A Study of Cotton Breeding

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"A STUDY OF COTTON BREEDING"

A Thesis

Submitted to the Faculty

of the

Louisiana State University

and

Agricultural and Mechanical College

For the Degree

of

Master of Science

by

En-lin Sun

Baton Rouge, La.

1918
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INTRODUCTION

Being endowed by nature with suitable climate and fertile soils, China is an ideal country for cotton production. The Chinese cotton industry like all other industries was in a deplorable condition during the oppressive days of the old monarchs. Its recent growth and development did not begin till the establishment of the Republic. Yet the progress of the industry during the late six years is marvellous and unparalleled. Before the Revolution, China ranked fifth among the cotton producing nations; her annual output of lint was only about 600,000 bales of five hundred pounds each. In 1914 she jumped up to the third place and put out 1,600,000 bales of cotton. The total production of lint cotton last year is placed above the mark of 2,000,000 bales. Although statistics for last three years are not on hand, the figures for years previous to 1915 will suffice to show the rapid growth of Chinese cotton industry.

<table>
<thead>
<tr>
<th>Year</th>
<th>Bales of Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>1911</td>
<td>625,000</td>
</tr>
<tr>
<td>1912</td>
<td>1,074,000</td>
</tr>
<tr>
<td>1913</td>
<td>1,200,000</td>
</tr>
<tr>
<td>1914</td>
<td>1,599,000</td>
</tr>
</tbody>
</table>

* Numbers in parentheses denote references.
Along with the increase of production, the growth of cotton manufacture is likewise enormous. In 1910, there were only a few cotton mills at Shanghai, most of which were started with foreign capital. In 1917, there were thirty nine mills, with 1,813,132 spindles and 5,810 power looms. Thirty one of these mills are owned and operated by Chinese merchants. The export of raw cotton to Japan is decreasing rapidly, showing the development of cotton manufacture at home. In a word, the outlook of Chinese cotton industry at present is both promising and encouraging.

While the total production of cotton is increasing, the quality and productiveness of native cotton have not been improved. The question of cotton improvement is at present quite a fascinating topic of popular discussion. The government, the manufacturers, and the farmers alike are all attempting to exercise the magical power of cotton breeding.

In 1913 (3), the Chinese Department of Agriculture made an extensive investigation into the conditions of cotton farming and manufacture in the various provinces. Later in the year, the extent of the "Cotton Belt" in China was ascertained and the Belt surveyed. In 1914, three cotton experiment stations were established, and the provincial experiment stations were also ordered to pay special attention to cotton improvement. In the same year, the Department of Agriculture
announced the bounty laws which provide that whoever increases the acreage of cotton will receive a bounty of one dollar and fifty cents for every acre increased, and that whoever improves the methods of cotton culture will receive two dollars and twenty cents for every acre of cotton thus cultivated. In 1916 (4), the cotton experiment stations began free distribution of improved cotton seeds and started the annual expositions of cotton goods. The Department of Agriculture at the same time established the Board of Cotton Industry the function of which is to investigate the methods of cotton improvement. Since 1913, hundreds of foreign varieties of cotton have been introduced. Last year, the Department of Agriculture reviewed the varieties planted in different experiment stations and published a list of one hundred seventy varieties with their names standardised and their merits commented. Such is a short sketch of the activities of the Chinese Government directed toward the improvement of cotton.

Trying to supplement the efforts of the Government, the cotton manufacturers (5) in different parts of the country established cotton experiment stations near their mills. Their efforts are wholly directed toward the introduction of American cotton, because they see that native cotton is not suited for making fine yarns.

The cotton farmers, likewise, are trying hard to do
their share in the revolution of China's cotton industry.

Last year, the Chinese Cotton Planters' Association established a Cotton Experiment Station in the neighborhood of Shanghai, the work of which is entirely devoted to cotton breeding. An Extension Department was also organised with the mission that the results of this station as well as of others may be disseminated to all cotton farmers of the country(6).

Of all the desirable points of cotton, increased yield of lint and greater length of fibre are the two prominent features that are generally sought by cotton breeders in China to-day. The Chinese cotton, though white in color, is too short and too weak to be made into fine yarns. According to a report of the Ta-Tung Cotton Mill (5), Shanghai, Kiangsu, the native cotton can produce yarns of only the sixteen's count, while those of twenty's and up are spun from mixtures of native cotton and American or Indian lint. The South Tung Chow cotton, the best variety in the country in regard to general excellence, may also be spun to thirty-two's, but because of its limited production, the demand far exceeds its supply. It is therefore necessary that the mills have to import American or Indian cotton for spinning the finer grades of yarns. At this point, if we think that ordinary American cotton may be made into yarns of forty's (7) and with improved machinery even to fifty's, we will then readily see what grade
of cotton is being produced in China. Again, the actual lengths of the Chinese lint may be understood if we review for a short while the standard measurements of the leading varieties. The following table lists forty five varieties from the Second Cotton Experiment Station, South Tung-Chow, Kiangsu.

LENGTHS OF LINT OF CHINESE COTTON (1)

<table>
<thead>
<tr>
<th>Name</th>
<th>Length of Lint</th>
<th>Name</th>
<th>Length of Lint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chingtu</td>
<td>22.50mm</td>
<td>Kuhnhai</td>
<td>22.14mm</td>
</tr>
<tr>
<td>Ching Long Staple</td>
<td>26.60 &quot;</td>
<td>Chingchi</td>
<td>22.90 &quot;</td>
</tr>
<tr>
<td>Hsun Long Staple</td>
<td>28.00 &quot;</td>
<td>Big Boll</td>
<td>22.60 &quot;</td>
</tr>
<tr>
<td>Chi Long Staple</td>
<td>26.20 &quot;</td>
<td>Small Boll</td>
<td>22.26 &quot;</td>
</tr>
<tr>
<td>Naked Seed Pa Long Staple</td>
<td>28.20 &quot;</td>
<td>Weichi</td>
<td>20.29 &quot;</td>
</tr>
<tr>
<td>Brown Fuzzy Seed Pa Long Staple</td>
<td>25.80 &quot;</td>
<td>Taipu</td>
<td>24.07 &quot;</td>
</tr>
<tr>
<td>Chingpei</td>
<td>18.30 &quot;</td>
<td>Anchang</td>
<td>24.20 &quot;</td>
</tr>
<tr>
<td>Koatu</td>
<td>21.10 &quot;</td>
<td>Haipei</td>
<td>21.30 &quot;</td>
</tr>
<tr>
<td>Ching-ping-chi</td>
<td>21.75 &quot;</td>
<td>Shioutao</td>
<td>26.40 &quot;</td>
</tr>
<tr>
<td>Pa-ping-chang</td>
<td>21.40 &quot;</td>
<td>Luting</td>
<td>21.30 &quot;</td>
</tr>
<tr>
<td>Lion's Head</td>
<td>23.55 &quot;</td>
<td>Shinchow</td>
<td>25.00 &quot;</td>
</tr>
<tr>
<td>Pei-ku-new</td>
<td>22.67 &quot;</td>
<td>Chuangpei</td>
<td>23.00 &quot;</td>
</tr>
<tr>
<td>Chuan-kwan-chi</td>
<td>22.70 &quot;</td>
<td>Chuang-lun-chi</td>
<td>24.00 &quot;</td>
</tr>
<tr>
<td>Chin-san</td>
<td>21.05 &quot;</td>
<td>Lung-hua-pei</td>
<td>24.30 &quot;</td>
</tr>
<tr>
<td>Putung</td>
<td>22.84 &quot;</td>
<td>Chang-in-sha</td>
<td>23.59 &quot;</td>
</tr>
<tr>
<td>Name</td>
<td>Length of Lint.</td>
<td>Name</td>
<td>Length of Lint.</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------</td>
<td>------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Koatao</td>
<td>23.80mm.</td>
<td>Kai-kai-hua</td>
<td>24.50mm.</td>
</tr>
<tr>
<td>Lu-pei-hua</td>
<td>19.90 &quot;</td>
<td>Chen-chin-hua</td>
<td>23.52 &quot;</td>
</tr>
<tr>
<td>Black Seed</td>
<td>23.79 &quot;</td>
<td>Chin-gien-chi-chu</td>
<td>25.75 &quot;</td>
</tr>
<tr>
<td>Brown Seed</td>
<td>20.00 &quot;</td>
<td>Chu-lung-shin-pei</td>
<td>25.70 &quot;</td>
</tr>
<tr>
<td>Naked Tungmien</td>
<td>20.90 &quot;</td>
<td>Chu-lung-shin-lui</td>
<td>25.15 &quot;</td>
</tr>
<tr>
<td>White Fuzzed Tungmien</td>
<td>22.60 &quot;</td>
<td>Nien-yao-hun-chin</td>
<td>20.30 &quot;</td>
</tr>
<tr>
<td>Chi-huan Tungmien</td>
<td>21.10 &quot;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This collection of varieties gathered from different parts of the country may well represent the actual quality of the Chinese cotton as a whole. Out of the forty five varieties, only ten have a staple of five millimeters or one inch in length. The longest lint listed does not exceed one and one-eighth inches. The average length of the Chinese lint as indicated by the above table is placed between three-fourth of an inch to one inch. From both actual measurement and spinning quality, improvement of cotton in regard to the length of staple is, therefore, the first and the most important problem that Chinese cotton breeders have to solve.

While short in lint, the Chinese cotton neither shows any superior capacity in productiveness. Chas. W. Dabney (8) stated in 1896 that the yield of cotton in China varies from fifty to one thousand pounds of unginned cotton per acre. This statement, while not exactly right in itself, does indicate the
fact that the yield of cotton in China is neither high nor uniform. According to the Statistical Report of the Chinese Department of Agriculture and Commerce for 1914 (9), the cotton crop harvested that year amounts to 2,098,636,144 pounds of unginned cotton from 4,510,126 acres. The average yield per acre is 465.4 pounds seed cotton or 155.1 pounds of lint. Comparing this with the average yield of cotton in the United States from 1907 to 1916 at 181.5 pounds of lint per acre (10), we will notice that the Chinese cotton yields 14.5% less than American cotton. This difference of yield is not strange in itself, but when we consider that the highly intensive method of farming brings greater yields of other crops in China than in most other nations, then the low yield of Chinese cotton will point to something abnormal and wrong. Among other suggestions for improvement as proper cultural methods and proper fertilization, I am of the opinion that intelligent cotton breeding will bring more efficient and profitable results than any other means.

It is with this belief in mind, namely, the productivity and the length of lint of Chinese cotton may be increased by cotton breeding, that I began to make a systematic study of this subject in the United States. America, the center of cotton production of the world, should be looked upon as a model for revolutionising China's cotton industry. The fol-
Following pages are devoted chiefly to the methods of breeding which are being practised by American cotton farmers and breeders.
BOTANY OF COTTON

A botanical survey of the cotton plant is a stepping stone to the study of cotton breeding. As cotton breeding involves dealing with varieties and strains, the smallest divisions of any group of plants, it is necessary that the distinctions between them should be made clear in the breeders' mind. Indeed, the breeders should be able to perceive the most minute differences between their plants so that selection and hybridisation may be effectively done.

The cotton plant belongs to the genus Gossypium of the family Malvaceae. This genus comprises annual herbs or shrubbery perennials having erect branching stems and alternate, petioled, palmately lobed leaves. The floral characteristics of this genus are as following (11):- Flowers showy, on axillary peduncles, with three or four involucral bracts at its base; sepals five, inferior, united into a cup-like calyx; petals five, hypogynous and involute, white or yellowish, often turning into pink or magenta; stamens numerous, monodelphous, forming a staminal column dilated at base; filaments filiform, exerted; anthers kidney shaped, one-celled; ovary sessile, three to five celled; style clavate, united into a three to five grooved column; ovules numerous in each cell. Squares appear about two months after planting, which
open into flowers at the end of three weeks (12). Forty to fifty days are required for the bolls to ripen after blooming. The flowers last but two days, while pollination is usually effected in the first day.

Several species of the genus Gossypium are cultivated in different parts of the world (13). The three kinds of cotton cultivated in this country fall into two species: the Egyptian and the Sea Island belong to Gossypium Barbadense L, and the American Upland to Gossypium herbaceum L. The cultivation of Sea Island cotton is limited to the Atlantic States of Florida, Georgia, and South Carolina, and the Egyptian cotton to the Southwestern Arid Section. But the American Upland produces by far the greatest bulk of cotton grown in this country.

Gossypium herbaceum L to which American Upland cotton belongs may be distinguished by the following points:—Seeds of six to seven millimeters broad, usually fuzzy though sometimes naked; stems of three to fifteen decimeters tall with rather erect and short branches; leaf blades with three to five triangular or ovate lobes, mostly shorter than the body of the blade; and lint of three-fourths of an inch to one and five-eighths inches in length. Gossypium Barbadense L, on the other hand, has seeds of four to five millimeters broad, nearly always naked except sometimes a tuft of short fibres
at the apex; stems of two decimeters tall or more, with long slender limbs; leaves of three to five lanceolate or ovate-lanceolate, acuminate lobes which are longer than the body of the blade; and lint of fine and strong structure, varying from one and two-fifth inches to two inches in length. While Sea Island cotton of this country represents a uniform type of white fine staple, the Egyptian cotton as grown in Egypt consists of a number of different types and has a staple varying from white to brownish in color and from very fine to very coarse in diameter. So far as grown in this country, the Egyptian cotton may be distinguished from Sea Island by its greater capacity of productiveness and by its creamy white staple tinged with a characteristic brown color.

From the structure of the cotton flowers, it is easy to see that the cotton plant is very liable to produce natural crossings. Observations were made in 1910 and 1911 in Montserrat, British West Indies (14), in regard to the manner of cross-pollination of cotton, and it was found that three species of bees, Centris haemorrhoidalis, Megachile (?), martindalei, and especially Dielis dorsata, are responsible for the natural crossings of cotton in that region. These bees, while entering the open flower primarily for gathering nectar, sometimes make their way between the bracts and the corolla and visit the interior of the flower. When emerging
out, they come into contact with the stigma, covering it with masses of pollen grains. The extent of natural crossing depends upon the weather of the season, kinds and number of insects, the duration of the flowering period, the relative prepotency of different pollens, and the distance apart between varieties. Robson of Montserrat stated that during the middle of the flowering period in the West Indies, the percentage thought to be cross-pollinated was twenty one, ranging from four percent on a dull showery day to thirty three percent on a bright day. Experiments to determine the extent of natural crossing in Georgia (15) gave the result of only two percent, but the average crossings in the United States under natural conditions are estimated between one and fourteen percent, evidences strongly indicating that ten percent is the minimum. Indeed, observations and experiments conducted in different places all tend to emphasize the fact that natural crossings do occur between varieties of cotton.

After the cotton flower is fertilised either by open or by close pollination, the ovules begin to develop and the ovary to enlarge. The enlarging ovary forms the boll. The shape and size of the bolls vary with different species and varieties. They may be short and rounded at the apex, or long, slender, and pointed. At maturity, they dehisce at the external sutures, exposing as many locks as there are number of cells
in the ovary. Each lock contains five to twelve seeds, each of which is surrounded by a tuft of fibres. The seeds together with their fibres are termed seed cotton. The size of bolls is usually expressed in terms of seed cotton in each; in other words, bolls are classified in regard to size by their numbers necessary to make a pound of seed cotton. According to Duggar (16), the number of bolls required to make a pound of seed cotton is forty to sixty eight for large boll varieties, sixty nine to eighty for medium, and eighty one and more for small boll varieties of cotton.

Seed cotton, as stated, consists of seeds together with fibres. In the American Upland, the fibres may be differentiated into long fibres called lint and short fibres called fuzz. Through the process of ginning, the long fibres are separated as lint cotton, while the fuzz remains attached to the seeds giving the latter a brownish velvety appearance. The proportion of the weight of lint to the total weight of seed cotton is termed the percentage of lint. This is a very important factor to be considered in cotton breeding. According to Duggar, a lint percentage of thirty six or more is considered as high, thirty three to thirty six as medium, and thirty three or less as low proportions.

Cotton seeds may be smooth and naked as in Egyptian cotton and Sea Island cotton, or may be fuzzy as in the Amer-
ican Upland. The hilum end of the seeds (17) is tapering and pointed, while the free end is swollen and rounded. Variation in size, according to Duggar, ranges from thirteen-hundredths of a gram in weight for a large seed, eleven-hundredths to thirteen-hundredths of a gram for medium-sized, to seven-hundredths of a gram for a small seed. Each seed consists of a hull, a layer of endospermic cells, and the meat which includes a pair of cotyledons and an embryo.

Lint cotton is nothing more than a collective term for the individual fibres with which the cotton seeds are covered. Each fibre is the outgrowth of an epidermical cell of the seed. During the development of the latter, each epidermical cell elongates into a tiny tube like a quill. Like the mother cell and in connection with it, the young fibre is equipped with an outer wall, an inner cellular deposit, and cell sap filling the rest of the tube. The cellular deposit is not uniform throughout, but is spirally arranged on the inner surface of the wall. This deposit increases in thickness as the fibre grows older, while the cell sap gradually disappears. Upon desiccation after exposure, the fibre quickly loses all its inclosing moisture, and collapses into a flat ribbon-like body. Upon further drying, this little ribbon curls up on account of the spiral cellular deposit, which loses water unevenly at various thicknesses. The curling or twisting property
of cotton fibres is very important in regard to their spinning quality, because it is the twist that makes spinning possible, and it is the high twisting power of good lint that gives strength to threads. Only the properly matured fibres manifest high twisting quality, while immature ones, without much difference in the thicknesses of cellular deposits, and overripe fibres, possessing too much cellulose and becoming rod-like, are deprived of this property.

The lengths and diameters of the individual fibres vary to a large extent in one seed, but their means are considered as hereditary characters within a strain or a variety. According to Duggar (16) and Evans (18), the average lengths and diameters of different classes of cotton are given in the following table.

LENGTH AND DIAMETER OF COTTON FIBRE.

<table>
<thead>
<tr>
<th>Class of Cotton</th>
<th>Length</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Island</td>
<td>1.61 in.</td>
<td>0.000640 in.</td>
</tr>
<tr>
<td>Egyptian</td>
<td>1.41 &quot;</td>
<td>0.000655 &quot;</td>
</tr>
<tr>
<td>American Upland Short Staple</td>
<td>0.93 &quot;</td>
<td>0.000763 &quot;</td>
</tr>
<tr>
<td>American Upland Long Staple</td>
<td>1.30 &quot;</td>
<td></td>
</tr>
<tr>
<td>Brazilian</td>
<td>1.17 &quot;</td>
<td>0.000790 &quot;</td>
</tr>
<tr>
<td>Native Indian Cotton</td>
<td>0.89 &quot;</td>
<td>0.000844 &quot;</td>
</tr>
<tr>
<td>Indian American Cotton</td>
<td>1.08 &quot;</td>
<td>0.000825 &quot;</td>
</tr>
<tr>
<td>Indian Sea Island</td>
<td>1.50 &quot;</td>
<td>0.000730 &quot;</td>
</tr>
</tbody>
</table>
The strength of the individual fibres is sometimes looked upon as an important quality of lint cotton. Hilgard found that the breaking strength of single fibres varies from four to fourteen grams in the American Upland. The cotton fibre, while not as strong as fibres of hemp, Manila hemp, or silk, is stronger in proportion to its size than jute or flax and three times as strong as wool.

The branching habit of cotton is peculiar and worth studying. There are always two kinds of branches in a cotton plant, the vegetative and the fruit branches. The former is developed from the axillary bud, while the latter from the extra-axillary. The vegetative branches are usually limited to the five lowest nodes of a plant, and their length varies to a great extent in the different types of cotton. They usually send out sub-branches bearing bolls and are thus fertile, but they may sometimes remain perfectly sterile. Higher up on the main stem, the vegetative branches are often very short, while the extra-axillary buds shoot out fruit limbs. Thus, there may be two branches found at the same node. Still higher on the main stem, the axillary buds do not develop at all, so that the only branch seen at each upper node is the fruit branch. From this branching habit, it is clear that only the fruit branches will produce cotton, and that a knowledge of controlling the branching habit of cotton will contribute much
value to economic production. Indeed, the branching habit of cotton is so important that the classification of the varieties of American Upland cotton is chiefly based on this character. Duggar's types of Upland cotton with their distinguishing characteristics are given below.

1. Clustered Type. Plants tall and slender; basal limbs few and long, or none at all; fruit branches extremely short with bolls clustered together; seeds and bolls small; early. Examples are Dickson, Jackson, Welborn, etc.

2. Semi-clustered Type. Plants tall and slender, bearing bolls singly but close together; fruit limbs short along the upper part of the main stem, increasing in length toward the bottom; basal limbs two to five, medium long; early or medium early. Examples are Barnett, Peerless, Hawkins, etc.

3. Rio Grande Type. Plants medium tall and well branched; vegetative limbs bending upward and their sub-branches tangling badly with those of the main stem; stems and branches usually deep red colored; bolls small to medium large; medium early; percentage of lint high, usually thirty-five percent or more. There are two sub-groups:

a. Seeds naked. Examples are Anson Cream, Brannon,
Braddy, etc.

b. Seeds with a scanty fuzz. Examples are Borden, Favorite, etc.

4. King Type. Plants small with numerous limbs; fruit branches rather long and often crooked at the joints; basal limbs short; bolls and seeds small; very early. Examples are Dozier, King, Missionary, etc.

5. Big-boll Type. Plants various in form; bolls large, forty-five to sixty-eight of which will make a pound of seed cotton; seeds large and thickly fuzzed; late. Examples are Cleveland's Big Boll, Truitt, etc. A sub-group distinguished by its storm resistance was recently developed. Examples are Triumph, Rowden, Texas Storm Proof, etc.

6. Long-limbed Type. Plants of large size with long limbs and joints; general appearance straggling; bolls and seeds medium to large; percentage of lint low; very late. Examples are Petit Gulf, Louisiana, etc.

7. Intermediate Type. Plant form like the long-limbed type but more spreading; other characters very variable. Examples are Boyd, Gold Standard, etc.

8. Long Staple Upland Type. Plant tall, slender, spreading; limbs long; bolls medium large, long, narrow and pointed; seeds medium to large; staple very long, measuring one
and one-fourth inches to one and one-half inches in length; percentage of lint low; late maturity. Examples are Griffin, Columbia, Peeler, Allen, etc.

From the above description of cotton, we have seen that each and every character of the cotton plant varies more or less. Varieties are distinguished from others by certain characteristics, but these again vary within each variety and even among different individual plants of the same field of cotton. Indeed, it is variation alone that makes systematic breeding necessary for economic production, and it is also variation that makes the problem of breeding complicated. A brief study of the causes of variation in cotton is therefore appropriate in connection with its morphological characteristics.

Because cotton is open pollinated, cross fertilisation takes place freely between different plants. In a pure stock, natural crossing may not introduce a great number of characters into the progeny within a short period; but in a mixed stock or among a poorly kept variety, where "off-types" are already numerous, cross pollination will bring many different characters into the future generations. Further back when the cotton plants were still growing wild with widely different forms or even different species side by side, much more different characters must have been combined by cross pollin-
ation. However pure a variety of cotton may be at present, their ancestors must have passed through the stages of both growing wild and growing among mixed stocks.

After a character is fixed in a plant, it will be infinitely transmitted to the progeny. Any cultivated cotton plant of to-day, therefore, possesses an infinitely large number of characters acquired through free pollination of its ancestors in the wild state. All the characters inherited by a plant, however, cannot be expressed at the same time; a number of them have to be suppressed from expression. Thus we may conceive that the inherited characters of a plant are constantly struggling against each other for the mastery of expression, and that under the present conditions there is an equilibrium established between the expressed and the suppressed characters (19). A well selected variety of cotton, then, means a group of cotton plants in which a similar equilibrium exists under the prevalent conditions of the locality where it was originated. Conversely, a neglected variety is a group of plants in which a number of different equilibriums are found.

So long as a variety of cotton is kept very pure, the equilibrium of expression in that variety will generally be maintained. But for some reason or other, the equilibrium of expression in some plants is sometimes disturbed and mutations
appear. This mutative variation (20), a well known phenomenon to many farmers, does not represent new characters as most people believe, but rather represents some characters which may be traced to more or less remote ancestors of the variety and which were crowded out of expression in the former equilibrium. Mutants, therefore, will breed true. If allowed to remain in the field, they will cross-fertilise with the normal plants, so that the common equilibrium of expression in the latter will also be disturbed, and a greater and greater diversity of characters will be displayed. This is the way a selected variety runs down when neglected.

Like the crossing between mutants and normal plants, artificial hybridization will likewise disturb the equilibrium of expression. The reason why the later generations of hybrids often do not segregate according to the Mendelian theory is because that many ancestral characters are recalled into expression. Similarly, any violent change of environment (21) will also upset the existing equilibrium of expression, and result in a diversity of characters. The diversity in the latter case will be well demonstrated by the new place effects when a variety is transferred to a new locality.

So far we have seen one class of variations which are more or less diversified and will breed true. There is another class of variations entirely different in nature. It
is called environmental variation, because the change of environment is directly responsible for the appearance of such variations. For instance, if we transfer a variety of cotton from a poor upland region to an alluvial soil, all plants will have a tendency to take too much vegetative growth and to decrease in fertility; if we bring it back to its original home next year, the normal development will return. In the same way, when a season is unfavorable, the yield of a variety may fall far below its standard, but it may come up again, should the conditions of the next year be favorable.

Thus environmental variation, unlike the other, is shared by a majority of individuals and is not transmitted to the progeny.

Inspite of the variations, there has been discovered that certain characters of cotton tend to vary together, while others to vary in an opposite direction. Such a relationship between variable characters is spoken of as correlation. The three kinds of correlations may be distinguished as follows:

1. Symphony in which two or more characters appear together in expression.

2. Antiphany in which the expression of one character excludes the appearance of another.

3. Paraphany in which there is no definite correlation between characters and their combination is entirely go-
vernied by chance.

A few important characters of cotton are found to be correlated with each other as following (16):

1. Earliness is symphanic with suppression of vegetative branches, short internodes, small bolls, small seeds, short staple, and small or medium yield.

2. Long lint is antiphanic with abundance of fuzz, large, short, rounded bolls, large number of locks in each boll, and high percentage of lint.

3. Large boll is symphanic with small seeds, productivity, and is antiphanic to very long staple.

4. High percentage of lint is antiphanic with large, heavy seeds and high yield.

5. Vigorous growth of vegetative branches and long internodes are antiphanic with earliness, high yield, good quality and good length of staple, and are symphanic with sterility.

These correlations, while they will not hold absolutely true, will serve as a fairly good guide to the cotton breeder, so that he may not unnecessarily disappoint himself by trying to combine characters which are antagonistic to each other. If he tries to improve a certain quality of cotton, he will also be able to look after its antiphanic characters without letting them recede too much from the standard.
PURPOSE OF COTTON BREEDING

Cotton breeding is difficult to define. The scope of the work is so variously assigned by different authors that there is a general confusion about its nature. Some restrict breeding to "the production of strains or varieties that are better adapted to specific conditions or requirements". Here the difficulty lies in the fact that such a definition would exclude from cotton breeding the rouging system and mass selection, because those methods do not produce any better strain or variety for any purpose, but they serve only to check deterioration which would otherwise proceed very rapidly. Others, on the other hand, lay too much emphasis on the production of new varieties without regard to their value, and there is at present in the market a number of new varieties which do not possess any specific value over the old. In my mind, the origination of new varieties of no superior value should be excluded from proper cotton breeding. Again, the recently demonstrated possibility of importing new varieties from foreign lands also necessitate a change and a broadening of the old definition, as acclimatisation decidedly deserves a place in the breeder's mind.

In order to clear up this disputed matter, let us conceive three states of things in which we will do breeding work.
1. When we have on hand an excellent variety, either imported or locally grown, which begins to deteriorate for some reason or other.

2. When we have a fairly good variety, which is not very pure.

3. When we have a poor variety which does not deserve cultivation.

In the first case, we should direct our attention to check the rapid deterioration and to preserve the superior qualities we have. In other words, we should aim at the maintenance of an existing good variety. In the second case, our variety is not very satisfactory, and we believe it can be made better. Here improvement is our aim. In the third place, the poor variety must be discarded, and a better one has to be created. We should then focus our attention to originating new varieties to supply our need. In either case we will do breeding work although our conditions are different, and, in all, we will strive for the same ultimate purpose no matter where we are at the start, namely, we will treat our cotton crop in such a way that its progeny will respond most efficiently to subsequent cultivation.

Cotton breeding, then, may be defined as the systematic treatment of the cotton crop, whether to maintain a superior variety imported or locally grown, or to improve a variety, or
to originate new varieties, so that the progeny of the crop will give us the best desired results under the existing cultural methods.

The characters that are generally desired in cotton breeding are: (23)

1. High yield of lint per acre. Productiveness is by far the most important factor of all that should be taken into consideration. Although the standard yields of different varieties of cotton vary considerably, yet the highest possible yield of any variety should not be sacrificed for any other character.

2. Long staple. Without decreasing the total yield, the staple should be bred to as a great length as possible.

3. Fine staple. The manufacturing value of cotton depends upon the length as well as the fineness of the staple.

4. Strong staple.

5. Uniformity in both the length and fineness of staple.

6. Big boll which facilitates picking.

7. Earliness. Earliness should be obtained without decreasing the yield. Under boll weevil conditions, earliness has become the most important factor that the breeder has to deal with, because an early crop may insure less damage by the insects.

8. Disease resistance.
9. Storm proof.

10. High lint percentage.

11. Desirable form of plants.

All these characters, of course, cannot be secured at the same time in the same plant, because some of them are antagonistic to each other. The real problem of breeding, then, is to maintain or to improve one set of characters without deteriorating the other, or to get into combination as large a number of these characters as possible.

The various systems of cotton breeding may be grouped into three headings:

I. Selection,

II. Acclimatization, and

III. Hybridization.

These will be treated separately one after another.
SELECTION

Selection as a method of cotton breeding is based upon two fundamental laws of nature, namely,

1. Certain characters of cotton are transmissible, and
2. Like produces like.

In an ordinary field of cotton, there is represented a composite mixture of individuals differing from each other in regard to any definite character. Even a pure strain of cotton will tend to display a diversity of characters when neglected. The length of staple, for example, may vary in different individuals of a certain variety from half an inch to one inch with all intermediate measurements. Since we prefer the longer staple for our economy, we cannot afford to let the cotton crop go by itself. Being guided by our knowledge that the length of staple is a transmissible character and that long staple parent cotton will produce long staple offspring, we would naturally discard those individuals which yield short lint and prevent them from propagating themselves. Only those which give the longest fibres will be allowed to reproduce. Thus, selection is an act to limit the line of descent to the best and the most desirable parent cotton.

As the line of descent may be limited to various degrees of purity, there are various stages of effectiveness to
be obtained by different systems of selection. A stricter system necessitates more complicated procedures but will result in a greater uniformity in the later crops. A less strict method, on the other hand, usually gives less satisfactory improvement although it is easier to handle. The different methods of selection with varying ease and effectiveness in the reverse proportion may be practised by different classes of breeders. Provisionally, the methods are grouped into two classes.

I. Methods for general use, and

II. Methods for agricultural experiment stations.

I. SELECTION FOR GENERAL USE

Selection for general use may be again divided into three methods, namely, (A) Rouging, (B) Mass Selection, and (C) Pedigree Selection. These methods vary in the ease of manipulation according to their order of arrangement and will be discussed one after the other.

(A) ROUGING

Selection by rouging is to pull up all undesirable plants and deviatives either superior or degenerating. The "off-types" are indeed worse than weeds and must not be tolerated, because if allowed to remain, they will not only multiply by themselves but will also cross with other normal in-
individuals. If farmers could not do better selection, they must at least exercise strict rouging should they ever expect to keep a pure stock.

In order to do rouging effectively, we must have a definite system to carry on the work. We must aim not only to put an end to the "off-types" themselves, but also to prevent them from degenerating the rest of the field. Hence, we should start rouging before the plants blossom. Fortunately, any deviation in lint and seed characters is accompanied well advanced by deviations in vegetative growth (24), so that the off-types may be recognised early in the season, and exterminated before they will have a chance to reproduce. When the field is in full blossom, we should go over it again, so that any plant showing deviations in floral characters may be pulled up at this time. When the bolls are well set, repeat the work once more. Finally during the first picking, rouge out all that are too late or deviate too much from standard lint and seed characters. Such a system, if done intelligently, will be at least good enough to retain the existing superiority of a variety.

Rouging is recommended only to those we have on hand a very good variety. While rouging must be strict, the variety that may be thus treated with advantage should not produce a large number of off-types. If our stock is poorly kept and
rouging can not be effectively done without decreasing the yield, we better substitute it with the next method of selection.

(B) MASS SELECTION.

Mass selection is a much stricter method to limit the line of descent than rouging, although it is only a little more complicated. Its underlying principle is to pick in the general field, between the first and the second regular pickings, enough seeds from superior, uniform plants to sow the next general crop. This method is recommended to all farmers who can afford to do it.

The first essential to success in practising this method of selection is to conceive an ideal type and to fix it in mind at the beginning. If our ideal plant is not well established, we might select a number of types instead of one. Such a composite mass of individuals, when planted together, may cross pollinate with each other, produce a diversified display of characters, and ultimately lower the productiveness of the variety. Provision against this danger is found in an ideal plant previously conceived and established.

The next step is to select the best plants conforming closely to the standard and uniform among themselves. The selection will be more judiciously done, if we begin the work early in the season. Before the time of blooming, we should
examine our general field of cotton at some leisure hour and
mark a number of good plants that we might select. When the
field is in full blossom, we should go over the plants again,
so that any floral deviations in them might be detected. When
the bolls are well set and again when the time for first pick-
ing is near, we should repeatedly examine our marked plants,
so that we may conclude at this time which plants ought to be
selected. During the second regular picking, we should go
over our selected plants again, and with a few necessary elim-
inations, their seed cotton is picked and bagged separately
from the the general crop.

Finally, strict attention should be given to ginning. Public
gins are the places where admixture of foreign seeds is liable to happen. Provisions must be made to avoid any contamination, as it will certainly upset all the efforts pre-
viously devoted to selection.

(C) PEDIGREE SELECTION

Pedigree selection is the strictest form of selection for general use. It limits the line of descent to a single superior individual year after year, so that the general field in later years will contain plants all of one type and all of the highest excellence. The whole system is built upon the idea that only the best plant of the year is allowed to produce pro-
geny.
As in mass selection, the success in this case also depends upon the ideal type of plants in the breeder's mind. This ideal type needs be well established in advance; any discrepancy in selection will only delay improvement. The ideal plant, moreover, must conform as closely as possible to the well recognised characters of the variety on which we are working, and all subsequent selections should follow its standard.

With the ideal type of plant in mind, we may proceed with the first year's selection (25). During the growing season, go over several times the field of cotton previously planted for the purpose. Select a number of superior individuals conforming closely to the ideal type. For the best results, the primary selection should be made before the time of blooming, and each selected plant should be caged separately in order to avoid cross pollination. When the bolls are well set, examine the caged plants carefully and discard any which might have shown undesirable characters. This elimination should be practised once more at the time of the first picking. Then pick the seed cotton of each selected plant in a separate bag. In all cases, avoid picking very late bolls, because seeds from them will not produce early progeny. The different bags of seed cotton are then examined in regard to lint and seed characters, and discard all plants which do not
show superior characters at this stage. Then, the seed cotton is ginned and the percentage of lint noted. After all these points have been carefully considered, a final selection of a number of plants is made and their seeds kept separately for next year's work.

In the second year, the seeds of each selected plant are sown in a separate row. As every plant produces from five hundred to two thousand seeds, there may be easily raised five hundred seedlings in each row. The object of this planting is to determine if the selections will breed true. Throughout the season, the general excellence of the plants in each row should be carefully watched. Any row lacking uniformity to a marked degree should be eliminated from consideration. At the end of the year, the best and the most uniform row is finally selected, its seed cotton ginned separately and the seeds kept apart with care. This plant-to-row planting is called the progeny test, by which we are able to select only the pure bred individuals. In this year, we should also select a number of individual plants as in the first year, selections being taken preferably from only the uniform rows. The seed cotton from each of them is to be ginned separately, and the seeds from each to be kept apart for the progeny test in the following season.

In the third year, seeds from the best row selected in
the second is planted in a multiplying plot of several acres. Conduct the progeny test with the selected individuals as before, and select the best row at the end of the season. Seeds from this row will be used for multiplication planting next year. Select also a number of excellent individual plants for future plant-to-row test.

In the fourth year, seeds from the increasing plot are planted in the general field. Seeds from the best row selected last year are planted in the increasing plot. Test the progeny of the selected individuals, and again select a number of the best plants from the uniform rows.

To make the pedigree selection more clear, let us think of only one plant at a time. In the first year, a single superior plant is selected. Its progeny is tested in the second year, and is supposed to give satisfactory results. The best plant among the progeny is again selected, while the rest of the seeds are reserved for multiplication in a several acre plot in the third season. After this multiplication, there will be enough seeds for a general crop in the fourth year. The line of descent in this selection may be expressed in the following diagram.
DIAGRAM SHOWING THE LINE OF DESCENT IN
PEDIGREE SELECTION.

First Year  Second Year  Third Year  Fourth Year  Fifth Year
1 plant.....500 plants...5 acres.....General crop

i plant.....500 plants...5 acres.....General crop

i plant.....500 plants...5 acres

i plant.....500 plants

i plant

From the above description we have seen that the pedigree selection is not a simple task. Technical training and close observation are requisites for practising such a selection to success. It is not expected that all cotton farmers will be able to carry on pedigree selection, but all seed growers and those who are producing a high grade of cotton like the Sea Island are advised to use this method.

II. SELECTION FOR EXPERIMENT STATIONS

Experiment stations, as a rule, are in a better position to conduct more scientific and extensive methods of cotton breeding than farmers. The stations alone can afford to attempt methods of uncertain value, as their mission is to investigate agricultural possibilities without regard to ac-
tual profit to themselves. To them the following two methods of cotton breeding are recommended.

(A) REGULAR SCIENTIFIC SELECTION

The procedure of the regular scientific selection is exactly the same as that of the pedigree selection described. It differs from pedigree selection, however, in the extreme care to be taken in all stages of performance. There is a system of numbering different selections, and there are definite scientific ways of determining the various characters of cotton and certain forms of records to be regularly kept. The purpose of all this care is to eliminate the possible errors of selections which are very liable to happen otherwise, and subsequently to increase the effectiveness of selection.

SYSTEM OF NUMBERING. In the first year, select one hundred plants and number them consecutively from one to one hundred. The separate bags in which their seeds are kept are also correspondingly numbered. The progeny rows planted next year should have the same numbers as those of their respective parent plants. The one hundred plants to be selected from the uniform rows will be numbered in the following manner:

<table>
<thead>
<tr>
<th>Position of the Plant</th>
<th>Number to be Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>First plant in the first row</td>
<td>1-1</td>
</tr>
<tr>
<td>Eleventh plant in the first row</td>
<td>1-11</td>
</tr>
<tr>
<td>Seventh plant in the second row</td>
<td>2-7</td>
</tr>
</tbody>
</table>
Position of the Plant  Number to be Assigned

Nineteenth plant in the second row  2-19
Twentieth plant in the third row  3-20, etc.

In the third year, seeds from these plants are again planted in individual rows. The rows are given annual numbers from one to one hundred. At the end of the season, one hundred plants are again selected. They are numbered in the same way as described, but they are finally prefixed by the numbers of their respective parents. Thus,

Position of the Plant, Annual Numbers of the Rows in Parenthesis, Temporary Number of Parent. Permanent Number.

5th. in 1st. row (1) (1)-5 1-1 1-1-5
56th. in 2nd. row (2) (2)-56 1-11 1-11-56
143rd. in 4th. row (4) (4)-143 2-19 2-19-143
83rd. in 5th. row (5) (5)-83 3-20 3-20-83, etc.

The selections of the fourth year are to be numbered in the same fashion, and the numbers may be kept compounded for a number of years.

DETERMINATION OF SOME OF THE LINT CHARACTERS. In the pedigree selection, the lint characters are determined by the breeder's personal judgement, the probable errors involved being usually very large. In the scientific selection, however, the lint characters are determined by actual measurements and expressed by mathematical terms. Methods for determining
a few of the lint characters are given below.

(a) Length of Staple. Dr. Cobb of the United States Department of Agriculture (26) recommends the map measure as the most accurate method ever devised for measuring the length of cotton staple. The single fibres are taken at random and each pressed between two glass plates. The fibres thus mounted are projected in an ordinary projecting lantern. The projection is received on a glass-mounted tracing paper, and the image of the fibre, which resembles the picture of a river, is measured with an instrument called the map measure. Two hundred measurements thus made will fairly represent the average length of a sample, with a probable error of about one two-hundredth of an inch. This method, however, accurate it may be, is too cumbersome for extensive use.

A simpler method of measuring the length of cotton staple is as follows. Comb the lint into a winged fashion, take six measurements altogether with a millimeter rule, one along the posterior margin, one across the middle, and a third along the anterior margin of each wing. Then, calculate the average of these six measurements. Ball (27) stated that if the lint of five seeds of Egyptian cotton be combed out and the average length taken, the results will show a probable error of 2.9% in both ways on a mean of thirty five millimeters. Harland of the British West Indies likewise
stated that the average length of staple measured from five seeds of Sea Island cotton will show a probable error of 1.3% on a mean of forty four millimeters and 2.6% on a mean of forty seven and eight-tenth millimeters. The average of five seeds is therefore fairly accurate for comparative purpose.

(b) Uniformity of the Length of Staple. Pull off from a combed seed all fibres of or over a definite length which is to be determined by the average length of the staple of a variety. Weigh these fibres collectively as the "available fibre" and express it as a percentage of the total lint of the seed. The average of five such determinations shows a maximum probable error of 7.1%, and the average of ten determinations reduces the probable error to 3.5% of the mean of available fibre. Ten determinations are therefore sufficient to give a fairly accurate idea of the uniformity of the length of cotton staple.

(c) Strength of Fibres. Strength of fibres is here meant the breaking strength of single fibres with no reference to the area of their cross-section. The machine generally used for determining this strength is the one devised by A. S. MacKenzie of Philadelphia. It consists of a brass beam resting on a wedge-shaped fulcrum at the top of a vertical brass column. Above the fulcrum there is a horizontal bar attached to the beam. The bar may be driven forward and backward to
upset the equilibrium established by the beam. The driving device consists of a horizontal shaft which is in turn driven by a slanting shaft with a metal disk at its lower end. On the outer end of the horizontal shaft, there is attached a large graduated metal wheel which turns with the shaft. Attached to the beam in front of the wheel, there is a needle-shaped pointer which touches the zero mark on the wheel when the beam is in balance. At the front end of the beam, there is hung a metal clamp, and below it there is another one supported on a brace from the main column. When the beam is levelled and balanced, which condition is further indicated by another pointer on the zero mark of a vertical graduated rule above the hanging clamp, lock up the beam by means of a metal clip, and set up a single fibre between the two clamps. After the fibre is in position, release the clip, and turn the disk at the end of the slanting shaft. The large graduated wheel revolves as the brass bar is driven backward, and soon the fibre breaks. The number on the wheel opposite the pointer represents the number of decigrams at which the fibre breaks.

With this machine, Wilson of this University obtained the following results (28).
## BREAKING STRENGTH OF COTTON FIBER

<table>
<thead>
<tr>
<th>Variety of Cotton</th>
<th>Number of Tests Made</th>
<th>Average Number of Grams Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simpkins</td>
<td>250</td>
<td>5.92</td>
</tr>
<tr>
<td>Ounce Boll</td>
<td>50</td>
<td>5.82</td>
</tr>
<tr>
<td>Broadwell's Double Joint</td>
<td>50</td>
<td>5.51</td>
</tr>
<tr>
<td>Blanchard</td>
<td>50</td>
<td>5.36</td>
</tr>
<tr>
<td>Mortgage Lifter</td>
<td>100</td>
<td>5.22</td>
</tr>
<tr>
<td>Foster's Long Staple</td>
<td>50</td>
<td>5.07</td>
</tr>
<tr>
<td>Allen's Early</td>
<td>50</td>
<td>4.70</td>
</tr>
<tr>
<td>Triumph</td>
<td>50</td>
<td>4.34</td>
</tr>
<tr>
<td>Columbia Big Boll</td>
<td>100</td>
<td>4.06</td>
</tr>
<tr>
<td>Roseland</td>
<td>50</td>
<td>3.53</td>
</tr>
<tr>
<td>Sunflower</td>
<td>50</td>
<td>3.21</td>
</tr>
<tr>
<td>Cook's Improved</td>
<td>50</td>
<td>3.16</td>
</tr>
</tbody>
</table>

(d) Uniformity of Strength of Fibres. The uniformity of the strength of fibres is expressed by the percentage of weak fibres of the total lint. In combing the lint upon a seed, the procedure is to pass the comb through the fibres near their place of origin on the seed, and having carefully cleared this area, to grip the fibres with the fingers and comb out the rest of the lint with more vigor. The fibres that are combed off are supposed to be weak and immature. They are weighed collectively, and their weight is expressed
as a percentage of the total lint. An average of twenty five such determinations will show a probable error of four percent.

(e) Lint Index and Lint Percentage. The percentage of lint has long been considered as one of the important factors in cotton breeding. It is usually determined by weighing a certain amount of seed cotton, reweighing the seeds after ginning, and expressing the weight of the lint as a percentage of seed cotton. Cook of the United States Department of Agriculture (29), however, announces the danger of judging cotton varieties by the lint percentage alone. He maintains that high lint percentage gives no assurance of large yields or of high quality, but may result in getting smaller and lighter seeds, and may characterise weak or unproductive varieties. Instead of lint percentage, he suggests the lint index as a reliable guide in cotton selection, which is expressed by the number of grams of lint obtained from one hundred seeds of cotton. Cook's argument against the lint percentage has been questioned by many cotton breeders, although his lint index is accepted as an important factor in cotton judging. In fact, both the lint percentage and the lint index should be considered in scientific breeding, each characterising certain desirable points of cotton. Recently, Meloy of the United States Department of Agriculture (30) advocated the use of a standard weight of one hundred grams of seed cotton in determining the
lint percentage. If one hundred grams of seed cotton is used, the lint percentage may be read directly from the weight of the seeds, and the number of seeds necessary to make up one hundred grams of seed cotton is a direct indication of the size of seeds. Lint index, then, may be easily calculated from the following equation:

\[ \text{Lint Index} = \frac{\text{Percentage of Lint}}{\text{Number of Seeds}} \times 100 \]

(f) Diameter of Fibres. For determining the diameter of cotton fibres, Thornton of the British West Indies recommends the following method (30): "The diameter of fibres must be ascertained microscopically by means of a graduated eye piece. This work can be done very rapidly. It is not advisable to measure the weak fibres, these being flat and consequently broader, and besides, they constitute a factor which we are trying to eliminate. Five mounts should be made from the sample and the diameters of twenty fibres measured in each mount". In view of the great variations existing at different internodes, Harland (27) expresses the opinion that it is unnecessary to determine the diameters of single fibres. He believes that if a bundle of fibres be embedded in celluloid and a cross-section cut through the bundle, the mount will represent a large number of sections of fibres, the average of which will be fairly accurate. He also recommends to take a
photomicrograph of the whole section of the bundle to a known magnification; and then measure the diameters from the photograph.

WAYS OF KEEPING RECORDS. In selecting cotton, a score card is necessary for the guidance of fair judgement. The score of different characters should be variable for different purposes of breeding and for different varieties of cotton. The following two forms of score cards are herewith inserted as an illustration of their variable nature. Webber's form was used to judge hybrids of Sea Island and American Upland, (25), while Burkett's form was devised primarily for Upland cotton (32).

Besides the score cards, there are two forms of records that ought to be regularly kept by scientific breeders. One is the record sheet in which the data of the individual plants to be finally selected each year are entered as soon as they are available. The other is the progeny note which contains the behavior of the progeny of each selected individual. These forms are herewith inserted as they are presented by Webber with the addition of the number of the plant at the top right hand corner of the page.
WEBBER'S SCORE CARD FOR JUDGING HYBRID OF
SEA ISLAND AND UPLAND COTTON.

1. Size of Boll, 15 points

<table>
<thead>
<tr>
<th>Size</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very large</td>
<td>15</td>
</tr>
<tr>
<td>Large</td>
<td>14</td>
</tr>
<tr>
<td>Medium</td>
<td>12</td>
</tr>
<tr>
<td>Small</td>
<td>8</td>
</tr>
<tr>
<td>Very small</td>
<td>3</td>
</tr>
</tbody>
</table>

2. Length of Lint, 20 points

<table>
<thead>
<tr>
<th>Length</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 in.</td>
<td>20</td>
</tr>
<tr>
<td>1 7/8 in.</td>
<td>19</td>
</tr>
<tr>
<td>1 3/4 in.</td>
<td>18</td>
</tr>
<tr>
<td>1 5/8 in.</td>
<td>17</td>
</tr>
<tr>
<td>1 1/2 in.</td>
<td>15</td>
</tr>
<tr>
<td>1 3/8 in.</td>
<td>10</td>
</tr>
<tr>
<td>1 1/4 in.</td>
<td>5</td>
</tr>
</tbody>
</table>

3. Fineness of Lint, 10 points

<table>
<thead>
<tr>
<th>Fineness</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very fine</td>
<td>10</td>
</tr>
<tr>
<td>Fine</td>
<td>8</td>
</tr>
<tr>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td>Coarse</td>
<td>3</td>
</tr>
</tbody>
</table>

4. Yield, 20 points

<table>
<thead>
<tr>
<th>Yield</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>20</td>
</tr>
<tr>
<td>Good</td>
<td>18</td>
</tr>
</tbody>
</table>

5. Uniformity in Length of Lint, 7 points

<table>
<thead>
<tr>
<th>Uniformity</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>7</td>
</tr>
</tbody>
</table>

6. Strength of Lint, 10 points

<table>
<thead>
<tr>
<th>Strength</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very strong</td>
<td>10</td>
</tr>
<tr>
<td>Strong</td>
<td>8</td>
</tr>
<tr>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td>Weak</td>
<td>3</td>
</tr>
</tbody>
</table>

7. Percent of Lint, 18 points

<table>
<thead>
<tr>
<th>Percent</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 and up</td>
<td>18</td>
</tr>
<tr>
<td>31-32</td>
<td>17</td>
</tr>
<tr>
<td>29-30</td>
<td>16</td>
</tr>
<tr>
<td>27-28</td>
<td>15</td>
</tr>
<tr>
<td>25-26</td>
<td>10</td>
</tr>
<tr>
<td>23-24</td>
<td>5</td>
</tr>
</tbody>
</table>
BURKETT'S SCORE CARD FOR JUDGING
UPLAND COTTON.

1. Number of Bolls, 15 points.
   - Large, 15 "
   - Medium, 10 "
   - Small, 5 "

2. Size of Bolls, 15 points.
   - Large, 15 "
   - Medium, 10 "
   - Small, 5 "

3. Yield of Lint, 15 points.
   - Heavy, 15 "
   - Medium, 10 "
   - Light 5 "

4. Length of Fibre, 15 points.
   - 2 inches, 15 "
   - 1 3/4 inches, 12 "
   - 1 1/2 " 8 "
   - 1 1/4 " 5 "

5. Percentage of Lint, 15 points.
   - 35%, 15 "
   - 30%, 10 "
   - 25%, 5 "

6. Fineness, 10 points.
   - Fine, 10 "
   - Medium 7 "
   - Coarse, 5 "

7. Strength of Fibre, 10 points.
   - Strong 10 "
   - Medium 7 "
   - Weak 5 "

8. Uniformity in Length, 5 points.
   - Good 5 "
   - Medium 3 "
   - Poor 1 "
### RECORD SHEET

Number.............

<table>
<thead>
<tr>
<th>General Notes</th>
<th>Date of Planting</th>
<th>First Boll opened; Earliness</th>
<th>Height; Form of Plant</th>
<th>Disease Resistance</th>
<th>Number of Bolls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-16-18</td>
<td>8-23</td>
<td>5 1/2 ft</td>
<td>good</td>
<td>153</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bolls</th>
<th>Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing</td>
<td>Size</td>
</tr>
<tr>
<td>single</td>
<td>very large</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lint</th>
<th>Yield, Lint, Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Color</td>
</tr>
<tr>
<td>1 3/8in</td>
<td>white</td>
</tr>
</tbody>
</table>

48
PROGENY NOTE

Locality where Grown | Date of Planting | No. of Plants Grown | No. of plants Harvested | First Boll opened; Earliness | Height; Form of Plant
--- | --- | --- | --- | --- | ---
| | 4-16-18 | 1,205 | 41 | early | 5 ft.

Disease Resistance | Size of Boll | Opening of Bolls | Seed
--- | --- | --- | ---
good | large | good | medium | 15 | 85
--- | 14 | --- | --- | --- | ---

Length | Color | Fineness | Uniformity | Strength | Yield, seed Cotton | Lint | Total Score
--- | --- | --- | --- | --- | --- | --- | ---
3/8in | white | fine | fair | strong | good | 36 | ---
10 | ----- | 8 | 4 | 8 | 18 | 17 | 79
(B) MUTATIVE SELECTION

In a uniform field of cotton, there sometimes appear a few plants standing out prominently among all their neighbors. This phenomenon is called mutation. The plants which show up such variations will mostly breed true, because they result from a readjustment of the expression equilibrium of characters which will enable the reversion of characters to be continually expressed. The mutants are for the most part degenerating in nature, expressing characters inferior to the standard of the variety in which they are found. But once in a while, superior mutants do appear, and the principle of mutative selection is to isolate such plants, test their progeny, and propagate them if they will breed true. Thus mutative selection is a method of breeding for originating new varieties.

In order to avoid any crossing in the mutants to be selected, the selection should be started early in the season. Whenever a desirable mutant is seen in the general field, it should be caged immediately so as to insure in-breeding. Most of the plants should be selected before the time of blooming. Then, during the several stages of development, a rigid elimination is to be carried on, so that only the most desirable plants are finally selected.

In the following year, the selected plants are sub-
jected to a progeny test. The rows should be examined from
time to time, and only those are to be retained which show up
the greatest uniformity, superiority, and best conformation
to the parent plants. After picking, the seed cotton from
each row should be examined again before the final decision
is to be made. The selection in all cases needs be strict,
as there is no value to propagate inferior plants.

In the third year, seeds from the selected rows are
planted in separate increasing plots. Isolate each plot from
any other near-by cotton. If two or more plants are select-
ed at the same time, their progenies need be kept as far apart
as possible. A strict rouging should be practised during this
season, and through another year's multiplication, the seeds
from each parent mutant may be enough for planting a general
crop the next year.

The detailed methods of numbering the plants, determin-
ing the lint characters, and keeping records described under
regular scientific selection are equally applicable in this me-
thod. In fact, the procedure of mutative selection does not
differ from pedigree or scientific selection, except in the
fact that the characters for which mutative selection is car-
rried on need not conform to those of the parent variety but
must show up unusual excellence in themselves.

Having reviewed the different systems of selection, we
shall pause for a moment to see some of the essentials that underlie success in this branch of cotton breeding.

First of all, selection must be continuous. The single selection advocated by some for cereal breeding being not applicable to cotton. Because the cotton plant is open pollinated and because it is sensitive to environmental changes and produces mutants freely, a field of cotton will not retain its superiority and uniformity unless continuous selection is practised. In as much as selection is the only method of breeding that may preserve the high qualities of cotton, it should be practised at all times, and an interruption of its use will undo what has been previously obtained.

Another important thing that should be observed in following any system of selection is to start with the best variety obtainable. Superior varieties of cotton represent efforts of previous breeders; there is no reason why we should not utilise their efforts and spare ours for further improvement. The variety to begin with should also be well adapted to our local conditions; improvement by selection may be seen only when no other complications are involved.

To plant only the large and heavy seeds is another essential thing that cannot be too much emphasised. Small seeds do not germinate well and plants from them are liable to be weak and unproductive. To plant unseparated seeds is to hold
up the largest possible yield which may be obtained if only large and heavy seeds are sown. Webber and Boykin's report (33) of experiments in favor of heavy seeds against unseparated stock is summarized in the following table:

HEAVY SEEDS VERSUS UNSEPARATED SEEDS

<table>
<thead>
<tr>
<th>Kind of Seeds</th>
<th>Yield of Seed Cotton in Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lumar, South Carolina</td>
</tr>
<tr>
<td>Heavy seeds</td>
<td>1047 1/4</td>
</tr>
<tr>
<td>Unseparated seeds</td>
<td>944 1/4</td>
</tr>
<tr>
<td>Percent increase in favor of heavy seeds</td>
<td>10.9%</td>
</tr>
</tbody>
</table>

Before leaving the topic of selection, we should be aware of the fact that this method is the foundation upon which the whole system of breeding is built. No matter what methods we may take up at the start, either acclimatisation, or hybridisation, or selection itself, we must necessarily practise selection or continue to practise it in the later years, because it is the only means by which we can limit the line of descent of cotton to a single parent or to a few similar parents. Since uniformity is the thing that makes cultivated varieties superior to the wild stock, selection is therefore the most dependable system with which the art of plant breeding has contributed much to the progress of agriculture.
ACCLIMATISATION

Acclimatisation is a method of cotton breeding by which we may adjust a variety of cotton to a new climate. The new environment under which a transported variety is grown usually disturbs the normal equilibrium of expression in a large number of the seedling plants. As a consequence, they deviate from the normal type and display a great diversity of characters, while their equilibrium of expression is undergoing a process of readjustment. These deviatives are mutants in nature and will probably breed true. There are, however, many plants which will retain the normal behavior of the variety. The normal equilibrium of expression in these plants may be more stable than in others and may produce normal offsprings in the next generation. It is only these plants that we should propagate, while all the off-types must be pulled up as soon as they appear. In the second year, the diversity may be even greater than in the first, but if rigid selection is practised, the offsprings in the later years will gradually become uniform. Thus, acclimatisation is a method which does not produce anything new but is used to preserve the good qualities of an existing variety after its translocation.

The source of a variety of cotton to be acclimatised may be a near-by locality or a distant land. The influence of the new climate upon the translocated plants is in some way
dependent upon the distance through which it is carried, and
the ease with which acclimatisation may be accomplished will
vary in the reverse proportion. For convenience, acclimatisa-
sation may be looked upon from two points of view, namely,
I. To acclimatise a domestic variety in a new climate, and
II. To acclimatise a foreign variety.

I. ACCLIMATISATION OF A DOMESTIC VARIETY.

In any cotton producing country, there are varieties of
cotton which are superior over others, and yet in no country
are those varieties planted universally throughout its terri-
torial domain. Should their present limit of adaptation be
widened to replace the inferior varieties elsewhere, the value
of cotton produced in any country will be greatly increased.
The general agricultural importance of this phase of acclima-
tisation is well emphasised by Cook of the United States De-
partment of Agriculture who says (34), "The failure to make
use of local adjustment......causes a very general and regular
loss to the cotton industry, a loss that would be represented
by enormous annual totals if the facts could be definitely
known". He further says that with very slight expense of time
and effort in the selection of seed for local adjustment, and
with no other changes, either in varieties, lands, or method
of culture, it would be possible to add ten percent to the cot-
ton crop of this country. Indeed, what Cook said about the United States is equally applicable to all cotton producing countries.

To acclimatise a domestic variety from other localities is after all not a serious attempt in any sense; every farmer of ordinary means can afford to do it. If he wants to plant cotton, he should plant the best variety in order to insure the largest profit. In most cases, he does seek for a good variety, but he is liable to limit his field of search to his own locality, losing sight of all better things in other parts of his country. If he could spend only a little more time to secure the best variety of cotton he can possibly get, he will undoubtedly to able to reap more profit year after year for himself besides the good he will do to his country at large.

The procedure of acclimatising a domestic variety is exactly the same as pedigree selection and will not be discussed in length. Here it suffices to say that a domestic variety, after being translocated from its original home to a new climate or to a new type of soil, will behave differently as compared with its manner of growth under its old environment. The new place effects of cotton is well demonstrated by a comparison made by Cook in the season of 1907 between two fields of Triumph cotton, one at Lockart, Texas, and the other at Kerrville, Texas. Let it also be remarked
here that the diversity of characters displayed may be success-
fully eliminated by repeated planting and selection, and that
the failure of getting returns from a transferred variety in
the first two years should not lead one to conclude hastily
that the variety is not adapted to its new environment.

II. ACCLIMATISATION OF A FOREIGN VARIETY

To acclimatise a foreign variety or introduction is
one of the principal methods of breeding with which the crops
of a country may be improved. Since none of the small grains
is native in this country, all varieties now grown have been
at some time introduced from foreign lands. "It is natural,"
Carleton says (35), "that our greatest source of improvement
of these cereals must now, and for some time in the future,
lie in occasional introductions of varieties or strains su-
perior to those we already have..." Introduction, again,
has played an important part in the development of the horti-
cultural crops of this country, and indeed introduction of
foreign plants is one of the lines of regular work that the
United States Department of Agriculture is pursuing for the
progress of agriculture.

When we turn our attention to the cotton industry of
the United States, we will also see that the result of intro-
duction is no less remarkable with cotton than with
small grains or horticultural crops. Between the years of 1897 and 1907, the United States (36) imported annually from Egypt fifty-four million pounds of Egyptian cotton and eight and one-half million pounds indirectly from England. In 1907, the value of the direct imports from Egypt amounted to over $16,000,000. In view of the considerable value of this import, the Department of Agriculture endeavored to develop Egyptian cotton culture in the United States, and began its systematic work in 1902 in the Southwestern Section. Through ten years' work of breeding, the Department of Agriculture (37) was finally able to distribute to farmers of the Salt River Valley seeds of a carefully selected, uniform variety of Egyptian cotton, and to-day the cotton industry in the Southwest rests upon a foundation as stable as that of the main Cotton Belt.

Just as the United States has been profited by Egyptian cotton, other countries in the world to-day are either availing or trying to avail themselves of the American varieties. Both the short and the long stapled Upland cotton and the Sea Island have been grown in India for about thirty years, and it is due to these imported types that India succeeded in revolutionising her cotton industry. Many other countries such as China, Brazil, and Australia (38) are also purchasing and testing seeds of the improved varieties that
have been bred by the United States Department of Agriculture and the state agricultural experiment stations.

The first essential for successful acclimatisation is to introduce a variety of cotton to the right climate. This necessitates a careful study of the climatic conditions of the localities concerned. Chief among the conditions that need serious consideration is the length of the growing season and the distribution of rainfall. If the difference of climate between the two localities is great, it is better not to attempt an introduction, because the imported cotton will be bound to fail under the new conditions. The experiments with Egyptian cotton in this country affords us a good example as our guidance. The main Cotton Belt is too wet and the growing season is too short for the proper development of Egyptian cotton, whereas the arid section in the Southwest, having much more similar conditions like those along the Nile, is a much better region for that kind of cotton to thrive. It indeed came to pass that Egyptian cotton failed to adapt itself along the Mississippi River, while it has brightened the prospect of the cotton industry in the arid section. To have the right climate for the introduced cotton is therefore the key note to successful acclimatisation.

To introduce cotton to the right soil is the second
important principle that ought to be observed. It is the physical properties of the soil rather than fertility that should be carefully considered. By physical properties we mean to include the texture of the soil, its drainage condition, its reaction toward litmus, and its content of organic matter. A variety that is used to thrive in a heavy land will not do well in light soil, while an upland cotton will assume too much vegetative growth if grown in a bottom land. Provisions guarding against too great a difference in soil types will facilitate subsequent work in acclimatisation.

After the climatic and soil conditions have been investigated with the conclusion that an introduction is advisable, then the varieties grown in the foreign countries should be carefully studied. Successful acclimatisation urgently calls for a personal knowledge on the breeder's part of the normal behavior of the introduced varieties under their home conditions. After a variety is imported and grown in the new locality, it might show up so much diversity that the breeder will not be able to find any prevalent type. If he does not know what the variety normally looks like, he will absolutely lose his compass of selection in the vast field of diversity, and no encouraging results may be expected.

The last but not the least important of all precautions is the right choice of varieties to be introduced. The varie-
ties to be chosen must possess some specific features not found in the native stock and should have maximum development under their home conditions. They should also be productive and uniform, and come from a reliable source.

After the importation of seeds, the real work of acclimatisation begins. According to the procedure of introducing Egyptian cotton into this country, the work of acclimatisation is divided into three branches (39):

1. Plant-breeding investigation, the object of which is to secure improved, high yielding varieties or strains by the selection of superior individuals.

2. Acclimatisation investigation, the object of which is to study the diversity exhibited by imported and by more or less acclimatised stock, so as to ascertain what cultural methods are most favorable to uniformity, fruitfulness, and the production of good lint.

3. The study of irrigation and other cultural methods for growing the crop and of industrial methods for preparing and marketing the product.

With the exception of the third branch, the work of the Egyptian cotton investigation will be briefly presented.

In the early introductions of Egyptian cotton, the imported varieties were not very pure and the new place effects could not be well ascertained (36). Later introductions, ho-
wever, brought over three uniform varieties for the study of
diversity, namely Jannovitch, Mit Afifi, and the Dale. It
was found that all characters of the varieties exhibited more
or less diversity. The habit of growth, the form and color
of the leaves and flowers, the size and shape of bolls, the
fuzzy coating of the seeds, and the length, abundance, and
color of the lint were all shown to be capable of pronounced
variation. Taking the characters of the lint, for example,
we have found that some of the short lint of Jannovitch cot-
ton was less than half the length of the longest; some of the
seeds produced only half as much lint as others; some seeds
bore very strong lint for which Egyptian cotton is noted,
while others had lint so weak as to be worthless; some lint
was very fine and silky, while others were even coarser than
Upland staple; and some plants gave white lint as Upland cot-
ton while others retained the characterised brown tinge in
their staple. The Mit Afifi and the Dale diversified even more
than Jannovitch in all visible characters. Such diversities
as were found in the imported Egyptian cotton will serve at
least to indicate that the new place effect is not a minor
problem in acclimatisation.

Evidences gathered from experience reveal another fact
worthy of notice; namely, the diversity of characters in the
second and third generations may be greater than that of the
first, depending upon the extent to which the equilibrium of expression of characters is disturbed by the changed conditions. Such a phenomenon is explained by the fact that the seeds which produce the second generation must develop under the new conditions, whereas those which produce the first generation have been developed under conditions normal for the variety. It is therefore evident that no definite results may be expected from the first year's selection; real effectiveness will not appear until the third or the fourth generation.

Another important lesson learned from the acclimatisation of Egyptian cotton is the fact that the branching habit of the plants came into play against their productiveness. As the yield of lint is directly controlled by the manner of branching, the rank growth of Egyptian cotton with subsequent sterility became the chief objection that had to be removed. Observation has confirmed the fact that heavy yields of Egyptian cotton largely depend upon the size of the contribution made by the fertile branches formed on the main stem within two or three feet from the ground. Under the conditions of the Southwest, early planting and regular selection of the more fertile forms will suppress the rank growth and increase fertility of Egyptian cotton.

The work of the plant-breeding investigation, as re-
ported in 1910 (39), resulted in the production of a few new types of Egyptian cotton such as Yuma, Somerton, "Pima" (42), and some unnamed strains. The method of breeding used in producing these varieties is thus: "At the outset all the plants in the test field were examined, and those individuals which were the most fruitful, ripened earliest, and had the largest bolls and the best fibre were given numbered bags and picked separately. The seed cotton from these plants was then carefully compared in the laboratory and the final selection of the most promising individuals was made". After this, the procedure of pedigree selection was applied year after year. It is in this way that the Somerton was separated from the Mit Afifi stock in 1905, the Yuma from the same variety in 1906, and later "Pima" was obtained from Yuma. All the new varieties are distinct from their parents from which they were originated, and they are considered by the investigators as mutants in nature. After separation they were subjected to further pedigree selection, and year after year, quantities of relatively pure seeds were put out for general planting.

From this brief review of the work of the Egyptian cotton investigation, we have gathered a fairly good idea of how the imported plants will behave under the new conditions and what should be done in order to get them thoroughly accli-
tised. It is true that some phenomena exhibited by Egyptian in the Southwest might not hold true with the introduction of other varieties, but a general method for looking into difficulties is obtained from that investigation. We have also learned from it that the investigators, lacking a personal knowledge of the normal behavior of Egyptian cotton, were much handicapped in subsequent selections. Having lost the compass of selection in the midst of diversities, they could select only what they considered the best without regard to such standards as inherent to Egyptian cotton in Egypt. The result of acclimatisation might have been delayed on account of this handicap on the part of the breeders. Nevertheless, they have revealed to us the fact that mutative selection is a very important side issue of acclimatisation.

If the breeders do have a personal knowledge of the normal behavior of the introduced variety under its home conditions, regular scientific selection may be practised to advantage. Let the regular selections form one series of experiments by themselves, while another series of mutative selections should be carried on at the same time. If both of these lines of selection are to be carried on, results of acclimatisation will be surer than when only one line is maintained.

After thorough acclimatisation of the introduced varie-
ty or after the origination of new strains therefrom, they should be subjected to a comparative test with the home grown superior varieties. If the former prove themselves superior over the native stock in regard to those characters for which they are introduced, then the work of acclimatisation is said to be complete.
HYBRIDISATION

Hybridisation was defined as a process of artificial cross fertilisation between species, and hybrids as products of such crosses (43). Of late the word hybridisation has been used by most writers to comprise all crosses between species and varieties. Others again extend the scope of hybridisation to crosses between strains and races. In fact, there are no hard and fast lines between species and varieties in the botanical usage of these terms, while in the language of agriculture, varieties and strains are again mixed up. For our convenience, we assume that hybridisation denotes artificial cross fertilisation between agricultural varieties and higher groups, because variety is the unit division of cultivated plants.

The purpose of hybridisation is two fold. First, if two desirable characters of cotton are found in two different varieties, and if these two characters cannot be obtained together in one variety by straight selection, then hybridisation affords us a means for effecting such a combination. Second, hybridisation may disturb the normal equilibrium of expression of characters in the parent stock and may bring into expression in hybrids a number of ancestral characters which may continue to appear in the following generations. By the
theory of chances, there may appear some plants possessing in combination a number of desirable characters, and these if separated and propagated will produce a distinct superior variety. Thus hybridisation is used as a means to induce variation for subsequent selection.

Before going further into the work of hybridisation, let us stop for a while to see some of the theories concerning hybridism (44). Heretofore we have spoken of the characters of cotton such as long lint, high percentage of lint, early maturing, and so on, and in opposition to them, we have also noticed such characters as short lint, low percentage of lint, late maturing, and so on. These different characters which are carried over from generation to generation without any essential change and act independently of each other are called unit characters. Those which are opposite to each other, as long lint and short lint, or early maturing and late maturing, are spoken of as character pairs or allelomorphic pairs of characters. In pure parental stock, only one character of any pair is present, whereas both of them may be found in hybrids. The former is spoken of as homozygous, and the latter as heterozygous individuals. In order to explain Mendel's Law of Segregation, which will follow presently, the homozygotes are supposed to possess double doses of one character of each allelomor-
phic pair, whereas the heterozygotes have one dose of each of the two characters. The two characters of any pair, however, cannot come into expression in the same heterozygote, and one of them has to be crowded out of expression. The one which is expressed is therefore stronger than the other and is called the dominant character, while the other suppressed from expression is the recessive.

If a cross is made between one parent having long lint LL and another having short lint ll, the first generation hybrids will all be heterozygotes Ll, and will all have long lint, because long lint is dominant over its alleleomorph. If these hybrids are bred with each other, their offsprings will segregate into two main groups. One group consists of individuals having short lint, representing twenty five percent of the whole number. These individuals are all homozygotes in respect of the recessive character and will breed true in succeeding generations. The other group representing seventy five percent of the whole may be divided into two sub-groups, although all the individuals possess long lint. The first sub-group is made up of homozygotes in respect of the dominant character, representing twenty five percent of the whole, and will breed true to long lint. The second sub-group, representing fifty percent of the whole, consists of heterozygotes which will
segregate in the next generation and will produce the same proportions of constant and inconstant forms as their parents do. This fact of segregation is one of the essential discoveries in Mendel's Law. The manner of segregation in a monohybrid combination is shown in the following diagram.

A MONOHYBRID COMBINATION

Parents

\[
\begin{array}{ccc}
& \text{LL} & \text{x} & \text{ll} \\
(\text{long lint}) & & (\text{short lint}) \\
\end{array}
\]

First Generation

\[
\begin{array}{c}
100\% \text{ Ll} \\
(\text{long lint})
\end{array}
\]

Second Generation

\[
\begin{array}{ccc}
25\% \text{ LL} & 50\% \text{ Ll} & 25\% \text{ ll} \\
(\text{long lint}) & (\text{long lint}) & (\text{short lint})
\end{array}
\]

Third Generation

\[
\begin{array}{ccc}
100\% \text{ LL} & 50\% \text{ Ll} & 100\% \text{ ll} \\
(\text{long lint}) & (\text{long lint}) & (\text{short lint})
\end{array}
\]

In presenting the above diagram, we presuppose that the first year hybrids are bred with each other. But if they are crossed back with a parent like LL, then we shall have the following combination.
A MONOHYBRID BACK CROSS

Parents  

\[
\begin{array}{ccc}
\text{LL} & \times & \text{LL} \\
\end{array}
\]

Second Generation  

\[
\begin{array}{ccc}
50\% \text{ LL} & \text{(xLL)} & 50\% \text{ Ll} \\
\end{array}
\]

Third Generation  

\[
\begin{array}{ccc}
100\% \text{ LL} & 50\% \text{ LL} & 50\% \text{ Ll} \\
\end{array}
\]

In such a back crossing, we are able to get a greater percentage of homozygotes in regard to the dominant character of long lint which is by all means desirable. In this lies the value of dilute hybrids as a parent which will be taken up in a later page.

So far we have considered only one allelomorphic pair of characters involved in crossing. In fact, if our purpose in doing hybridisation is to combine two desirable characters, we will have two allelomorphic pairs to be involved. Mendel's Law of Segregation will also hold true in this case, but the range of combinations will be more complicated. Suppose that a cross is made between a parent of long lint lacking uniformity represented by LLuu and another of uniform short lint represented by lLuu; then, the first generation hybrids, having the composition of LlUu, will all show uniform
long lint of heterozygous nature. They will segregate in the second generation into four main groups according to appearance and nine sub-groups in regard to constitution.

GROUPS OF SECOND GENERATION HYBRIDS
OF A DIHYBRID UNION

Group I. Uniform long lint, representing 56.25%.
   Sub-group 1. UULL, representing 6.25%.
   Sub-group 2. UULL, representing 12.50%.
   Sub-group 3. UuLL, representing 12.50%.
   Sub-group 4. UuLL, representing 25.00%.

Group II. Non-uniform long lint, representing 18.75%.
   Sub-group 5. uuLL, representing 6.25%.
   Sub-group 6. uuLL, representing 12.50%.

Group III. Uniform short lint, representing 18.75%.
   Sub-group 7. Uull, representing 6.25%.
   Sub-group 8. Uull, representing 12.50%.

Group IV. Non-uniform short lint, representing 6.25%.
   Sub-group 9. uull, representing 6.25%.

Thus in a dihybrid combination, there are only 6.25% of the second generation hybrids representing the form of UULL that we want to produce. In actual work, a great number of allelomorphic pairs of characters are involved in segregation, and the percentage of the desired homozygotes is indeed very small.
Since the appearance of hybrids is controlled by the dominant characters, it is very necessary to understand which characters are dominant and which ones are recessive. According to past experience (15), the following character pairs have been determined in this respect.

**DOMINANT AND RECESSIVE CHARACTERS OF COTTON**

<table>
<thead>
<tr>
<th>Character</th>
<th>Dominant</th>
<th>Recessive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leaf</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light green</td>
<td>Dominant</td>
<td>Dark green</td>
</tr>
<tr>
<td>Red</td>
<td>Dominant</td>
<td>Green</td>
</tr>
<tr>
<td>Red spots</td>
<td>Dominant</td>
<td>No spots</td>
</tr>
<tr>
<td>Glabrous petiole</td>
<td>Dominant</td>
<td>Hirsute petiole</td>
</tr>
<tr>
<td>Narrow segments</td>
<td>Dominant</td>
<td>Broad segments</td>
</tr>
<tr>
<td>Large</td>
<td>Dominant</td>
<td>Small</td>
</tr>
<tr>
<td><strong>Flower</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red spots on petals</td>
<td>Dominant</td>
<td>No spots on petals</td>
</tr>
<tr>
<td>Reddish petal</td>
<td>Dominant</td>
<td>White petal</td>
</tr>
<tr>
<td>Yellow petal</td>
<td>Dominant</td>
<td>White petal</td>
</tr>
<tr>
<td>Large petal</td>
<td>Dominant</td>
<td>Small petal</td>
</tr>
<tr>
<td>Yellow anther</td>
<td>Dominant</td>
<td>Buff anther</td>
</tr>
<tr>
<td>Long filament</td>
<td>Dominant</td>
<td>Short filament</td>
</tr>
<tr>
<td>Long style</td>
<td>Dominant</td>
<td>Short style</td>
</tr>
<tr>
<td>Long column</td>
<td>Dominant</td>
<td>Short column</td>
</tr>
<tr>
<td>Red bracts</td>
<td>Dominant</td>
<td>Green bracts</td>
</tr>
<tr>
<td>Large bracts</td>
<td>Dominant</td>
<td>Small bracts</td>
</tr>
<tr>
<td>Early flowering</td>
<td>Dominant</td>
<td>Late flowering</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Dominant</td>
<td>Recessive</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>Boll</td>
<td>Reddish</td>
<td>Green</td>
</tr>
<tr>
<td></td>
<td>Few loculi</td>
<td>Many loculi</td>
</tr>
<tr>
<td></td>
<td>Long and narrow</td>
<td>Short and wide</td>
</tr>
<tr>
<td>Anthracnose susceptibility</td>
<td>Anthracnose resistance</td>
<td>Smooth surface</td>
</tr>
<tr>
<td>Pitted surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant body</td>
<td>Tall stem</td>
<td>Short stem</td>
</tr>
<tr>
<td></td>
<td>Basal branch</td>
<td>No basal branch</td>
</tr>
<tr>
<td></td>
<td>Late maturity</td>
<td>Early maturity</td>
</tr>
<tr>
<td>Lint</td>
<td>Colored</td>
<td>White</td>
</tr>
<tr>
<td></td>
<td>Even distribution</td>
<td>Uneven distribution</td>
</tr>
<tr>
<td></td>
<td>Regular length</td>
<td>Irregular length</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>Weak</td>
<td>Strong</td>
</tr>
<tr>
<td></td>
<td>Sea Island quality</td>
<td>Upland quality</td>
</tr>
<tr>
<td></td>
<td>Good drag</td>
<td>Poor drag</td>
</tr>
<tr>
<td></td>
<td>Low lint percent</td>
<td>High lint percent</td>
</tr>
<tr>
<td>Seed</td>
<td>Colored fuzz</td>
<td>White fuzz</td>
</tr>
<tr>
<td></td>
<td>Fuzzy</td>
<td>No fuzz</td>
</tr>
<tr>
<td></td>
<td>Little fuzz</td>
<td>No fuzz</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>Light</td>
</tr>
</tbody>
</table>

The above study of the various theories concerning hybridism gives us a general idea in regard to the nature of different hybrids. But when we come to study the results
of practical crosses, we will encounter a number of exceptions to the rules. Cook of the United States Department of Agriculture (45) distinguishes the characters of hybrids into three main classes.

I. Parental characters, inside the normal range of variation of one of the parental groups.

II. Interparental characters, representing combinations of parental characters or intermediate between them.

III. Extraparental characters, not within the parental groups or between them. This class may be further differentiated into three kinds:

1. Suppressed characters, representing the deficiency of a parental character or its reduction below either of the parental groups.

2. Intensified characters, attaining to a higher expression than in either of the parental groups.

3. Primitive characters, representing ancestral characters long suppressed in expression.

Mendel's Law of Segregation together with all its supplementary theories admits characters only of the first two classes, while the third class of characters remains to be explained by other theories. A study of the actual behavior of some hybrids obtained by former breeders is therefore necessary in the absence of definite laws governing the beha-
vior of hybrids.

The first year hybrids or conjugates should be uniform according to Mendel's Law, and should take on such characters as called for by the theory of dominance and recessiveness. In general, they are actually uniform, but the characters expressed are sometimes different from what they should be. Thus in many crosses between the Kekchi cotton of Guatemala and Upland varieties of this country, the lint of the conjugate hybrids was notably inferior to that of either parental stock. The conjugates from crosses between Upland and Egyptian cottons, on the other hand, give a lint longer than that of either parent, and their vigor and fertility were likewise intensified. Hybrids of Kekchi and Egyptian cottons also showed up extra large bractlets, larger than those of the parental stocks. Again, hybrids from crosses between Kekchi and Sea Island or Egyptian cotton often developed a green fuzz around their seeds, whereas this primitive character does not normally appear in either of the parental varieties (46). Such intensifications, suppressions, and reversions were often quite common among the conjugate hybrids studied by Cook, and sometimes were remarkably uniform among them.

Generally speaking, however, conjugate hybrids represent the ideal combination of characters that the breeders
are seeking for by hybridisation. The hybrids are uniform, vigorous, and productive. "Conjugate hybrids of cotton", says Cook, "are not only more vigorous than the parent stock but usually more uniform and more productive, thus arousing lively hopes of developing superior hybrid varieties". To utilise the conjugate hybrids for building a superior variety, however, is practically impossible on account of reasons to be explained. But if some methods of vegetative propagation can be carried on economically, the conjugate hybrids might be used to advantage. Harland of the British West Indies pointed out the possibilities of budding by saying, "When one has a particular quality and a pure strain and wants to continue it, one can do so by budding". That hybrids may be grown from cuttings was also shown at Bard, California, in the season of 1911. The plants thus obtained were very vigorous and productive, and their bolls were even larger than those of other first generation hybrids raised from seedlings.

The perjugate hybrids or the second year plants from crosses, according to Cook and others, are extremely variable. It is in this generation that the parental characters should segregate into different combinations and they do. But beyond the prediction of Mendel's Law, there usually appear many more variations not traceable to parental
characters. Suppressions and degenerating mutations generally abound. Not only will the vigor, the fertility, and the productiveness of the conjugate hybrids disappear, but those of the perjugates will also go down far below the standards of either parent. In the midst of such diversities, it is impossible to recognize the different Mendelian types of combinations, and the hope of separating out a homozygote must be abandoned.

When hybrids do not breed with each other, but are allowed to cross back on one of the parental types, the effect of degeneration will not be so obvious as in the perjugate hybrids just described. This phenomenon agrees very well with Mendelian segregation as we have seen, and the reduced diversity might facilitate results of future selection. This value of dilute hybrids has been shown in corn breeding, but no good results have yet been obtained with cotton. It has also been suggested that if two types of cotton grown under two different climates will not cross successfully with each other, a dilute hybrid of one type might be used to induce cross fertilisation with the other. In the absence of definite information, however, we will not dwell on the values of dilute hybrids.

The procedure of hybridisation begins with the choice of the parental stock. With the ideal combination of char-
acters in mind, the parental varieties should be so selected that each of the characters to be combined must have been strongly expressed in one or the other of the parents. The parental varieties should also be uniform, should have general excellence, and should be well adapted to the local conditions under which hybridisation is to be done. Then each variety is planted in a separate plot, the seedlings are to be well cared, and finally select a number of individual plants which are to be cross fertilised. These plants should be marked with sticks, clothes, or any prominent label.

Late in the afternoon preceding the day on which artificial pollination is to be done, a few large flower buds should be selected that would open the next morning. The anthers are at once removed from those buds which are to be used as the female parents. This can be done with a pair of scissors, and care must be taken not to injure the pistils. Then, cover the entire emasculated bud with a paper bag in order to prevent any incidental visit of insects. In the same way, other flower buds are selected on the male parent plants and properly bagged to prevent admixture of pollen from other flowers. In the following morning, both the emasculated and the perfect flowers should reach the proper stage for crossing. This stage can be recognised by
the dehiscence of the anther sacs and the stickiness of the stigmas. If such a stage is reached, pull the flower from the male parent plant and rub its anthers gently over the stigmas of the emasculated flower, until it is observed that some of the pollen grains have adhered to the stigmas and the sides of the pistil. Then, the paper bag is returned in position and is properly numbered. If the crossing is a success, the ovary will enlarge within a few days.

With this method a large number of crosses may be performed among several varieties at the same time. With extensive study of hybridisation, a systematic method of numbering is as necessary as with regular scientific selection. A convenient system is as following: Varieties are numbered consecutively from one to any number. Parent plants of each variety likewise receive a number, but the latter is preceded by the number of the variety. Thus, plant 10-6 denotes the sixth plant selected from variety 10, and plant 20-3 means the third plant selected from variety 20. An alphabet is assigned to each series of crosses, and each cross of the series bears a number prefixing the alphabet. All crosses, for example, between variety 10 as male parent and variety 20 as female parent will be designated by the same alphabet, while reciprocal crosses between the same varieties will constitute another series. If A is
the alphabetic sign of the first series, and if the cross between plant 10-6 and plant 20-3 is the seventh one made, then this cross will be numbered 7A. Such a number should be put on the paper bag of each pollinated flower immediately after the transfer of the pollen. In the next year when plants from each cross are grown in a separate row, the number of any plant in the row prefixed by the designation of the cross will be the permanent number of that plant. The second generation hybrids are numbered in the same way, but its number is separated from that of its immediate parent by a dash. Thus 7Al, 5H97, 85518, and so on will be the numbers for first generation hybrids, and such numbers as 7Al-53, 85518-3, and so on, will represent second generation hybrids. The numbers may thus be kept compounded for hybrids of the later generations.

The method of taking notes in hybridisation should likewise be systematised. The Agricultural Experiment Station of Georgia recommends a series of blanks for parent plants and for hybrids. One blank is given to each plant, the serial number of which is placed at the top left hand corner of the page. The left hand columns reserved for inserting the remarks or history of the plant, while the rest of the page contains a tabulated form for the description of the various characters. The characters to be des-
cribed are as follows.

1. **Plant body:**
   - Stem; tall or short.
   - Branching; branched or not branched at base.
   - Maturity; early or late.

2. **Leaf:**
   - Color; dark green, light green, red, or green.
   - Spots; red spots or no spots.
   - Petiole; glabrous or hirsute.
   - Segments; narrow or wide.

3. **Flower:**
   - Petals; yellow or white, spotted or not spotted.
   - Anthers; yellow or buff.
   - Filaments; long or short.
   - Style; long or short.
   - Column; long or short.
   - Opening; late or early.

4. **Boll:**
   - Division; few or many.
   - Shape; long and narrow, or short and wide.
   - Surface; pitted or smooth.
   - Disease resistance; good or poor.

5. **Lint:**
   - Length; _____-inches, regular or irregular.
Strength; weak or strong.
Quality; fine or coarse.
Color; colored or white.
Drag; good or poor.
Lint percentage;----percent.
5. Seed:
Weight; heavy or light.
Fuzz; fuzzy or not fuzzy, fuzz white or colored.
The above form of note may be simplified as well as modified. For the production of new superior varieties, due emphasis should be laid on branching habit and on the characters of lint, bolls, and seeds, while those pertaining to leaves and flowers may be omitted from consideration.

After all the above considerations, we have come down to the practical question of how to separate out a uniform strain from the hybrid stock. In the second season, seeds from each cross are planted in a separate row. The first generation hybrids are uniform and we do not have much to do among them except to pull up some aberrant plants that may be found. It is among the second generation hybrids that all types are formed, the separate individuals exhibiting the characters of the two parents in very different degrees. We should carefully examine hybrids of this generation, and select those which conform most closely to the ideal combin-
ation of characters that we want to produce. The selection should be made before the time of blossoming, and each of them should be caged in order to insure inbreeding. Seeds from the selected individuals are to be planted again next year, and the selection repeated in the same way. Thus, what should actually be done in fixing hybrid strains is nothing more than pedigree selection.

As to the number of years required for the separation of a pure, superior strain, it entirely depends upon the skill of the breeder. A skilful breeder may secure more striking and valuable results in three or four years than a less discriminating observer would obtain in a period of eight or ten years. Owing to the large amount of training and experience necessary to produce desirable results from hybridisation, this method of breeding is recommended only to the experienced workers.
SUPPLEMENTARY FACTORS TO COTTON BREEDING
IN THE ECONOMIC PRODUCTION OF COTTON.

In the foregoing pages, cotton breeding is considered as the chief factor influencing the economic production of cotton. Cotton breeding alone, however, is unable to bring in maximum yields of lint, and it is only the combined influence of breeding and other factors that may insure the greatest returns from cotton culture. In so far as breeding cannot control the environmental variations, other means must be provided in order to regulate the manner of growth of the cotton plants. It is true that some of the desirable characters are transmissible, but most of them may also be intensified by favorable conditions. Again, certain critical situations will call for some specific properties, such as insect resistance, which cannot be directly developed in cotton. From these considerations, it becomes evident that if we expect to get the best results from cotton breeding, other problems of culture such as fertilisation, planting, and control of insects and diseases should be considered in conjunction with breeding itself.

Fertilisers have two very important effects on cotton which will either undo the efforts of breeding or will help it to advantage according to the way in which fertilisers
are handled. First, the yield of cotton in any locality is directly controlled by the amount of available fertilising elements supplied. The specific requirement of fertilizers by any soil depends upon the amount of fertility already in it, and it is not attempted here to suggest any definite formula for any locality. But we know for certain that a good crop of cotton yielding five hundred pounds of lint, one thousand pounds of seeds, and two thousand pounds of stalks requires the following amount of fertilising elements.

**REQUIREMENT OF PLANT FOOD BY A GOOD COTTON CROP (22)**

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Phosphoric Acid</th>
<th>Potash</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 pounds lint</td>
<td>1.5 lbs.</td>
<td>0.5 lbs.</td>
</tr>
<tr>
<td>1000 pounds seed</td>
<td>31.5 &quot;</td>
<td>12.6 &quot;</td>
</tr>
<tr>
<td>2000 pounds straw</td>
<td>51.0 &quot;</td>
<td>20.0 &quot;</td>
</tr>
<tr>
<td>Total crop</td>
<td>84.0 &quot;</td>
<td>33.1 &quot;</td>
</tr>
</tbody>
</table>

Since seeds and stalks are returned to the soil in common practice, then the cotton crop does not remove excessive amounts of fertilising elements from the land. Losses of plant food from leaching, erosion, and other sources, however, make it necessary to apply more or less fertilisers to almost all soils. In general, phosphorus and nitrogen may be applied to advantage.

The second important effect of fertilisers on cotton
is the time of maturity. If too much nitrogen is applied or if applied too late, it will retard maturity and induces too much vegetative growth. Phosphorus, on the other hand, has the power of hastening maturity of the crop. The Agricultural Experiment Station of Texas has demonstrated that when plants fertilised with nitrogen or potash grew eight or nine inches high, those fertilised with acid phosphate were already eighteen inches in height, and that when plants of the nitrogen and potash plots bore only four bolls, those of the acid phosphate plot already had eight to sixteen bolls. The influence of acid phosphate in hastening maturity will be further increased by the addition of some nitrogenous fertilisers, so that nitrogen and phosphorus together will insure the earliest maturity of the cotton crop. Potassium, when used alone, will cause the plants to retain leaves and to continue growth late in the fall, but if it is used with other elements, it will not affect the time of maturity. Calcium in the form of slacked lime will also hasten the maturity of cotton when used with a complete fertiliser.

Several other effects of fertilisers upon cotton have also been noticed. In Egypt, it was found that acid phosphate may improve the quality of lint produced. This effect, however, is considered by some as an indirect in-
fluence resulting from early maturity. Potassium in the form of kainit is generally used in this country as a means to check rust, thus increasing the disease resisting ability of cotton plants.

Among the cultural methods, those which may be used to control the branching habit and the time of maturity of cotton will be briefly discussed. In regions where the growing season is short or the Mexican boll weevil is bad, the single stalk culture may be practised to advantage (48 and 49). The essential feature of this system is to leave plants close together in the early stages and then thin them to stand after the stalks have grown beyond the stage of vegetative development. Thus each plant practically has only one stalk, and hence the name of the name of the method. These single stalked plants will of course bear less bolls than those grown in wider spaces, but the difference in the number of bolls per plant is more than compensated by the greater number of plants grown in the same area of land under the new system. Thus, with a shortened period of growing season, the yield of cotton may be maintained or even increased by the control of vegetative branches.

Early and thorough preparation of land and hence early planting will likewise insure an early crop. This does not mean to plant cotton too early before the danger of
killing frost is over, but in regions badly infested by boll weevils, planting should be done as early as the weather admits, so that the crop will not be unnecessarily delayed and endangered by the weevils. In passing, it is interesting to note how the Indians of Guatemala use a perennial cotton in order to avoid the damage of weevils (50). The stalk of the perennial cotton grown there are cut back to the ground annually, and in the early spring, the new shoots come to bearing very rapidly, making the crop earlier than any annual cotton.

The control of insect pests and diseases is always a very important economic problem in cotton culture as well as in the production of other crops. It is true that breeding may develop some disease resistant varieties, but the direct control of diseases, if there is any, should be equally emphasised by the farmers. As to insect resistance, it is one of the properties that cannot be developed in the cotton plant. Indirect measures such as hastening maturity and using insecticides must be taken in order to avoid insect damages. A few of the important diseases and insects of cotton will be here presented together with measures for their control.

COTTON WILT. Cotton wilt is caused by a fungus of minute mold-like form (51 and 52). It grows in the tracheal
vessels of the roots and the stems of cotton, thus cutting off the water supply of the host plants. Cotton plants after being badly infested with wilt gradually turn black and finally die. The wilt propagates itself by means of spores, which will grow wherever they spread. The ideal condition favoring the spread of wilt is abundance of moisture, so that this pest is often very bad during wet seasons. The damage done by wilt is usually greatly augmented by the presence of root knots, which are galls on cotton roots caused by the irritation of certain minute eelworms. So far there are no efficient measures to control wilt. To plant wilt resistant varieties is now looked upon as the best method, although rotation may help some by reducing the number of root-knots.

COTTON RUST. Cotton rust is primarily a physiological disease (53). The check of vigorous growth of the cotton plants is followed by the attack of certain fungi. The leaves first turn yellow in the small areas bounded by the veinlets, and then the yellow color may be marred by discolored spots produced by the growth of fungus organisms in the tissues. Soon, there appear minute brownish spots, gradually increasing in size and assuming a circular outline marked with concentric rings. Finally the whole leaves are destroyed and the plants greatly weakened. As the fun-
gi which are responsible for this disease cannot attack vigorous plants, there is every means to believe that proper culture and proper fertilisation will prevent the appearance of rust. Application of any potash fertiliser as kainit, or sulphate or muriate of potash, will act as an almost complete preventive of this disease.

COTTON BOLL-WORM (HELIOTHIS OBSOLETA). Cotton boll-worm is the same insect as corn earworm, tomato fruit worm, and false budworm of tabacco (54). The full grown worm is about an inch to an inch and a half in length. The color and markings differ with different individuals, varying from pale green through pinkish brown to almost black. When first hatched, the worms are very minute and often go unnoticed. They feed on corn, cotton, tomatoes, and tobacco. The young ear of corn is the most favored food of this insect, and it is only when the corn kernels harden up that the worms begin to damage cotton. They first feed on the tender shoots of cotton plants, then bore into the young bolls, and eat the entire contents therein. Then the worms bore their way out and go into other bolls. In this way, a single worm may destroy a number of cotton bolls. The worm or larval stage of this insect lasts about eighteen to twenty days. The larvae then turn into pupae and hibernate in that form. In summer months, this stage lasts twelve to fifteen days, but the pupae formed in late fall will remain
as such through the winter. The adults evolved from the pupae are brownish yellow moths, measuring an inch and a half in breadth with the wings fully expanded. The moths lay eggs on growing corn, cotton, and all other food plants of the larvae, the silks of corn being preferred to any other place. The eggs hatch within three or five days after deposition into the minute worms, thus completing the life history of the insect. At present, there are four measures that may be successfully used for protecting cotton against the bollworm.

1. Fall plowing which will destroy many pupae of the insect.
2. Dusting young cotton plants with powdered arsenate of lead.
3. Hastening maturity of the crop.
4. Using late corn as a trap crop.

MEXICAN BOLL WEEVIL (ANTHONOMUS GRANDIS). The Mexican boll weevil is a native insect of Mexico and Central America. It crossed the Mexican border into Texas in 1892, and then spread all through the southern portion of the Cotton Belt. It is the worst insect enemy of cotton at the present time in the United States. The adult weevil is about one-fourth an inch long including the snout which is one half the length of the body (55), and is one third of
an inch in breadth. The color of the adult varies from yellowish to nearly black according to the age of the weevil and the advance of the season. Eggs are deposited in the cotton square. They hatch into tiny white grubs, which feed on the inner tissue of the squares or the young bolls later developed. The grubs become full grown within six to twelve days, then pass into the pupa stage, and after three or five days they come out as adult weevils, eating their way to the outside of the boll or the square. The young squares after being punctured by the weevils will cease to develop, and even relatively larger bolls thus injured will either make no further growth or open only one or two locks. Cotton is the chief food plant of this insect, although they may live on okra, hibiscus, and other related plants (56). The longevity of the adults is found to be about fifty four days if they feed on cotton squares. The average number of eggs deposited by one female weevil is one hundred thirty two, and the number of generations averages four in ordinary years. Thus a single pair of weevils may produce 12,755,100 offsprings in one year. When cold weather comes, the adults disperse by successive short flights in searching for hibernating quarters. It is by these flights that the insect spreads from one locality to another. Then, the weevils go into hibernation in any place
that will afford protection. By next spring, they will come out ready to do further damage.

In fighting against the boll weevil there are three essential measures to be taken into consideration. First, the vast majority of weevils must be destroyed in the fall by plowing under or uprooting and burning the plants. Second, those survived the preceding operation must also be destroyed by cleaning the fields, hedge-rows, fences, and buildings. Third, make all provisions to insure an early crop. No one method will be entirely successful, but all of the three combined will greatly reduce the number of weevils in the next year.

PINK BOLL WORM. A new insect enemy of cotton was discovered last year at Hearne, Texas (57). That is the pink boll worm. It was introduced from Mexico which country had probably got it from Egypt. This insect not only injures or destroys the bolls and lint but also the seeds, and greatly reduces the yield of oil. It hibernates in the cotton seeds, and in this way they can be carried from place to place. It has done great damages in Egypt, Hawaii, and other cotton producing countries. If it gets a hold in this country, it will prove to be the most destructive insect that has ever threatened the cotton crop of the United States. Since this insect was discovered in Te-
last year, the United States Department of Agriculture has put up all efforts to prevent its spread. To destroy all cotton that has been infested, to inspect all cotton goods from Mexico, and to establish a cotton free zone of fifty miles on the Mexican border are the principal measures taken in preventing the spread of this cotton enemy.
CONCLUSION.

In the light of the above study of cotton breeding, it is evident that the problem of cotton improvement in China as well as in any other country may be solved by three lines of work.

1. To improve native varieties.

2. To introduce foreign varieties, and

3. To produce hybrid varieties.

The possibilities of improving the native cotton of China are numerous and great. It is true that most of the Chinese varieties have short staple, but there are some that possess fairly long lint. The Naked Seed Pa Long Staple and the Hsun Long Staple, for instance, both have lint of more than twenty eight millimeters. The Pingkau cotton of Chili, again, has been long noted for its good quality of lint, but the recent investigation of the Chinese Department of Agriculture shows that this cotton is limited to the little district of Pingkau of the Chili Province (2). Many other varieties of long staple and good quality may be cited that are cultivated only in limited areas. If these local varieties can be transferred to sections where they are needed, the prospect of the cotton industry in the latter will be greatly brightened. As we have seen, the accli-
matisation of domestic varieties under new conditions is not a very difficult task, and every farmer can afford to do it. If the farmers are reluctant to do this work, the agricultural experiment stations in all provinces in the cotton district of China should search for these local promising varieties and try them in different parts of their respective sections. After thorough acclimatisation, their seeds may be distributed to the more progressive farmers.

The existing varieties of cotton in any locality may also be more or less improved by regular selection. To-day seed selection is practised to some extent by most Chinese cotton farmers, but I am afraid that their method of selecting seeds at a random would not be very efficient. Pedigree selection is practically unknown among the farmers, while this method is much needed in China. To educate farmers to practise pedigree selection is probably the best thing that the experiment stations can do at present.

The popular belief among Chinese cotton breeders that American cotton may be introduced into China with advantage is a good and correct idea so far as I can see. The climatic conditions of the cotton districts of the United States and of China are indeed very similar to each other, and after several years of acclimatisation, I believe, American cotton will be finally adapted to the conditions in the East. The
problem of introducing foreign varieties to-day is not to see whether the United States is the best place for furnishing superior varieties of cotton. The problem is to investigate which part of America and which part of China corresponds most closely to each other in regard to climatic conditions. Shanghai of Kiangsu and Baton Rouge of Louisiana lie on the same latitude, but Baton Rouge has a warmer climate than Shanghai as my experience goes. Temperature records likewise indicate that the range of temperature according to latitude in the United States is greater than that in China, so that in the southern portions of these two countries, the climate of a locality in the United States is warmer than that of a locality of the same latitude in China, and the reverse is true in the northern halves of the two nations. Experience in growing American Upland cotton in China further affirms this condition, because seeds from the Gulf States grown in Kiangsu do not give satisfactory results, yielding a few pounds to two hundred pounds of lint to the acre, while the same stock of seeds have done fairly well in Kwangtung, giving five hundred to eight hundred pounds of lint cotton per acre. Yields of a few of the American varieties as reported in 1916 by the Agricultural Experiment Station of Canton City, Kwangtung, China, are annexed in the following table.
YIELD IF AMERICAN COTTON IN KWANGTUNG.

<table>
<thead>
<tr>
<th>Variety Name</th>
<th>Seed Cotton per acre</th>
<th>Lint Cotton per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadwell's Double Joint</td>
<td>2425.8 lbs.</td>
<td>795.6 lbs.</td>
</tr>
<tr>
<td>Floropary</td>
<td>1807.8 &quot;</td>
<td>611.4 &quot;</td>
</tr>
<tr>
<td>Cook</td>
<td>1554.0 &quot;</td>
<td>630.8 &quot;</td>
</tr>
<tr>
<td>Sunflower</td>
<td>1802.4 &quot;</td>
<td>663.2 &quot;</td>
</tr>
<tr>
<td>Russell</td>
<td>1300.2 &quot;</td>
<td>420.2 &quot;</td>
</tr>
<tr>
<td>Hawkins</td>
<td>2031.2 &quot;</td>
<td>660.5 &quot;</td>
</tr>
<tr>
<td>Toole</td>
<td>2024.0 &quot;</td>
<td>763.2 &quot;</td>
</tr>
<tr>
<td>Allen</td>
<td>2200.0 &quot;</td>
<td>718.7 &quot;</td>
</tr>
<tr>
<td>King</td>
<td>1353.6 &quot;</td>
<td>428.4 &quot;</td>
</tr>
<tr>
<td>Poorland</td>
<td>1588.0 &quot;</td>
<td>500.0 &quot;</td>
</tr>
<tr>
<td>Excelsor</td>
<td>1271.2 &quot;</td>
<td>485.6 &quot;</td>
</tr>
<tr>
<td>Junes</td>
<td>1386.4 &quot;</td>
<td>485.4 &quot;</td>
</tr>
</tbody>
</table>

The above yields from American varieties are indeed very encouraging. This is the first year planting from seeds directly imported from this country, and serves well to show that the climate of Kwangtung is better suited than that of Kiangsu to American varieties from the Gulf States. In order to introduce a right variety to a locality in China, it is advised to seek for one in the United States at a latitude of about one hundred miles farther south than the latitude of that locality.
In order to make a successful introduction of cotton, other factors besides climate should also be taken into consideration. The soil types of the locality wherefrom the seeds are imported should be known, so that they may be planted in a similar soil. The source of the seeds should also be reliable. They may be best obtained from reliable breeders in the United States or from the United States Department of Agriculture through the Chinese Government. Then only the best varieties should be introduced. The following are some of the excellent varieties which might be successfully introduced.

1. Toole, Trice, Hawkins, and King. These varieties have small bolls, short lint, but are early and very productive.

2. Triumph, Russell, Cleveland, Cook's Improved, and Truitt. They have short lint, big bolls, and high productivity, but are rather late.

3. Columbia, Hartwell, Griffin, Allen, and Sunflower. They have long staple and high productiveness.

Besides the American Upland varieties, Sea Island cotton may also be introduced. The sandy islands along the eastern coast of Kiangsu, Chiekiang, Fukien, and Kwangtung, according to their climate, soil, and geographical position, will be very suitable for the maximum development of Sea Island
cotton.

Then, the third line of breeding work, namely to produce hybrid varieties, should also be started by the cotton experiment stations, while other improvements are being in progress. At present, we are not sure whether we need to take such a step as to hybridise cotton. But if intelligent work is to be devoted to it, profitable results will be obtained in later days. If the experiment station men are not too busy, this line of breeding is also recommended to them for insuring future progress.

All these three lines of cotton breeding have been started since 1912 in the various experiment stations in China. The real problem of cotton improvement in China today is to see that the work is carried on in its proper way. If intelligent breeding is to be continued for twenty or thirty years, the future of the Chinese cotton industry is bright indeed. With same acreage in cotton, the annual output of lint may be increased thirty to fifty percent. The value of lint per pound will also be raised much above the present level, because the quality of lint is to be greatly improved. Then, following the increased production of cotton per acre and the increased value of lint per pound, the cotton acreage in the country is bound to increase too. It would not be too much to expect that twenty years later,
China has the opportunity to become the second, if not the first, greatest cotton producing nation in the world.
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BIOGRAPHY

En-lin Sun was born at Kaoyu, Kiangsu, China. He received his early training in the High School Department of Fu-tan College, Shanghai, Kiangsu, and then in Tsing Hua College, Peking.

He came over to the United States in 1914 and entered the University of Illinois. In 1916, he was awarded a Preliminary Honor by the College of Agriculture, University of Illinois. He graduated there in the summer of 1917 and obtained the Degree of Bachelor of Science.

Upon his graduation, he was appointed by the Chinese Department of Agriculture and Commerce as China's Delegate to the Twelfth International Farm Congress which was held at Peoria, Illinois. He published an article entitled "The Agricultural Conditions in China" in the September issue of "The Agricultural Review", the official magazine of the International Farm Congress. His report of the Twelfth Session of the Farm Congress was published in Chinese in the 1918 January issue of the Journal of Chinese Agriculture and Commerce.

He entered the Louisiana State University in the fall of 1917 as a graduate student. He is a candidate for the Degree of Master of Science.