is necessary to determine the development reproductively. The storage should be such that for a number of weeks the temperature limits should not fall low enough to suspend growth". His experiments show further that the lower temperature limits for the growth of beets lies between 1.75 and 3.25 degrees Centigrade. Shaw (1918) states that it is best to store beets where the temperature will range from 0.5 and 5.0 degrees Centigrade. Thus a variable which enters into the handling of seed sugar beets is reduced to a definite figure.

3-Past Methods.

When all the variables that enter into sugar beet breeding are also known in such quantitative terms it will be possible to decide what operations can be dispensed with and what other changes in past methods can be profitably made. Much of the routine concerning methods of breeding the sugar beet have been worked out in Germany. The Germans have also made some advance in the science[1] of sugar beet breeding. The essential features

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1 - Bibliography reference number 6b.

of the system are simple and may be briefly stated as follows:

First year - In spring the very best pedigreed seed known as "super-elite" seed is planted. In the fall those beets which pass a thorough examination of both foliage and root characters are given a chemical test of the root. The roots that pass the test are placed in a cellar where they are kept from freezing or from heating during the winter months. These siloed beets are known as "seed beets" of "mother beets".

Second year - In spring these seed beets are uncovered and after passing a thorough examination are planted in a field at such a distance from other beet fields that they will not be cross fertilized by inferior pollen. The seed produced from these seed beets is divided into two classes; namely, super-elite and elite. Super-elite seed is that produced by the very best individuals. It is used to produce future generations of super-elite and elite seed. Super-elite seed beets are selected on the merits of their progeny and are used to produce from three to seven crops of seed. Rekowski (1908) states that analysis proves that the third crop from a seed beet produces seed of better quality than either the first or second crop.

Third year - In spring the elite seed is planted closely in order to grow a crop of small beets called "steckling" which are gathered in the fall and preserved in silos until the following spring.

Fourth year - In spring the steckling are planted. In the fall they produce a crop of commercial seed.

Fifth year - Commercial seed is planted in spring to produce the roots from which sugar is extracted.

4-Progress in Past.

Thus five years elapse between the planting of super-elite seed and the production of the root crop from which sugar is extracted. It is evident that all breeding operations which make for the improvement of the sugar beet occur in the selection and testing of the mother beet. The selection of these roots is therefore an important step which requires the ability of one who not only knows the principles of plant breeding but also one who understands the plant itself.

A slow but continuous improvement has been made in the sugar beet plant. Rigid selection long continued has resulted in the annual increase of from one-eighth to one-half of one percent in the beet. It has also appreciably decreased the percentage of impurities in the juice. Otken (1915) states, "the selection of individuals whose sugar content was high because of adaptation has resulted in the partial exclusion of a series of factors which under certain conditions cause a reduction of sugar content; and this, in conjunction with the gradual fixation of characters positively determining a higher percentage of sugar, has reduced in the course of time, the variability of sugar content". The process has been not only a slow but it has also been an expensive one because a vast amount of chemical work has been necessary in determining the quality of the plants selected.

The technique of selection has developed gradually. At first, from 1812 till 1868, physical selection was practiced. This method considered only the morphological characters and the yielding capacity of the beet. The sugar content was increased slightly by this method. The next method known as physical and chemical selection considered the relation to soil, climate, fertilization, relation to disease, together with the morphology, weight, specific gravity, and chemical tests of the root. This method produced better results than the previous method but it gave way to a better method whereby plants which have the ability to transmit type and quality to their progeny are conscientiously selected. This last described method is known as pedigree breeding in which selection is based upon the physical, chemical, and physiological characteristics of the plant. It may be emphatically stated that selection of individuals because of their

pedigree is an interesting and most reliable method which must bring the most sure success. The value of the individual is determined from the record of its progeny. This record makes a specific strain of seed originating from an individual valuable or valueless.

The modern breeder employs as a "standard" a single super-elite plant whose descendants are studied and found to be superior. Those beets which come up to or approach the standard in uniformly good heredity are selected as foundation stock. Fruwirth[1] states that the foundation stock must be as uniformly high in desirable qualities as possible, and that the strain must show a small range of variability with the greatest number of plus variations and the smallest number of minus variations. He writes further that the selection of the best individual is made possible from a scientific knowledge of its family record. Improvement of the beet both from the standpoints of the farmer and the manufacturer, he says, has resulted from the application of this so-called pedigree or family breeding.

On the other hand the breeding of the sugar beet is a very complicated process due mainly to the fact that the starting point will be an individual of which the entire genetics is obscure or only a very small part of it known.

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1 - Bibliography reference number 6b.

That so little is known regarding inheritance in the sugar beet may be excused by the fact that scientific foundations for intelligent plant breeding are of very modern date. Only since Darwin introduced us into the study of natural selection and evolution could our aim in breeding be intelligently pursued. The Statistical Methods of Galton, Weismann's Germ Plasm Theory, De Vries' Mutation Theory, Mendel's Law and Johannsen's Pure Line Theory are foundations without the knowledge of which no scientific methods of breeding can be followed.

5-Inheritance of Characters.

In all methods of breeding, the ultimate aim is to obtain a strain which will produce the greatest quantity of sugar per acre and which will transmit this quality to after generations. Experiments by Andrlik (1909), Bartos (1909), Urban (1909), Pritchard (1916), and Fruwirth (1908) indicate that sugar content is a transmissible character. Urban (1912) states that "beet seed with inherited tendency to produce beets high in sugar will show this character in different fields and in all years". Like factors determining the shape of root this character is probably transmitted in a very complex manner. Kajanus (1912) assumes four different and independent factors determining shape of root. Two factors seemed to act on the diameter and two on length. Any one of the factors may appear separately or there may be an appearance in any combination. Regarding other characters in the sugar beet Fruwirth (1908) states that the spherical shape of beet is dominant over cylindrical shape, pear shape, over olive, and scantiness of foliage is dominant over abundance of leaves. In a case of color inheritance Kajanus (1912) notes that in a cross between yellow and red, the yellow is dominant and in the second generation the segregation is in the ratio of fifteen yellow to one red.

6-Correlations.

Although little is know regarding the inheritance of characters in the sugar beet, certain correlations have been worked out which have a direct bearing upon methods of breeding in that they aid in selection. These correlations help the breeder understand the plant and to know what to select and what to discard. From a survey of the literature on this subject written in German, French, Italian, and in English, the following summary may be made.

A - There is a positive correlation between percentage of sugar in the beet and :

1-Leaf Surface[1]; Rabbetge[5], Knauer[5], Rimpau[5], Mestermeier[5], Maerck[5], Plahn (1911), Strander[5], Janesz (1904),

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1 - Leaf surface is judged before any leaves turn yellow but as late in the season as possible.

5 - Bibliography reference number 6b.

Malpeaux (1915), Pritchard (1916).

2-Beet having many fine rootlets and deep root furrow; Rabbethge[5], Knauer[5], Schindler[5], Von Proskowetz[5], Pritchard (1916), Townsend (1909), Shepard (1913).

3-Number of vascular rings per unit area of cross section; Schindler[5], Von Proskowetz[5], Petsch (1913), Pritchard (1916).

4-Semi-erect rosette-like spread of leaves; [2]Pritchard (1916), Vychinski[5], Karmrodt[5].

5-Root carrying size to center and then gradually tapering[3]; Townsend (1909), Pritchard (1916), Schindler[5], Von Proskowetz[5], Malpeaux (1915).

6-Leaves with fine texture[4] and many fine veins; Herzfeld[5], Kneifel[5], Mestermeier[5], Vychinski[5], Rabbethge[5], Knauer[5], Pritchard (1916).

7-Percentage impurities; Maerck[5], Von Proskowetz[5], Gortner (1913), Harris (1913), Pritchard (1916).

8-Specific gravity; Von Proskowetz[5], Petsch (1903).

9-Dry matter; Von Proskowetz[5], Petsch (1903).

B - There is a negative correlation between percentage of sugar and:

1-Weight of root; Pritchard (1916), Harris (1913), Gortner (1913), Von Proskowetz[5], Briem[5], Von Rumker[5], Towar (1909)

2-The crown should not be pinched nor overly large.
3-Ratio of length to breadth below 2.5 to 1 is a poor beet.
4-A thin blade easily folded denotes fine texture.
5-Bibliography reference number 6b.

Maas[5], Novotnz (1912).

2-Size of crown; Von Proskowetz[5].

Pritchard (1916) has shown a positive correlation to exist between size of root and the quantity of sugar. He has also emphasized that beets having leaves with a deep petiole groove yield the greater quantity of sugar. Harris (1917) has found that: the weight of the seed beet, height of seed stalk, the number of days to mature seed, and the number of seed stalks per crown are each positively correlated with the quantity of seed produced.

7- Desirable Type of Beet.

In the light of these correlations it appears that the proper beet to select would have a large leaf surface, have a semi-erect rosette-like spread of leaves with fine leaf texture and many veins, and have leaves with a deep petiole groove. The crown of the beet should neither be pinched nor overly large and it is generally conceded that a beet whose crown extends far above the surface of the ground is a poor beet. The root should not be branched and it should carry its size well toward the center and then gradually taper so that it would be at least two and one-half times as long as wide. It should have many fine rootlets, and a deep root furrow which

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5-Bibliography reference number 6b.

may or may not be spiral. The onion shaped, pear shaped, cylindrical shaped, and branched roots are types in contrast to the desired form and are to be avoided. The highest testing roots would have a high specific gravity, high coefficient of purity, and the greatest number of vascular bundles per unit area of cross section. The highest testing beet would also be a small beet. However, the larger beet would give the greater quantity of sugar. In conformity with a statement by Fruwirth (1908) a medium sized root should be the best size to select as such a beet would combine average percentage of sugar with average weight of root, hence the result would be a greater quantity of sugar. It seems from a judgement of the correlations worked out by Harris that for the greatest possible seed production and quantity of sugar combined the medium sized beet is best.

8-Variations from Desirable Type.

Regardless of the fact that one should keep in mind an ideal type, such a root would be very hard to find. This is because the plant is so variable that it is doubtful if two plants even apparently alike could be found. Plates II, III, IV and V, are photographs taken on a small plot of beets grown from commercial seed, and they illustrate somewhat the variation of the sugar beet.

-PLATE II-

Fig. 1.- Aborescent type of beet.

Fig. 2.- Variation.

-PLATE III-

Fig. 1.- Bushy type on left and mixed type on right.

Fig. 2.- Variation.

-PLATE IV-

Fig. 1.- Variation.

Fig. 2.-Variation.

-PLATE V-

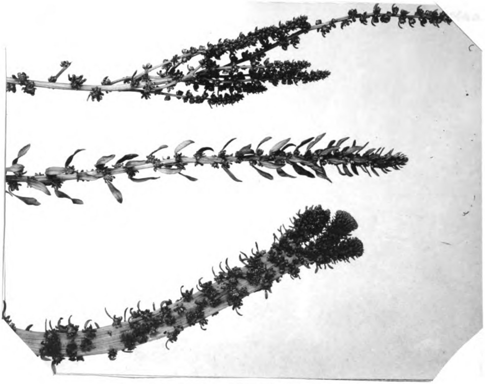

Fig. 1.- Variation.

Fig. 2.- Typical seed stem.

The three principle types of seed stalk frequently described are the aborescent, the bushy or shruby, and the mixed types. Plate II, Fig. 1, illustrates the aborescent type. The mixed type is illustrated by the plant on the right in Plate III, Fig. 1. The bushy or shrubby type is illustrated by the plant on the left in Plate III, Fig. 1. The following form of notes point out the possibility of a great number of different types.

A - Shape of root
Branched, smooth, or slightly branched.

- a-conical,
- b-pear shaped,
- c-onion shaped,
- d-cylindrical.

B - Crown

- a- Flat,
- b-Rounded,
- c-Conical,
- d-Extension in inches.

C - Furrows

1-Direction

- a-vertical,
- b-spiral.

2-Depth

- a-deep,
- b-shallow.

D - Foliage

1-Color

- a-light,
- b-dark.

2-Habit

- a-erect,
- b-semi-erect
- c-flat

3-No. of leaf circles.

E - Leaf
- 1-Length
  - a-long,
  - b-medium,
  - c-short.
- 2-Breadth
  - a-wide,
  - b-medium,
  - c-narrow.
- 3-Surface
  - a-smooth,
  - b-wrinkled.

F - Estimated leaf surface
- 1-Great,
- 2-Medium,
- 3-Small.

G - Petiole Groove
- 1-Deep,
- 2-Medium,
- 3-Shallow.

Pritchard (1916) states that the range of variation for percentage of sugar in individual beets is ordinarily from eight to twenty-four. Small immature beets frequently contain less than eight percent and occasionally a root is found which contains more than twenty-four percent. In an experiment he found that rows of from eighty to one hundred percent stand varied from 10.1 to 15.7 percentage of sugar and from 2383 to 5654 pounds of root weight per row. Such differences certainly offer ample opportunity for selection. In fact, the plant is so variable that selects and discards are often made on small differences.

The greatest aid to selection is the record of the progeny of an individual. For this reason very extensive notes should be taken, including clear cut photographs. The ideal desired should be definitely, clearly, and fully described. The description should be supplemented with photographs so that it will be possible to determine at all times how closely the ideal has been approached. Pritchard (1916) states that it is only by breeding for the same qualities for a number of years that we may hope to secure constant results in the progeny.

9-Adaptation.

As stated by Townsend (1909), it is not probable that a single strain of beet seed produced will be equally satisfactory for all parts of the sugar beet area. This is especially true in a country like the United States where there is a great variation in soil, climate, and cultural conditions under which the plant is grown. Even in Germany where there were in 1908 twenty-one breeders of sugar beets, each breeder, according to Fruwirth[1], had a distinct sort adapted to a particular locality. Tracy (1914) states, that "the sugar beet being one of the most highly bred plants, is very susceptible to the influence of both climate and soil conditions; hence, seed should be grown which is produced

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1-Bibliography reference number 6b.

under the most favorable conditions for the production of beets best suited to each particular locality".

10-Pure Line Solution.

The problem is to develop an adapted homozygous line of sugar beets which will transmit the highest possible combination of quality and yield in the follow-generations. After a pure line of sugar beets is obtained there will be no need for so many chemical tests as are now necessary in sugar beet breeding. Characters which make for the greatest possible quantity of sugar in the beet are probably inherited in a very complex manner, and work along this line offers enormous opportunity for research. However, before a thorough study can be made of the inheritance of characters in the sugar beets one should know how to develop a strain which will breed true.

C - SELF FERTILIZATION EXPERIMENTS.

1-Definition.

Regardless of the fact that random mating is the natural habit of the sugar beet plant, it is possible to practice autogamous mating. In this thesis autogamous mating will be taken to mean that effected by pollen from the self same individual. Shaw (1916) makes the

distinction between self-fertilization and close fertilization. Self-fertilization, he says, is "that effected by the self same flower" and close fertilization is "that effected by the pollen of one flower upon any other flower of the same plant". These distinctions need not be made, as the mendelian segregation is identical in both cases, because in either case the individual fertilizes itself.

2-Reported Experiments.

Fruwirth[1] states that self-fertilization is possible either by covering the individual, or by isolating the individual by space. He writes that the best results are obtained if excess pollen is present, and he believes that the best method to self-fertilize the plant is to isolate it by space. Shaw's (1916) experiments show that self-fertilization is possible both by isolating plants and by hand pollinating covered plants. He states, "apparently the only available method of isolating beets under normal conditions is to plant individual mother beets so remote from each other as to prevent pollination by wind and insects. To be safe from cross pollination by insects a distance of probably two miles is necessary". He tried to isolate plants with the most closely woven fabric and found that wind-borne pollen sifts thru it. The fabric he used was finer than any used by European beet

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1-Bibliography reference number 6b.

breeders. A case is reported by Gaudot (1908) of France where sugar beets were covered with fabric. He reported a perfect setting of seed on the plant, but it is doubtful if the fabric he used kept out the wind borne pollen. Munerati (1914) reports a special cage having a square framed top covered with wire netting to which was attached muslin that surrounds the stalk. The muslin was secured around the base of the stalk. The whole is supported by two sticks driven into the ground on opposite sides of the plant. He believes that this cage effectively prevented cross fertilization. Townsend (1905) in his work with single germ seed reports the self-fertilization of beet flowers by covering spikes with paper bags. He has said also that self-fertilization is possible in sugar beet plants isolated by space. Shepard (1913) reports the selfing of beets by sacking and without the artificial transfer of pollen. Froelich (1908) isolated sugar beets by covering as well as by planting roots at some distance from one another. Vilmorin isolated beets by space to self-fertilize them. Andrlik, Bartos, and Urban successfully self-fertilized sugar beets in 1909.

An extensive experiment conducted by Reed in 1920 at Blissfield, Michigan, easily convinces one that sugar beets may be successfully self-fertilized by planting the roots at a distance from one another. The quantity of

seed obtained varied with the individual plant, some plants producing only a few seeds and other plants producing over a pint of seed. Reed isolated about two hundred plants.

3-Degenerative Influence of Selfing.

Andrlik, Bartos, and Urban reported in 1908 that the degenerative influence varies with different individuals and manifests itself in a reduced sugar content and a prevalence of red and yellow roots. Other indications of degeneration were changes in shape of crown and of root. The appearance of green crown beets is also an atavistic characteristic. Kajanus (1912) reports that repeated isolation of individuals seems to weaken the seed bearing ability of the plant and the germination of the seed. He states further that form characters segregate rapidly. Tracy (1904) writes, "if beets are inbred year after year distinct signs of degeneration or 'running out' will appear".

4-Experiments at Michigan Station.

a-Phases of Experiment.

From the light of these reported experiments, one must conclude that self-fertilization in the sugar beet is possible. Experiments carried out during the season of 1920 at the Michigan Agricultural Experiment Station bear out this conclusion. Six hundred and fifty plants were experimented with to determine the possibility of self-fertilization by sacking and by isolating sugar beets. The technique of note taking, sacking, pruning, and protection from thrips was studied. Various emasculation (see Plate I, Figs. 1 and 2) and crossing experiments previously described were accomplished to determine the length of time that the stigma remains receptive. Beets were isolated during the winter months in various green houses. Other beets were isolated during the summer months over the experimental plots.

b-Material Used and Notes Taken.

Material used for the experiment was grown from commercial seed during the season of 1919. In the fall of 1919 plants free from disease were selected from as many different types as could be distinguished. These roots were divided into nine different piles in the field according to root and leaf characters; such as smooth, slightly branched, and greatly branched roots; besides smooth, slightly wrinkled, and greatly wrinkled leaves; also erect, semi-erect and recumbent leaves.

The roots were then put into sacks and taken to the laboratory where other notes such as number of leaf circles, length of leaf, percentage of petiole on leaf,

shape of leaf, netting of leaf, size of neck, rough drawing of root shape, number of rootlets, length of root, weight of root, inches which crown extended above the surface of the ground, and whether the root was spiral or not spiral. These roots were given a number according to a definite system. Numbers in a selection book corresponds to the number with which the beets were tagged.

The roots were then taken to a root cellar and placed inside of a box covered with fine chicken wire where they were protected from the weather and from mice. The roots were taken out and planted three feet apart each way on April 25th, 26th, and 27th, 1920. Other notes such as date up, date seed stalk was one foot high, date sacked, date unsacked, number of seed stalks, uniformity percent of seed stalks, height of mature seed stalk, and whether or not there was one prominent seed stalk, were taken throughout the season. These same notes were taken on the beets isolated by space.

c-Experiment in Covering Plants.

Various methods were employed to determine the technique of covering the plant for selfing purposes. The size of paper sack was the first thing to determine.

The first sacks tried were $7\frac{1}{2}$ inches long, $3\frac{1}{2}$ inches wide, and $2\frac{1}{2}$ inches thick (see plant on right of Plate VI, Fig. 1). These small sacks were put on at various places over the plant. Some plants contained as many as twenty of these small sacks. Sometimes it was found necessary to tie the sacks which were put on the side branches to the main stalk to keep them from lopping over. All sacks were fastened in place by tying them around the bottom. The small sack was found to be unsatisfactory because it took a long time to cover a single plant with so many sacks, but unsatisfactory mostly because the plants grew up thru the sack.

Another sack of unsatisfactory size is the one quarter barrel paper flour sack (see Plate VI, Fig. 2). This sack is 30 inches by $16\frac{1}{2}$ inches by 6 inches. Twenty five plants were covered with this size of sack. This sack is unsatisfactory because it is expensive, but mainly because it covers up too much of the plant. It was observed that the plant behaved more abnormally when covered with this size of sack than when it was covered with a smaller sack. When the sack was taken off the plant had a very unhealthy appearance.

Still another unsatisfactory method of covering is illustrated in Plate VII, Fig. 1. This shows a

-PLATE VI-

Fig. 1- Too small sack on right.

Fig. 2.- Too large sack on left.

plant completely covered with a double layer of cheese cloth. The plant remained covered the entire season and although the flowers had opened, absolutely no seed formed on the plant. The plant was stimulated to abnormal growth, became sprangly of stem, and light in color of foliage. This method of covering is very slow and it is expensive.

The most satisfactory size of sack is the number 16 manila sack. This sack is 16 inches by $7\frac{3}{4}$ inches by $4\frac{3}{4}$ inches (see Plate VII, Fig. 2). This size of sack seemed to have the right thickness of paper to allow a practically normal development of plant. In some cases there was a moulding of the stems due to crowding inside of the sack. In other cases there was an excessive bending of the stems and this condition was also due to crowding. Plate IX, Fig. 1, shows how crowding has twisted and bent the stems. The number 16 sack was of sufficient thickness of paper to withstand the weather and was of such strength that the plant did not push up through it.

d-Experiment in Pruning Plants.

Besides the necessity of knowing the size of sack it was also found necessary to determine whether or not it was a good plan to strip off the parts of the plant which were not covered by the sack. To determine this

-PLATE VII-

Fig. 1.- Plant covered with cheese cloth.

Fig. 2.- Satisfactory size of sack.

point two rows were stripped and two rows were left unstripped. It was found that as many of the leaves as possible should be left on, but all parts which might bear seed should be pruned off. Figure 1 of Plate VIII shows a plant before it was stripped and Figure 2 of Plate VIII shows the same plant after it was stripped. If the parts outside of the sack are trimmed off those parts inside of the sack are more liable to remain alive and to develop healthy large seed. Not all of the stripping can be done at one time as new growth appears through out the season. After the sacks have been removed, the plants should be gone over every two weeks or every month depending on the amount of growth present.

e-When and How to Sack.

In order to limit the amount that must be trimmed from the plant and at the same time to limit the number of stems covered by any one sack, it was found best to use a number of the size 16 sacks on each plant. The number of stems that should be covered is determined by their position on the seed stalk and the maturity of the flowers. Figure 1 of Plate X illustrates improper sacking. It is a good plan to have the sack only partially filled as subsequent growth will cause crowding. See

-PLATE VIII-

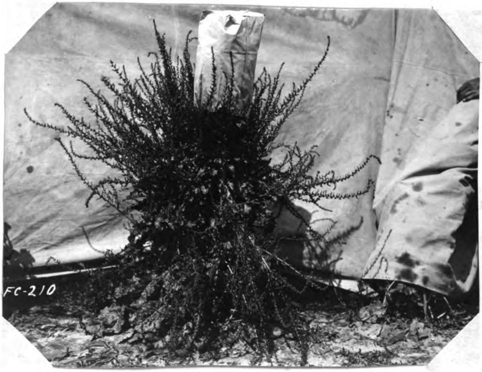

Fig. 1.- Plant unpruned.

Fig. 2.- Plant of Fig. 1 after pruning.

Plate IX, figure 1. However, in accordance with Fruwirth (1908), there should be a sufficient number of flowers inside of the sack to insure the presence of excess pollen. Experiments conducted in covering from one to two feet of flower stem with small sacks resulted in sterility in all of some one hundred cases. The sterility was probably due to the scarcity of pollen produced by such a small number of enclosed flowers. In nearly all cases where excess of pollen was formed, because of the great number of flowers enclosed, some self fertilization took place. Since the beet flower is indeterminate and since the pollen is usually ripe before the stigma on the same flower is receptive, it follows that the pollen on one flower will fertilize the stigma of a more mature flower inside of the same sack. The sacks may be put on at various times throughout the season, depending on the ripeness of the flowers. For selfing purposes the sacks must be put on before a bit of yellow shows in any of the flowers sacked.

f-Experiments with Thrips.

If thrips are numerous, nicofuma must be used. This may be applied by putting a few drops of the liquid in a wad of cotton held in place at the end of a stick to which it is fastened by wrapping with string. The cotton

-PLATE IX-

Fig. 1.- Effect of crowding in sack.

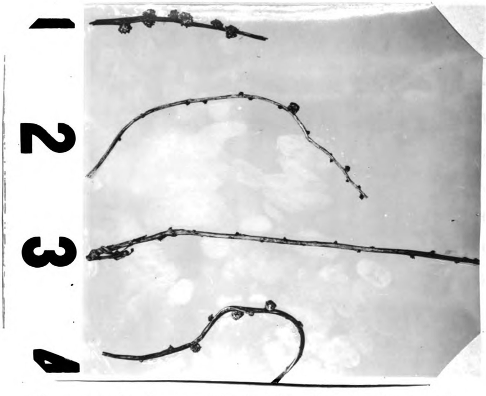

Fig. 2,- 1 shows effect of not covering, and
2, 3, 4 show effect of covering.

may also be held in place by glueing it or pinning it to the inside of the closed end of the paper sack. There should be a small hole in the sack over this wad of cotton so that every few days a drop or so of nicofuma may be applied with a dropper. The cotton absorbs the liquid and it also serves to keep pollen from sifting into the sack thru the small hole made for the dropper.

g-When to Take Sacks Off.

The sacks may be left on the entire season or they may be taken off after four or five weeks. If the sacks are taken off early,new flower bearing stems appear which may produce cross fertilized seed. The cross fertilized seed may be confused with the self fertilized seed; hence, the removal of sacks before harvesting the seed introduces difficulties which are dispensed with if the sacks are left on the plants. The sacks should be left on at least long enough to eliminate the confusion of selfed with crossed seed. Very often these two may be distinguished by the spacing on the seed stem. Numbers 2, 3 and 4, in figure 2 of Plate IX, illustrate the spacing on a stem self fertilized by the sacking method. Number 1 of the same photograph illustrates the spacing as effected by cross fertilization.

h-Experiments in Isolating plants.

1. In greenhouse.

It is evident that a good many problems enter into the self-fertilization of sugar beets by sacking them. The problems are so pronounced that the isolation of plants by space stands out as a more sure method. A number of plants were isolated in green houses during the winter in 1919-1920. Not all of these produced seed stalks and flowers but those which did bloom were taken from the greenhouse about the first of June and planted at the end of a plot on the College Station where they matured seed. See figure 2 of Plate X. In the picture those plants which are shown to be supported with stakes are the ones grown over winter in the greenhouse. These plants matured seed only about two weeks earlier than those plants stored over winter and set out in the spring. It is, therefore, probably not practicable to use the greenhouse for growing roots over winter in order to obtain seed a year earlier.

2. In field.

Fifteen plants were isolated during the summer of 1920 at various places over the Michigan Experiment Station. Due to various reasons such as destruction by stock, lack of experience in isolating, and carelessness of some station hands all but six of these plants were destroyed. These six plants bore self-fertilized seed with a germination test

-PLATE X-

Fig. 1.- Improper sacking.

Fig. 2.- Appearance of experimental plat.

of from ten to sixty percent. It is believed in agreement with Fruwirth (1909), Townsend(1921), Shaw (1916) and Reed (1921), that the best way to obtain self-fertilized seed is to isolate the plants by space. Gardens owned by people living some distance from one another may often be used for this purpose.

i-Need for Selfing.

Self-fertilization is a means at hand by which a pure line may be developed in the least possible time. Various methods of selection by autogamous and allogamous mating will be described under their respective names and their effectiveness compared. These methods have not been practiced in the field with the sugar beet crop but the necessary steps for their application are pointed out. Genetic expectations[1] are used on assumed cases to work out the number of generations required to produce a practically homozygous line. There are five methods of selection by allogamous mating and four by autogamous mating. Methods under autogamous mating are especially fine methods as shown by their comparison with methods under allogamous mating.

D - METHODS BY AUTOGAMOUS MATING.

1- No Selection.

If one should pick individuals at random from a first

1- Bibliography reference number 24.

generation cross, should isolate these so as to produce self-fertilized seed, and should mix this seed together into one mass, then repeat this process year after year; he would be practicing no selection in autogamous mating. In order to illustrate this method assume the F_1 to be Aa. This individual if self-fertilized will produce zygotes in ratio of AA to 2Aa to aa. The allozygotes produce by autogamy only allozygotes. The heterozygotes produce one fourth allozygotes, one half heterozygotes, and one fourth protozygotes. The protozygotes produce only protozygotes. Thus the heterozygotes are reduced by one half in each generation. The protozygotes and allozygotes remain pure in all following generations. In F_2 the population is 50 percent heterozygous, in F_3 it is 25 percent heterozygous, and in F_n it is 0.01 of one percent heterozygous. Since 50 must be divided by some power of 2 to find the percentage of heterozygotes, and since in F_3 the desired power is one, in F_4 it is 2, in F_5 it is 3; then in F_n it is n-2. Therefore, 0.50 divided by 2^{n-2} equals 0.0001. Solving this, n is found to be equal to 14.2. This shows that it will take nearly 15 generations to produce a population composed practically entirely of homozygotes by no selection in autogamous mating.

2-Mass Selection-Autogamous Mating.

The selection and mixing together the seed of phenotypically allozygous individuals in a self-fertilized population is practicing mass selection in autogamous mating. This method of breeding may be illustrated as follows: Assume F_1 is Aa. Then F_2 will be in ratio of AA to 2Aa to aa. In this method of breeding the proto-zygotes are eliminated and, as in no selection autogamy, the number of heterozygotes are reduced by one half in each generation. Since the heterozygotes are reduced by only one half as before, it will take just as long to produce a true breeding strain by this method as it would by no selection in autogamous mating. By no selection 2^t pure lines will be produced while by mass selection only one[1] strain will be produced. Mass selection is an improvement over no selection if the inheritance of the character desired is known. If the inheritance of the character is not known, no selection is better than mass selection, because by mass selection some valuable material may be eliminated. However, in the sugar beet crop which is self-fertilized with such difficulty,it would be impossible to practice no selection. It has been shown that about 15 generations are required to produce a homozygous line in autogamous mating by mass and by no

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1- t in the formula is equal to the number of character pairs observed.

selection when one pair of characters is involved. It will be further pointed out that this is true regardless of the number of character pairs involved.

3-Allozygous x-Allozygous Selection-Autogamous mating.

Select roots which show from plant characters that the individual is phenotypically allozygous. Self fertilize these individuals. Keep seed of each individual separate. Plant some of this seed in progeny rows and save a remnant for future use. Those rows which do not show segregation must have been planted with seed which is allozygous. If the remnant or the mother beet of such tested seed is planted in an isolated place so as to exclude foreign pollen, it will produce a race of allozygotes. These may now be allowed to cross at random with one another. This method of breeding produces an allozygous line in one generation. It is the fastest way possible of producing a true strain of allozygotes.

4-Protozygous x Protozygous Selection-Autogamous Mating.

Select roots which show from plant characters that the individual is protozygous. Unless the character is one determined from the seed stalk, there will be no need for self-fertilization; for if the selects are protozygous they may be allowed to cross at random with one another. In case the character is one determined from the seed stalk, the plants must be self-fertilized and the seed from these

plants kept separated from the crossed seed. Such seed may be used as the starting point of a protozygous line pure for the observed recessive characters.

E - METHODS BY ALLOGAMOUS MATING.

1-No Selection-Allogamous Mating.

If one should take roots at random from a field of sugar beets and should grow seed from these roots planted so that they would cross at random, he would be practicing a method of breeding known as no selection in allogamous mating. To show that this method will result in no improvement one needs only to assume and explain a hypothetical case which will give a theoretical explanation of the genetic process. If a cross is made so as to involve one pair of characters all of the first generation seed will be heterozygous. Second generation seed is produced from the random mating of heterozygote with heterozygote. The seed produced will be in ratio of one allozygote to two heterozygote to one protozygote. The allozygotes produce as many allogenes as the protozygotes do protogenes. The heterozygotes produce allogenes and protogenes in equal numbers. Hence, the allogenes and protogenes will be in equal numbers. The male gametes may be designated by ($\frac{1}{2}A + \frac{1}{2}a$) and the female gametes by ($\frac{1}{2}A + \frac{1}{2}a$). These may be represented, as crossing at random by multiplying ($\frac{1}{2}A+\frac{1}{2}a$) by ($\frac{1}{2}A+\frac{1}{2}a$). This is equal to $\frac{1}{4}AA+\frac{1}{2}Aa+\frac{1}{4}aa$. Hence,

in the third generation the ratio will be the same as it was the previous generation. In like manner it may be shown that the fourth will be the same as the third, the fifth like the fourth, and so on. Thus it is proven that there will be no improvement if there is absence of selection in a random mated population.

2-Mass Selection-Allogamous Mating.

If one should select only roots which were dominant for a certain character and grow these so that the gametes produced would cross at random he would be practicing mass selection in allogamous mating. This method of breeding will result in slow improvement. Assume a pair of characters as represented by A and a. The zygotes produced in the second generation will be in ratio of AA to 2Aa to aa. Mass selection will eliminate from the breeding plot all zygotes which are not either allozygous or heterozygous. The AA and 2Aa zygotes are selected. These produce gametes in the ratio of 2Aa to a. These may be represented as crossing at random by multiplying (2A+a) by 2A+a) which is equal to 4AA+4Aa+aa. The allozygotes and heterozygotes are now equal. The gametes formed from these after mass selection are (3A+a). These cross at random producing 9AA+6Aa+aa zygotes. Table shows a summary of these and some following ratios.

-Table 1-

Gen.#	2	3	4	5	n	10	100	1000
AA	1	4	9	16	$(n-1)^2$	81	9801	998001
Aa	2	4	6	8	$2(n-1)$	18	198	1998
aa	1	1	1	1	1	1	1	1
Sum	4	9	16	25	n^2	100	10000	1000000

It can be observed from the table that the figures in the summation line are the square of the generation number; therefore, F_n will have a summation n^2. The aa line is 1 in every generation; therefore, in F_n it will be 1. The Aa is an arithmetic series in which two is the difference. In F_2 the figure is 2, in F_3 it is 2 x 2, in F_4 it is 2 x 3; therefore, in F_n it is 2(n-1). The AA line is a series in which each figure is equal to the square of the preceding number; therefore, in F_n it is $(n-1)^2$. This population will be homozygous when (n-1) is equal to n^2. This will never be absolutely the case, but, it is evident that the larger the n the more nearly it will approach the case. For all practical purposes a population is pure if it is not more than 0.01 of one percent mixed. When n is such a number that $(\frac{n-1}{2})^2 = .9999$, it will be a number designating the generations necessary to produce a practically homozygous line by mass selection in allogamous mating. This is found to be nearly 20,000 generations. This means for the sugar beet crop 40,000 years will be necessary. As far as an artificial selected strain is concerned this, of course, means the strain will never be developed.

3-Allozygous x Mass Selection-Allogamous Mating.

The selection of an allozygous female crossed with only allozygous and heterozygous males is a method of selection known as allozygous x mass selection in allogamous mating. To illustrate this method one may assume a cross (A x a) where one pair of plant characters observable in the first year of growth is involved. The first generation individuals will be Aa. The second generation individuals will be $\frac{1}{4}AA+\frac{1}{2}Aa+\frac{1}{4}aa$.

The protozygotes are eliminated on plant characters and the only roots selected for seed beets are the AA and the Aa individuals. These cross at random in the field producing third generation seed. Allozygous females cross with allozygous and heterozygous males, also heterozygous females cross with allozygous and heterozygous males. The problem is to select the allozygous mother plant. To do this the seed produced must be handled as follows. Keep the third year's seed harvested from each plant separate from that harvested from every other plant. Plant part

of the seed from the plants in progeny rows. For future use save a remnant of seed from each plant. Those rows which show no segregation of plant characters must have been grown from seed raised on an allozygous mother; while those rows which do show segreation must have been grown from seed raised on a heterozygous mother. Only the rows which show no segregation are saved for the next generation of seed beets. The remnants of seed producing uniform rows may be saved in case the character to be studied are seed stalk characters. If the seed stalk need not be studied the remnants may be discarded. This process is repeated every generation until the population becomes a practically homozygous line.

The ration of male gametes from the F_2 zygotes (AA+2Aa) is 2A to a. These male gametes cross at random with only female allogenes because of selection. The ratio of zygotes in F_3 after selection is 2AA to Aa. In F_4 the ratio will be 10AA to 2Aa, and in F_5 it will be 22AA to 2Aa. Table 2 shows a summary of these ratios. Other ratios are determined by formulae.

-Table 2-

Gen.#	2	3	4	5	6	n	10	16
AA	1	4	10	22	46	$3(2^{n-2})-2$	766	196,606
Aa	2	2	2	2	2	2	2	2
Sum	3	6	12	24	48	$3(2^{n-2})$	768	196,608

It may be observed that the Aa line is 2 in each generation; therefore, in F_n it will be 2. The summation line is 3 x 1 in F_2, 3 x 2 in F_3, 3 x 4 in F_4; or it is $3 \times 2^{n-2}$ in the n^{th} generation. The AA line is $3(2^{n-2})-2$. These formulae are verified by a method of recurrence[1] equations which solve algebraically the n^{th} term of a

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1-Recurrence equations.

Assume $y_n = ay_{n-1} + b_{n-2}$

Then $46 = 22a + 10b \quad (1)$

$22 = 10a + 4b \quad (2)$

$10 = 42 + b \quad (3)$

$$\begin{aligned} 22 &= 10a + 4b \\ 40 &= 16a + 4b \\ \hline 18 &= 6a; \ a = 3 \\ b &= -2. \end{aligned}$$

If a= 3 and b= -2, then these values must satisfy equation (1) above, or

$46 = 3 \times 22 = 2 \times 10 = 46.$

Let $y_n = x^n$; $y_{n-1} = x^{n-1}$; $y_{n-2} = x^{n-2}$

then $x^n = 3x^{n-1} - 2x^{n-2}$

$x^n - 3x^{n-1} + 2x^{n-2} = 0$

$$x = \frac{3 + \sqrt{9-8}}{2} = 2 \text{ or } 1$$

$x_1 = 2$, $x_2 = 1$.

$y^n = Ax_1^n + Bx_2^n$

$1 = A2^2 + B1^2.$

$4 = A2^3 + B1^3.$

$1 = 4A + B.$

$$\begin{aligned} 4 &= 8A + B \\ \hline 3 &= 4A; \ a = \tfrac{3}{4} \\ B &= -2 \end{aligned}$$

$y^n = \frac{3}{4}(2)^n - 2(1)^n$

$= 3(2^{n-2}) - 2$

Therefore since in every generation the Aa is 2, the summation must be $3(2^{n-2})$.

L. C. Emmons of the mathematics department of the Michigan Agricultural College has made it possible to thus apply recurrence equations to genetics.

series in case it can not be observed.

This population will be practically an allozygous line in a number of generations represented by n in the formula where $\frac{3(2^{n-2})-2}{3(2^{n-2})} = .9999$. Solving this,n if found to be equal to 14.7; therefore, by allozygous x mass selection in allogamous mating about 15 generations are required to produce an allozygous line.

4-Allozygous x Allozygous Selection-Allogamous mating.

Select individuals which are phenotypically allozygous for plant characters observable in the first year of growth. Grow seed from these and store the seed from each individual separately. Silo all mother beets. Test the purity of the seed by growing it in the fall of the year in which the seed is produced. At least ten days are required for the seed to become dry enough to plant. In some cases it may be planted out of doors, but in other cases it must be planted in the greenhouse. This, of course, depends on the season and the part of the country. These tests take for granted that the characters may be observed in the early stages of growth. Plant part of the seed in progeny rows, but save the remainder of the seed. Those rows which do not segregate must have been grown from seed produced by an allozygous mother beet. Select the allozygous mother beets and plant them in the spring in an isolated plot. The seed produced will be allozygous. Thus an allozygous line is developed by selecting in two generations. Three

years are required.

This method can also be practiced when selection is based on plant characters observable in the second year of growth. Silo all mother beets which are phenotypically allozygous and save the seed from each of these beets in a separate container. This seed may have been produced by an allozygous or a heterozygous mother. Plant this seed in the late fall in the open, or if necessary in greenhouses in order to produce small roots which may be tested the following spring. In the spring plant out the mother beets in a plot in order to preserve them for selection. Plant the small roots in progeny rows. Those rows which show no segregation must have been raised by allozygous mothers. These mother beets may be selected from the plot and siloed. Plant these allozygous mothers in an isolated plot the following spring. In the fall allozygous seed will be produced. In this case the selection is in two generations and four years are required.

5-Protozygous x Protozygous Selection-Allogamous Mating.

Select individuals which are protozygous for plant characters observable in the first year of growth. Discard all others. In the spring set out these protozygotes so that at the flowering period they will cross at random with one another, but will not cross with any other individuals. Seed produced from this plot of protozygotes

will be protozygous. It will remain pure as long as foreign strains are kept away from it. Thus a protozygous line is developed in one generation. This method of breeding is a very efficient method if the desirable characters happen to be recessive.

This method may be practiced if the plant characters desired are those observable in the second year of growth. Select plants which are protozygous. Silo the roots the second time and plant them in an isolated plot the following spring. These individuals, if crossed at random with one another will produce only protozygous seed. Thus a protozygous line is developed by selecting in two generations. Three years are required.

F- A TYPICAL METHOD ILLUSTRATING A GENERAL CASE.

Throughout this discussion of methods of developing a homozygous line of sugar beets, one pair of characters has been purposely used to illustrate the methods. One may desire to know that regardless of the number of character pairs observed, the time is the same as it is for one character pair. To illustrate this method assume a general case of a typical method. Take, for example, mass selection by autogamous mating for three genoplexes.

Assume a cross between ABC and abc. This when self-fertilized produces zygotes as follows: ABC, 2ABC', 2AB'C,

2A'BC, 4AB'C', 4A'BC', 4A'B'C, 8A'B'C', ABc, 2AB'c, 2A'Bc, 4A'B'c, AbC, 2AbC', 2A'bC, 4A'bC', aBC, 2aBC', 2aB'C, 4aB'C', Abc, 2A'bc, aBc, 2aB'c, abC, 2abC', abc.

By mass selection all individuals which have any protozygous characters will be eliminated. The individuals selected are represented by ABC, 2ABC', 2AB'C, 2A'BC, 4ABC', 4A'BC', 4A'B'C, 8A'B'C'. These when self-fertilized produce after selection the following zygotes:- 27ABC, 18ABC', 18AB'C, 18A'BC, 12AB'C', 12 A'BC', 12A'B'C, 8A'B'C'. The ratio in F_4 will be as follows:-343ABC, 98ABC', 98AB'C, 98A'BC, 28AB'C', 28 A'BC', 28A'B'C, 8A'B'C'.

These ratios are derived easily by observing the case where one genoplex is involved. Assume the F_1 as Aa. This individual when selfed will produce $\frac{1}{4}$A + $\frac{1}{2}$A' + $\frac{1}{4}$a zygotes and the ratio in F_2 is A to 2A' to a. The A' individual produces offspring segregation in ratio of A to 2A' to a. Hence the ratio of the population in F_3 will be 3A to 2A' to a. In like manner it may be shown that in F_4 the ratio is 7A to 2A' to a, and so on. The ratio for one genoplex is given in table 3.

-Table 3-

Gen.#	2	3	4	5	n	11	15
A	1	3	7	15	$2^{n-1}-1$	1023	15383
A'	2	2	2	2	2	2	2
a	1	1	1	1	1	1	1
Sum	4	6	10	18	$2^{n-1}+2$	1026	15386

From the table it may be observed that the A line in F_3 is 3 or 4-1, in F_4 it is 7 or 8-1; and it may be further observed that in any generation it is $2^{n-1}-1$. The A' is 2, the a line is 1, and the summation line is $(2^{n-1}+2)$. The ratio of dominant zygotes may be derived from the formulae $(2^{n-1}-1)+2$.

The ratio of zygotes dominant for t genoplexes may be found by the formula $((2^{n-1}-1)+2)^t$. In F_4 for three genoplexes the ratio will be $((2^{3-1}+1)+2)^3 = (3+2)^3$. Set these figures down in the brace form to determine the genotypes as follows:

$$3A\begin{cases}3B\begin{cases}3C=27ABC\\2C'=18ABC'\end{cases}\\2B'\begin{cases}3C=18AB'C\\2C'=12AB'C'\end{cases}\end{cases}\quad 2A'\begin{cases}3B\begin{cases}3C'=18A'BC\\2C'=12A'BC'\end{cases}\\2B'\begin{cases}3C=12A'B'C\\2C'=8A'B'C'.\end{cases}\end{cases}$$

In like manner the ratios for each generation may be found by first deriving the ratio for one genoplex in that particular generation. In F_4 the summation of

all the individuals will be $((2^{n-1}-1)+3)^3$ if three genoplexes are involved. The A line will be $(2^{n-1}-1)^3$. This population will be practically pure when $\frac{(2^{n-1}-1)^3}{((2^{n-1}-1)+3)^3}$ is equal to 0.9999. The cubic root of 0.9999 is 0.9999 which is correct to four decimal places. Hence, the formula becomes the same as if only one genoplex were involved. For the reason that any higher root of 0.9999 is equal to 0.9999 it is evident that the number of genoplexes involved does not effect the number of generations required to produce a homozygous line. The more pure the population becomes the more nearly is this fact true, and at the limit it is absolutely true. These facts prove that it is quite probable that in any particular method of breeding the generations necessary to produce a practically pure line will be the same regardless of the number of genoplexes involved.

However, other difficulties appear if very many pairs of characters are under observation. As the number of genoplexes increases, one by one, the chances of finding the desired individual is decreased by a multiple of four. If one pair of characters is involved, one-fourth of the population will be of the desired genotype; two genoplexes result in one sixteenth of the population being of the desired genotype; three genoplexes make only one sixty-fourth of the population desirable; and if t genoplexes are involved only one plant out of 4^t would be selected. Hence, if ten pairs of characters entered into the problem only one plant from over 1,048,576, would be of the desired genotype. This would require searching through an area of over three acres for one beet if the beets in the area have the common spacing.

G - CONCLUSION.

1 - There is a need for a study of methods, past and future in sugar beet breeding because of the atavistic tendency of the plant. It is important that an adapted pure line which will breed true for the greatest quantity of sugar per unit area of seeded ground be developed.

2 - The desirable type of beet as determined by correlations reported in the literature is described in B,7 of this thesis. It is an important paragraph.

3 - Because of the structure of the beet flower it is normally cross fertilized. However, the plant may be self-fertilized by covering the plant with sacks or by isolating the plant by space. Various size sacks were tried in covering plants for selfing purposes. The sack found most satisfactory was the number 16 manila

sack. This sack is 16 inches by $7\frac{3}{4}$ inches by $4\frac{3}{4}$ inches. This sack is put on before a bit of yellow shows in the flowers. A number of them should be put on each plant so as not to cause crowding within the sack. All parts which are liable to bear flowers and are not covered by the sacks should be pruned off. If thrips bother, nicofuma may be used as a fumigator. The sacks may be left on the entire season. Because of the uncertainty of the sacking method it is believed that the best way to self-fertilize the sugar beet is to isolate the plant by space. On the other hand, the sacking method warrants further investigation.

4 - A method of breeding using autogamous mating is the recommended method. Methods of breeding using allogamous mating are slow. They will result in improvement only from the standpoint of selection. They do not effieicntly apply modern genetics. No, mass, and allozygous x mass selection in allogamous mating are the methods which have, in most cases, been used in the past. The following summary compares these methods with other methods, and it may be observed that they are comparatively slow methods.

A - Allogamous mating.
- 1-No selection--never.
- 2-Mass selection-40,000 years.
- 3-Allozygous x mass--30 years.
- 4-Allozygous x allozygous--3 to 5 years.
- 5-Protozygous x protozygous--2 to 3 years.

B - Autogamous mating.

1-No selection--30 years.
2-Mass selection--30 years.
3-Allozygous x allozygous--3 years.
4-Protozygous x protozygous--2 years.

5 - If very many genoplexes are involved, methods 4 and 5 in allogamous mating are not applicable. For all practical purposes they are not possible of application.

6 - The degenerative influence of self-fertilization must be met. Fruwirth[1] believes that the introduction of new blood into the stock must be given great consideration. He advocates the crossing of the best two varieties to produce a new variety. The method of producing pure lines and then crossing them in double combination, as is recommended for corn by Jones (1920) offers great possibility in sugar beet breeding.

7 - As stated by DeVries in his "Mutation Theory" the sugar beet is an example of the most refined and elaborate system of selection known to any cultivated plant. Nevertheless, he authorizes the statement that past methods have failed because no pure lines have been developed. A method of breeding using autogamous mating has promise of being an improved method.

1-Bibliography reference number 6b.

-ACKNOWLEDGEMENT-

The writer is particularly indebted to Mr. F. A. Spragg for suggestions on the problem, on sources of literature, for aid in the construction of the thesis, and for a thorough criticism of the thesis. He wishes to acknowledge indebtedness to Mr. E. E. Down, for valuable aid in the field and laboratory. He is also indebted to Mr. F. A. Spragg, Mr. E. E. Down, and Mr. J. F. Cox, for the final review of the thesis.

-BIBLIOGRAPHY-

1 - Andrlik, K; Bartos, V; Urban, J - "Influence of cross fertilization on the sugar content in the sugar beet" in Zeitschrift für Zucker - Industrie in Böhmen 32 (1908) No. 7, pp. 373-387. "The sugar content as a transmissible character in the sugar beet" in Zeitschrift für Zucker - Industrie in Böhmen 33 (1909) No. 6, pp. 345-357. "The influence of self-fertilization on degeneration of the sugar beet" in Zeitschrift für Zucker - Industrie in Böhmen 33 (1909) No. 7, pp.409-418.

2 - Andrlik, K; Urban, J. "Abnormally large beets" in Zeitschrift für Zucker - Industrie in Böhmen 32 (1908) No. 9, p. 345-357.

3 - Castle, W. E. "Selection, Sugar-beets, and Thrips" in Amer. Nat. (1914) V. 49 p. 121.

4 - DeVries, Hugo - "Elementary species in Agriculture" in Amer. Phil. Soc. (1906) Vol. 45, p. 149-156.

5 - Froelich, G - "The selection of mother beets" in Blätter für Zuckerrubenban 15 (1908) No. 1, pp. 1-5.

6 - Fruwirth, (a) "Breeding of agricultural plants" in Naturwissenschaftliche Zeitschrift für Land-und Forstwirtschaft 6 (1908) No. 9, pp. 449-468. (b) Die Buchtung der Landwirtschaftlichen Kulturepflanzen.

7 - Gaudet, G - "The isolation of seed sugar beets" in Jour. Agri. Practique n. ser. 33 (1908) No.2, p.364.

8 - Harris, F. S; Hagenson, J. C - "Some correlations in Sugar beets" Genetics 1 (1916), No. 4, pp. 334-347.

9 - Harris, J. A - "Biometric studies on the somatic and genetic physiology of the sugar beet" in Amer. Nat. 51 (1917) No. 608, pp. 507-517.

10 - Harris, J. A; Gortner, B. A - "On relation between weight of Sugar beet and the composition of its juice". Biochen Bul. (1913) Vol. 11, No. 8, p. 529.

11 - Hays, W. M. - "Progress in plant and animal breeding" in U. S. Yr. Bk. (1901) p. 173.

12 - Jones D. F - "Selection in self-fertilized lines as a basis for corn improvement" Jour. Amer. Soc. Agron. (1920) Vol. 12, No. 3, p. 77.

13 - Janesz, S - "Differences in type of beets and variation " in Mitteilungen der Landwirtschaftlichen Institute der Koniglichen Universitat Breslau, 2 (1904) No. 5, pp. 913-970.

14 - Kajanus, B - "A mendelian study with beets" in Fruhlings Landwirtschaftlichen Zeitung 61 (1912) No. 4, pp. 142-149."The inheritance of certain characters in beets and turnips" in Zeitschrift fur Pflanzenkrankheiten (1913) No. 2, pp. 125-186.

15 - Malpeaux, L - "Relation of foliage to sugar content of beets" in Vie Agricole et Rurale 5 (1915) No. 12, pp. 213-216.

16 - Munerati, O - "A special cage for the isolation of the flower stalk of mother beets" in Reale accedamie die Lincei---Rendicenti, classe di scienze fisiche matematiche e naturali ser. 23 (1914) II No. 12, pp. 616-620.

17 - Novotnz, K - "Contribution on the relation between sugar content and weight of sugar beets" in Zeitschrift für Zucken - Industrie in Böhmen 36 (1912) No. 5, pp. 269-272.

18 - Otken, " - "Studies of variation and correlation of weight and sugar content of beets, especially of sugar beets" in Ztschr. Pflanzenzucht 3 (1915) No. 3, pp. 265-333.

19 - Petsch, O - "Anatomical structure in relation to sugar content" in Deutsche Landwirtschaftliche Presse (1903) Vol. 30.

20 - Plahn, H - "Correlations between weight and sugar content of beets" in Centrablätt fur die Zucker-industrie Forstwirtschaft, 19 (1911) No. 18, pp. 572-573. "Practical significance of the beet leaf" in Zeitschrift für Zucker Industrie 21 (1913) No. 46, pp. 1678-1680.

21 - Pritchard, F. J - "Some recent investigations in sugar beet breeding" in Botanical Gazette No. 62 (1916) 6 p. 425-465. "Correlation between morphological

characters and Saccharine content of the Sugar beet" in Am. Jr. Bot. 3 (1916) No. 7, pp. 361-376. "Relation of adaptation to the improvement of sugar beet varieties for American conditions"in B. P. I. (1912) Bul. 260; pp. 43.

22 - Shaw, H. B - "Thrips as Pollinators of Beet Flowers" in U. S. D. A. (1914) Bul. 104. "Self, close and cross Fertilization of Beets" in New York Bot. Garden Memoirs (1916) Vol. 6, pp. 149-152. "Climatic Control of the Morphology and the Physiology of beets in Sugar Magazine (1917) Vol. 10, p. 387 and p. 482; (1918) Vol. 20, p. 26, p. 68, p. 109, and p. 154.

23 - Shepard, J. H - "Growing Sugar Beet Seed in South Dakota" in S. D. Bul. 106 (1908); Bul. 117 (1909); Bul. 129 (1911); Bul. 142 (1913).

24 - Spragg, F. A - Unpublished manuscript on "Genetic Expectations".

25 - Townsend, C. O - "The Development of Single Germ Beet Seed" in B. P. I. (1905) Bul. 73. "Conditions influencing the production of sugar beet seed in U. S." in U. S. Yr. Bk. (1909) p. 173.

26 - Tracy, J. E. W - "Breeding of Sugar Beets for increase of sugar content and yield" in U. S. Yr. Bk. (1904) p. 341-352.

27 - **Urban**, J - "The chemical composition of atavistic beets" in Zeitschrift Zuckerindustrie in Böhmen 37 (1912) No. 2, p. 57-65.