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TECHNICAL BULLETIN No. 392 NOVEMBER 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

EFFECTS OF STRESS CONDITIONS ON THE COTTON PLANT IN ARIZONA

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CONTENTS

INTRODUCTION

It is well known to plant investigators that unfavorable environmental conditions (commonly known as stress conditions) may cause extensive alterations in the development of plants. Those who have made a scientific study of the cotton plant are familiar with the differences in the habits of growth and characteristics of the same varieties and strains of cotton when planted under extremely different climatic conditions. The shape of the plants, the form and texture of the leaves and bolls, the number of carpels in the bolls, the length and abundance of the fiber, and even the amount of fuzz on the seed may be subject to alterations from changes in environment.

Modifications are also brought about by unfavorable conditions of growth. It appears that little attention has been given to effects of this sort, although in some of the irrigated valleys of the Southwestern States they present some of the most important problems of production. The irregular conditions of growth in some parts of the irrigated region not only cause serious losses in yield but are responsible for lack of uniformity and strength in the fiber. Some

[1] The writer is indebted to H. F. Loomis, associate agronomist, and Claude Hope, junior horticulturist, of the Division of Cotton, Rubber, and Other Tropical Plants, who made the photographs and rendered valuable assistance in collecting the data for this study; and to C. A. Moosberg, scientific aid, of the same division, and G. J. Harrison, associate agronomist, of the Division of Egyptian Cotton Breeding, who made the fiber arrays with the Baer sorter.

of the manufacturers who have received shipments of cotton of poor quality from the irrigated valleys have become prejudiced against all cotton grown under irrigation, although it is well known that much cotton of good quality is produced in these areas. The fact that the States in which most of the irrigated cotton is grown usually produce higher average yields per acre than the other cotton-growing States provides evidence that conditions for the most part are favorable.

The irregularity of the fiber in the bales is not always detected in the usual methods of commercial classing, and, as the same price is paid for cotton grown under unfavorable as for that grown under favorable conditions, the growers have little inducement to take the precautions necessary to produce uniform fiber.

Investigations have shown that much of the irregularity is caused by soil variation and by differences in cultural practices, especially as regards irrigation. As a result, the plants are much better grown in some fields than in others, and the conditions of growth are reflected notably in the size and normal maturity of the bolls and in the quality of the fiber.

The damage to the plants can be seen easily by an inspection of the fields, and it is entirely practicable to separate the damaged from the good cotton at picking time.

A study of some of the effects of unfavorable conditions on the cotton plants in the Salt and Gila River Valleys of Arizona was made by the writer during the years 1926 to 1931.[2] The purpose of the study was to determine the extent of the damages suffered by the plants, with special effort to ascertain whether the quality of the lint was seriously affected. A further aim of the investigation was to learn the differences between the injuries to the plants resulting from unfavorable soil conditions and those caused by the crazy-top disorder. The data obtained in studying the effects of stress and crazy top on Acala, Mebane, and Pima cotton are presented and discussed in this bulletin.

RELATION OF IMPERVIOUS SOILS TO STRESS EFFECTS

There is great variation in soil types and soil conditions in the principal cotton-growing areas of Arizona. In a single small field there may be several areas with physical properties so different as to require different cultural treatments in order to produce the best results. The condition that usually presents the greatest difficulty in the application of irrigation water is the impervious character of some of the soils. Areas in which the soil is extremely hard and resistant to water penetration are referred to locally as "slick spots." Some of these do not absorb enough water to support plants and therefore remain barren throughout the year. In others the cotton plants undergo varying degrees of stress, sometimes receiving only a slight check in growth, but often their development is so affected that large portions of the buds and bolls are aborted,

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[2] The writer has discussed in a previous publication (*15*) [3] a condition of water stress which often affects cotton plants that have made luxuriant growth even when soil moisture is present in available quantities.

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

the fruiting branches are shortened, the bolls are reduced in size, and the lint and seed fail to develop normally (fig. 1).

In the early years of the cotton industry in Arizona little attention was given by the growers to the impermeable areas, but in recent years it has been observed that some of the land that has been cropped to cotton continuously for several years has become more impervious. The "spotted" condition has increased, and in some cases entire fields have shown a tendency to "seal up", rendering it difficult to grow crops of plants satisfactory in size or productive in character.

The Pima type of Egyptian cotton, which was grown exclusively in some of the large valleys for several years, is not as susceptible to the adverse conditions associated with impervious soil areas and faulty cultural methods as the upland type. Although it was noted from the first that plants and bolls were reduced in size by the insufficient moisture supply, it was not apparent that the quality of the lint was greatly impaired or that the plants were greatly deranged or unproductive. With the increase of the acreage planted to upland varieties the greater difficulty of properly irrigating this cotton was recognized and the problem of obtaining adequate depth of water penetration became more general and more serious.

FIGURE 1.—Acala cotton grown in an impervious area or "slick spot" on the Gila River Indian Reservation in 1931.

In recent years it has been observed that lint of the Pima variety also suffers some injury when the stress conditions are very severe. Under some conditions many of the bolls, even on large plants, may be "pinched" and contain lint that is of very poor quality.

The cotton plants in Arizona are exposed to extremely high temperatures during the summer months and are thrown off balance if the soil and moisture conditions are not favorable. In areas where the soil conditions are such that moisture is not regularly available for absorption by the roots, the plants react in many different ways to the influence of high temperatures.[4] The most characteristic be-

[4] COOK, O. F. COTTON IN IRRIGATED DISTRICTS. U.S. Dept. Agr. Press Serv. Release, 4 p. Oct. 3, 1928. [Mimeographed.]

havior is the suppression of growth and the excessive shedding of young fruits, but in many cases there is a great diversity in the shape of the plants, bolls, and leaves, the arrangement of vegetative and fruiting branches, the length and abundance of the lint, and the size and fuzziness of the seed.

THE CRAZY-TOP DISORDER

In addition to the modification of plant structures and characters that can be considered as ordinary effects of water deficiency and impervious soils, changes of a more severe type caused by a growth disorder called crazy top occur in some of the irrigated valleys of the Southwest. The symptoms and effects of this disease have been described by Cook (*8*) and by King and Loomis (*16*). The name "crazy top" was applied by the farmers because of the abnormalities of growth which became more apparent in the latter part of the season. Its peculiar manifestations and mode of occurrence have been puzzling to growers and investigators alike, and, since one of its principal effects is to render plants sterile, it has been responsible for rather serious losses in some fields. Instead of all of the plants being affected alike, there is a great diversity among them. Some become dwarfed and bushy, while others grow tall and spindling with nearly all fruiting branches suppressed. Many vegetative branches develop in the tops of the plants in positions normally occupied by fruiting branches. All parts of the plants may be affected. The leaves are often reduced in size, thickened, rounded, and cupped. The flowers are usually small, with many of the organs undeveloped. In extreme cases the stigmas are depressed below the anthers, and the anthers are defective and do not produce pollen. In Egyptian cotton the petal spots of affected flowers are less deeply colored than those of normal flowers. The bolls are often small and distorted in shape. A large proportion of the seeds are aborted, and those that develop are often reduced in size. The lint is usually short, weak, and scant. Upland plants may be affected so seriously that no long lint develops and the seeds are covered with a dense matting of fuzz.

It has been recognized by King and Loomis (*16*) that the severity of the crazy-top disorder is influenced by the conditions under which the plants are grown and that improvement of the soil and moisture conditions greatly reduces the injuries and abnormalities. This relationship might be considered as evidence that severe stress conditions cause the disorder, but it would then be necessary to assume that the stress conditions here are different from those in other cotton-growing areas, since cotton plants elsewhere have been subjected to many kinds of unfavorable environment without producing such effects. The fact that crazy top does not occur in all of the fields that are injured by unfavorable conditions places it in a class apart from the ordinary effects of stress with which most cotton growers are familiar.

Several theories as to the causes of the crazy-top disorder have been advanced, but so far none of them has been proved. Cook (*6, 7*) has pointed out the similarity of this disorder to those observed in China and Haiti, which appear to be virus diseases transmitted by insects. Some investigators have suggested that toxic substances in the soil are responsible, and others attribute the disorder to a deficiency of available phosphates. Chemical analyses made by the writer and his associates to determine the quantities of the various elements of nutrition in the ash of the affected plants and in the soil where they were grown have shown no indication of a lack of phosphates. Phosphatic fertilizers were applied to the soil in dry form in drills before planting and were also injected as solutions after planting, but they failed to affect the severity of the disorder.

The effects of this disorder and those of water shortage are much alike and respond to the same cultural treatment, but they are by no means the same. In this bulletin the terms "ordinary" or "normal" stress will be used to refer to the effects that are obviously caused by a shortage of moisture in impervious soils, and "crazy top" will be used to distinguish the effects that occur on plants that are definitely aberrant in character, especially from the standpoint of sterility and abnormal branching, even under conditions that permit normal growth of adjacent plants.

Regardless of its cause, the recent increased prevalence of crazy top in Arizona and its serious effects on the cotton plants make it necessary to include it in any study that has to do with the improvement of the quality of the cotton that is grown in the irrigated region.

STRESS EFFECTS AND INHERENT ABNORMALITIES

The diversity in cotton plants as a result of water deficiency and the crazy-top disorder in the irrigated areas has been so pronounced that many growers and even some plant investigators have been inclined to question the purity of the seed stocks. Complaints are frequently heard in the Salt River Valley of Arizona that the seed stocks of the Acala variety are "running out." The evidence advanced is that the plants are not uniform, the bolls are too small and round, and the lint is too short. Some growers, ginners, and buyers of Pima cotton maintain that the Pima cotton grown in the Salt River Valley is deteriorating because many of the plants show abnormalities, the bolls are smaller, the seed fuzzier, and the lint shorter and whiter in color than in years past (*10*). The plea is made for new seed stocks and greater improvement by breeding.

Experiments have shown that the diversity and abnormalities above described have no relationship to the purity of the seed stocks. Pure strains obtained directly from reputable cotton breeders have exhibited all sorts of abnormalities when planted on refractory soils. In one instance seed of two pure strains of Acala cotton obtained from a breeder in California were planted in two adjacent row sections, 100 feet long, in an area of impervious soil where previous crops had been affected with crazy top. Good stands were obtained, but when the plants were examined in the fall their growth was so distorted that they scarcely resembled cotton plants. Practically all the branches were vegetative, and all the plants were sterile except three or four, which had failed to develop any lint except a type of "substaple" or fuzz which was densely matted on the seed (fig. 2). On account of the large proportion of aborted seeds and the failure to develop long intermeshing fibers, the seeds were not firmly united into locks. The seeds from a few of these bolls were planted the following year on good soil, and the few that germinated produced normal and productive plants.

It is not surprising that growers should become alarmed by the great amount of diversity shown in some fields, and attribute it to the impurity of the seed. The aberrant plants are similar in many ways to those observed in fields planted with mongrel seed stocks (*18*). Cook has pointed out in several publications (*3*, *4*, *8*) the similarity between the diversity aroused by placing a variety under new or unfavorable conditions and that induced by hybridization, and he makes special reference to the fact that the rounded bolls induced by severe stress have shorter lint just as when there has been a permanent change of character as in round-bolled reversions or mutations.

The similarity between some of the stress-affected and crazy-top plants and off-type or rogue plants would make it difficult even for trained observers to carry on successful roguing operations in some of the upland fields in Arizona. To make progress in breeding under such conditions, the breeder would be obliged to make an intensive study of the plant reactions under stress, and even then it might not be possible to distinguish some of them from inherent characters.

In order to obtain some information regarding the inheritance of some of the unusual characters, such as nearly naked seeds and round bolls, which came into expression in impervious soil areas, plantings of seed of known purity were made on some of the areas. Seeds were obtained from such plants as produced nearly naked seeds or round bolls and were planted the following year on good soil. The progeny plants developed from these selections were normal in all respects. Some selections that were nearly naked seeded were also made from impervious spots planted to a somewhat mixed commercial stock of Acala. The plants were fairly uniform and only one or two naked-seeded plants were found in parts of the field where soil conditions were favorable. In the impervious area, however, the diversity was great and many round-boll types were observed. In some spots from 3 to 11 percent of the plants produced seed that showed only a thin covering of fuzz and many of the seeds were almost naked. Selections were made from these types and the seeds were planted in good soil the following year. A small percentage of the sparse-fuzz selections produced progenies with sparse-fuzz seeds; the others produced normal fuzzy-coated seeds.

CLASSIFICATION OF PLANT AND BOLL TYPES AFFECTED BY STRESS CONDITIONS

The study of reactions of cotton plants to improper water relations was carried on for the most part in six fields, in which both favorable and unfavorable soil conditions existed, and crazy-top data were obtained from two fields. The variety grown in field 1 was Mebane; in fields 2 to 4, Acala; and in fields 6 and 7, Pima. Field 5, which was planted to Acala, and field 8, planted to Pima, contained areas affected with crazy top, but in these no plant or boll classification was attempted. In each field where ordinary stress effects were studied a group of plants that showed injuries and a group that appeared to be normal were selected for examination. The area occupied by each group of plants was approximately 20 by 75 feet.

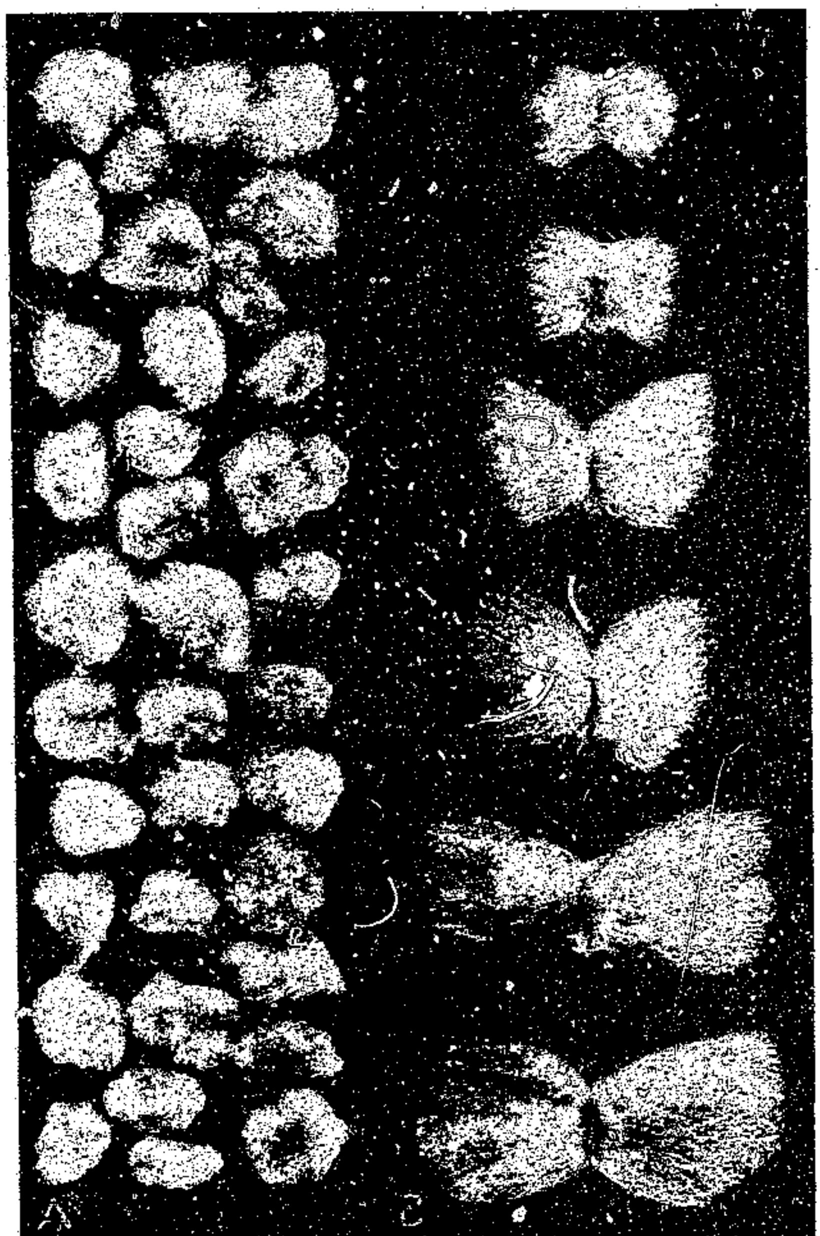

FIGURE 2.—Seeds and lint from Acala cotton plants severely affected with crazy top. *A*, Seeds with abundant fuzz, but no long fibers; *B*, variation in length of lint from bottom to top of a single plant. The bolls often show no effect of crazy top.

Since the injuries and abnormalities were by no means confined to plants that had been stunted or restricted in size, effort was made to select stress-affected areas in which about half of the plants were reduced in size and the other half were of normal size but showing unmistakable evidence of injury.

In the three Acala fields where water-stress effects were studied, the plants were examined in consecutive order as they stood in the rows, and each was classed according to plant and boll size and type. The summarized classification of the group of stress-affected plants examined in the impervious areas in these fields is given in table 1. The normal plants that were examined in the same fields showed little variation in plant or boll type, and no classification was possible. The plants in the Mebane field at the time of observation were too far advanced in maturity to permit a classification of the types of unopened bolls. It was also found impracticable to measure the effects of stress on the Pima plants even under the worst environmental conditions. The effects were much the same for each plant and the injuries were not nearly so great as those shown by the upland plants under similar conditions. The plants were frequently stunted, and these as well as many plants of normal size often showed almost barren fruiting branches on the lower half of the plants. The bolls were usually reduced in size, but there was little diversity in the type of bolls or plants.

Table 1.—*Summarized classification of the various types of plants and bolls of Acala cotton modified by stress conditions in three impervious soil areas, 1,500 square feet in extent, in the Salt River Valley of Arizona, in 1930*

Classification of bolls	Percentage of bolls in the plant types as indicated		
	Normal (235 plants)	Semicluster (96 plants)	Stunted (309 plants)
Bolls normal in size	54.0	38.8	13.9
Bolls stunted in size	46.0	61.2	80.1
Bolls normal in shape	17.9	24.5	8.7
Bolls round	48.9	31.0	60.2
Bolls pointed	14.0	21.4	6.8
Bolls deformed in shape	19.1	22.4	24.3

In making the classification of Acala plants, as shown in table 1, it was found that the most characteristic effect of stress was the reduced size of the plants. However, many of them showed evidence of having been checked at some period in their development, but later they had resumed growth at a rate such as to make them as large or larger than the average size under the best conditions in the field. In some spots there was a tendency for the fruiting branches to be restricted in length and to have shortened internodes, especially in the upper half of the plants. On account of their resemblance to some of the semicluster varieties this type was classed as "semicluster." Affected plants of normal size were divided into two classes, semicluster and normal. The normal classification was applied to the plants of open habits of growth with long-jointed fruiting branches resembling plants typical of the variety in good soil. The stunted plants were not divided into classes, as their individual types were not brought into expression so distinctly as those of the larger plants.

There was great diversity in the characters of the bolls, leaves, and branches of both normal and stunted plants, but the latter frequently set a large number of small bolls late in the season, and these were usually rounded in shape and deformed.

It will be noted from the classification in table 1 that very few of the plants in the bad areas were normal as to both plant type and boll type. The greatest number of off-type and malformed bolls were found on the plants that were stunted in size and had many small bolls. However, there were many off-type and deformed bolls on plants that were classed as normal in size or as semicluster.

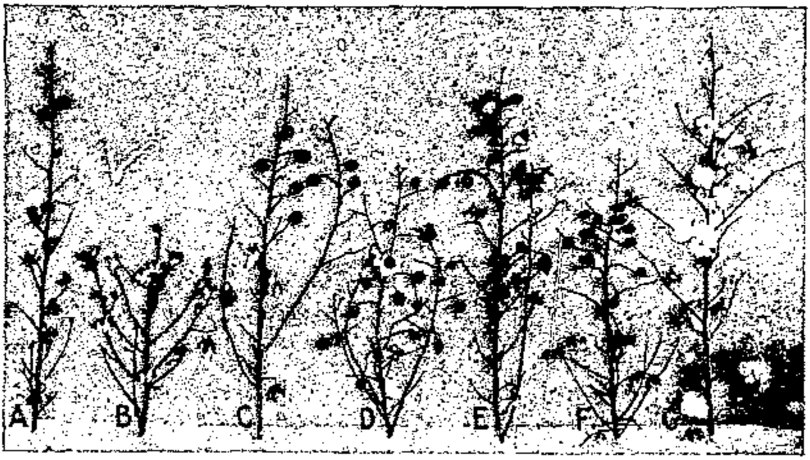

FIGURE 3.—Diversity in Acala cotton plants affected by water stress in an impervious area of soil: *A*, Spindling plant with fruiting branches suppressed; *B*, dwarf plant, with excessive development of vegetative branches on higher nodes; *C* and *D*, intermediate types; *E* and *F*, plants with a late crop of bolls produced after excessive shedding; *G*, plant from lower end of field where irrigation water was impounded.

INDIVIDUAL PLANT DIVERSITY

As with crazy top, one of the striking effects of water stress on cotton plants as manifested in slick spots is the great individual diversity. Most of the plants are reduced in size, but adjacent plants may show great differences, especially in the arrangement of vegetative branches, the length of fruiting branches and internodes, and the location and maturity of bolls. This diversity is illustrated by the group of plants shown in figure 3, which were selected from a slick spot near Casa Grande, Ariz., in 1926. In some individuals the fruiting branches are so shortened or suppressed that the plants have a tall whiplike appearance, as shown in figure 3, *A*. Others show a development of vegetative branches not only at the lower nodes of the main axis but also at many nodes near the middle of the plant, as illustrated by figure 3, *B* and *D*. Some of the plants after shedding excessively during the heat of the summer are able to make sufficient recovery to develop a top crop of bolls late in the season, as shown in figure 3, *E* and *F*, but the bolls are usually small and seldom reach maturity. The behavior of plants in impervious areas where the water "ponded" at the lower end of the field is illustrated in figure 3, *G*. Under this condition sufficient water was absorbed by the soil to furnish the plants a fairly steady supply, and they were able to develop a normal boll or two on almost every fruiting branch, although shedding was heavy.

Cook (*8*) made reference to the great diversity in plants affected with the crazy-top disorder. The range of differences is even wider than in plants that show normal stress reactions, but in some ways the effects are similar (fig. 4). Some plants affected with crazy top have the same spindling whiplike development that results from a suppression of the fruiting branches (fig. 4, *A*). Other types show the excessive development of vegetative branches at the expense of fruiting branches at the nodes on the middle portions of the plant (fig. 4, *B*). A crazy-top type that is distinct from any of the types resulting from normal stress effects is that in which the fruiting branches in the upper part of the plant are partially or completely transformed or replaced by vegetative branches (fig. 4, *C*). There are many other distinctions between crazy-top effects and normal stress effects, but they have little bearing on the general type of the plant.

EFFECTS ON BOLLS

The effects of stress on the bolls is as great as on the branches. In impervious areas the bolls of both Egyptian and upland varieties are usually reduced in size and contain fewer seeds than those developed under favorable conditions. The bolls on stressed upland plants have a tendency to be more rounded than typical bolls of the variety, but many pointed bolls are also formed. Many of the bolls are misshapen or lopsided, on account of the poor development of one or two carpels (fig. 5). Many plants late in the season show a tendency to recover from the stress conditions of midsummer and may develop an unusual number of late bolls. While some of these may be normal in size and shape, the majority are small, and in upland varieties they are unusually rounded. The Pima bolls show little effect of stress except a reduction in size and a greater number of aborted ovules and undeveloped seeds.

The crazy-top disorder has much the same effect on the bolls as normal stress conditions, but the injuries are often more serious (fig. 6).

Bolls from normal Pima plants grown in an area where moisture conditions were favorable and bolls from stress-affected plants grown in an impervious area in the same field are shown in figures 7 and 8.

In order to obtain some measure of the severity of crazy-top effects on the development of Pima and Acala bolls, representative samples consisting of 25 bolls were collected from 25 affected and 25 unaffected plants of each variety, and the average weight of bolls and the average number of seeds and aborted seeds were determined. These data are given in table 2.

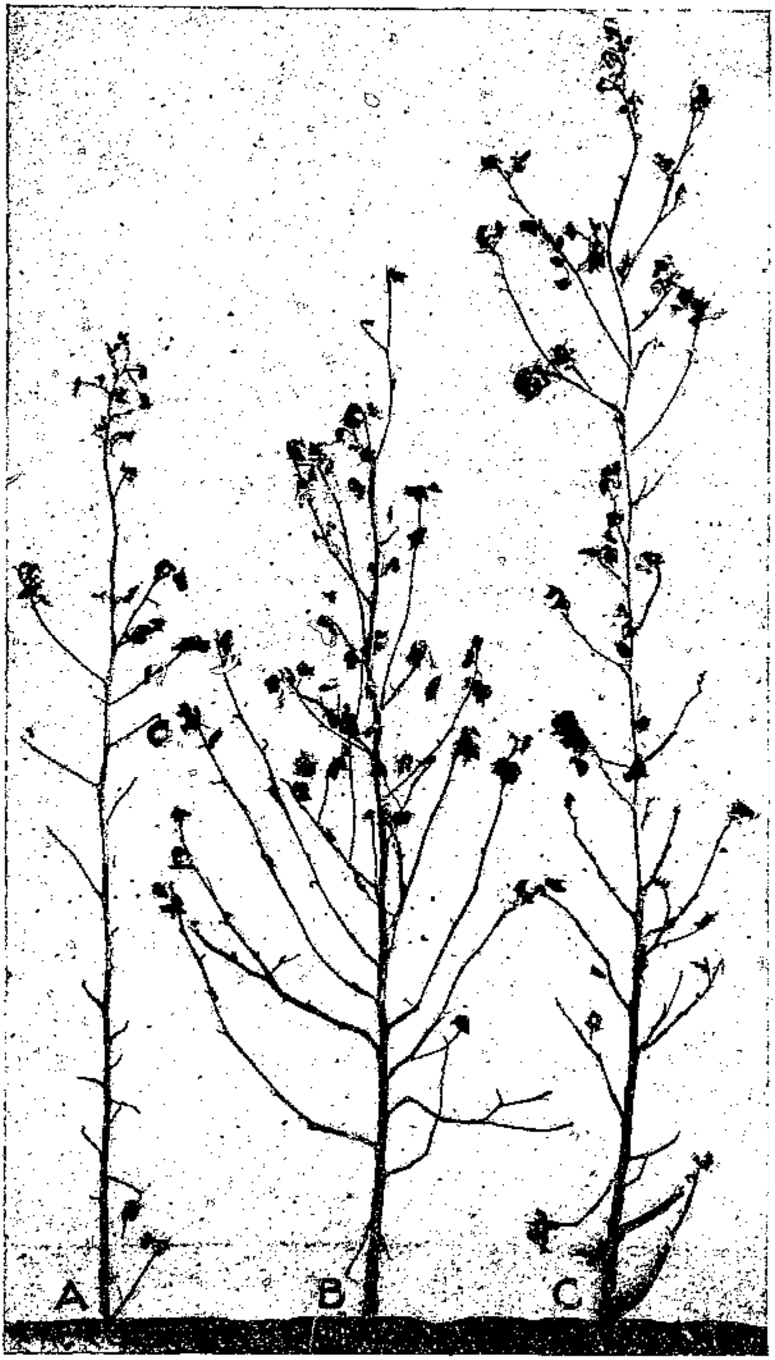

FIGURE 4.—Acala cotton showing diversity in plants affected with the crazy-top disorder: *A*, Spindling plant, the fruiting branches being suppressed with a few vegetative branches substituted for fruiting branches at the higher nodes; *B*, long vegetative branches replacing the fruiting branches at middle and upper nodes; *C*, vegetative branches replacing fruiting branches, especially at the top.

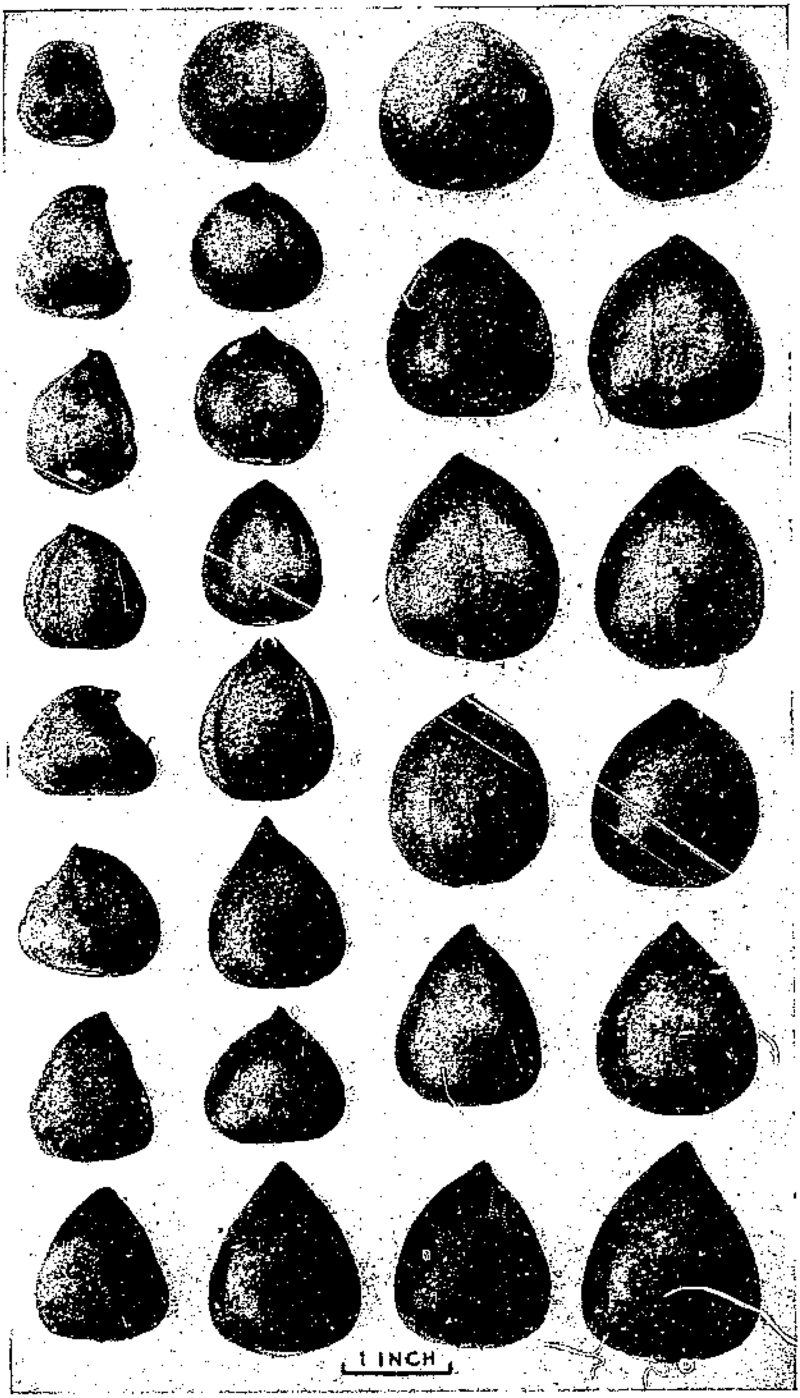

FIGURE 5.—Bolls of Acala cotton from plants grown in an area of impervious soil and affected by ordinary water stress. (About five eighths natural size.) Compare with figure 6.

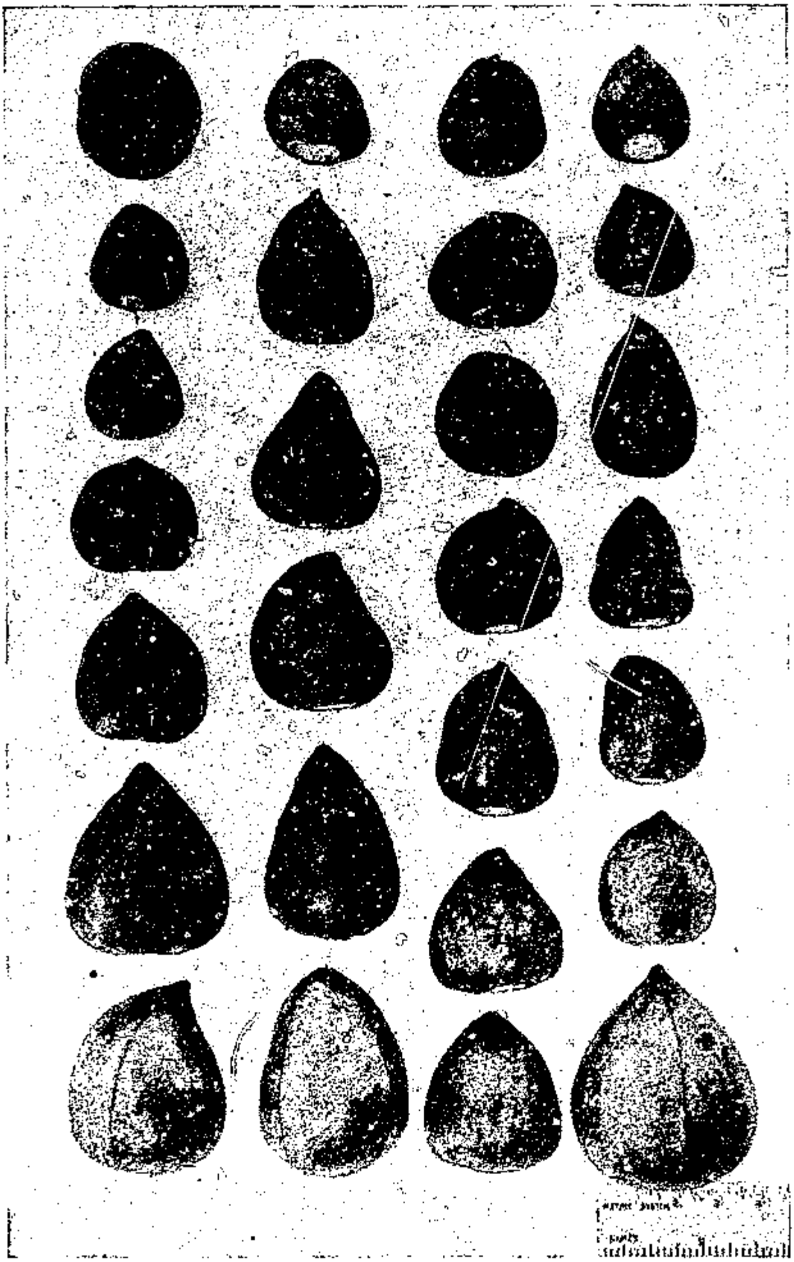

FIGURE 6.—Bolls from Acala plants affected with crazy top. Normal boll in lower right corner. (About nine sixteenths natural size.) Compare with figure 5.

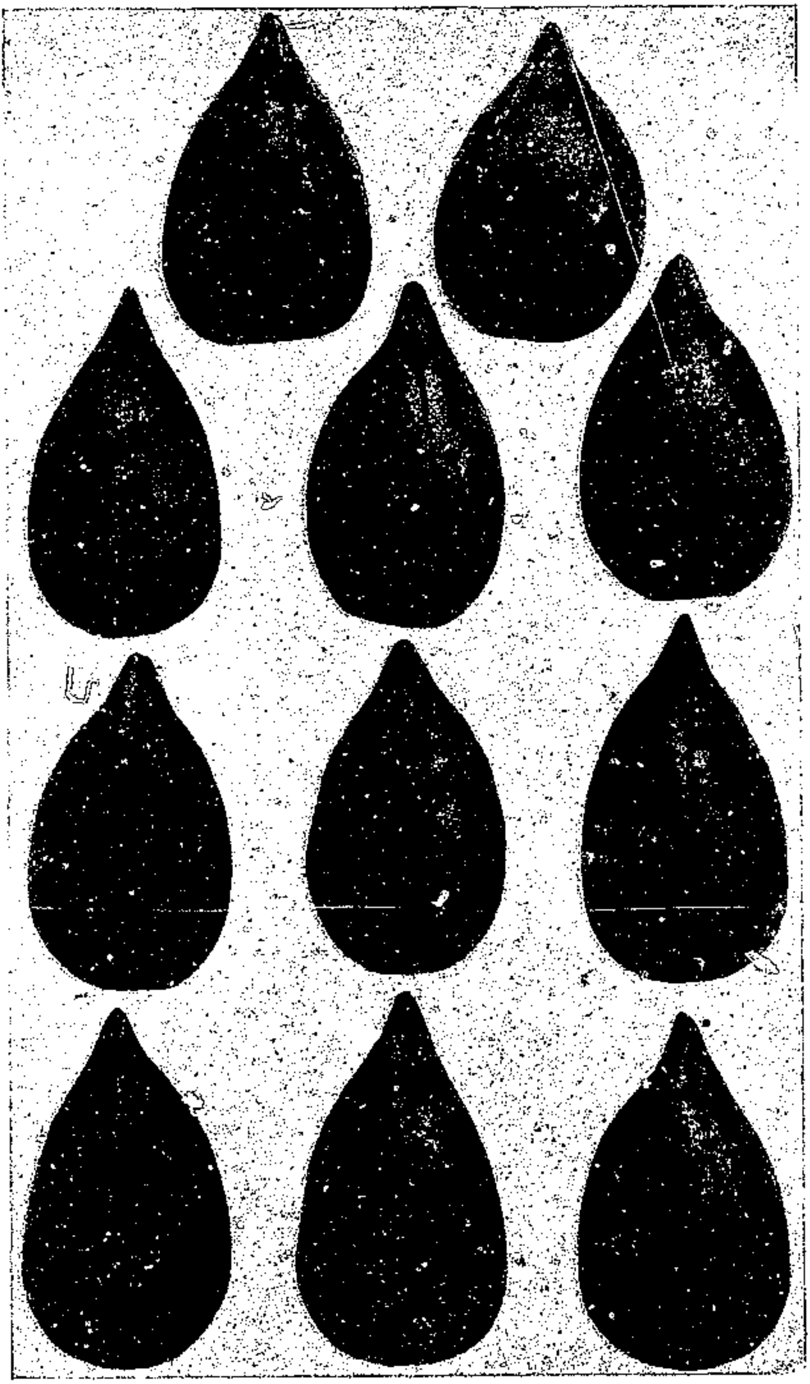

FIGURE 7.—Normal Pima bolls from plants grown in an area where conditions were favorable for water penetration. (Natural size.) Compare with figure 8.

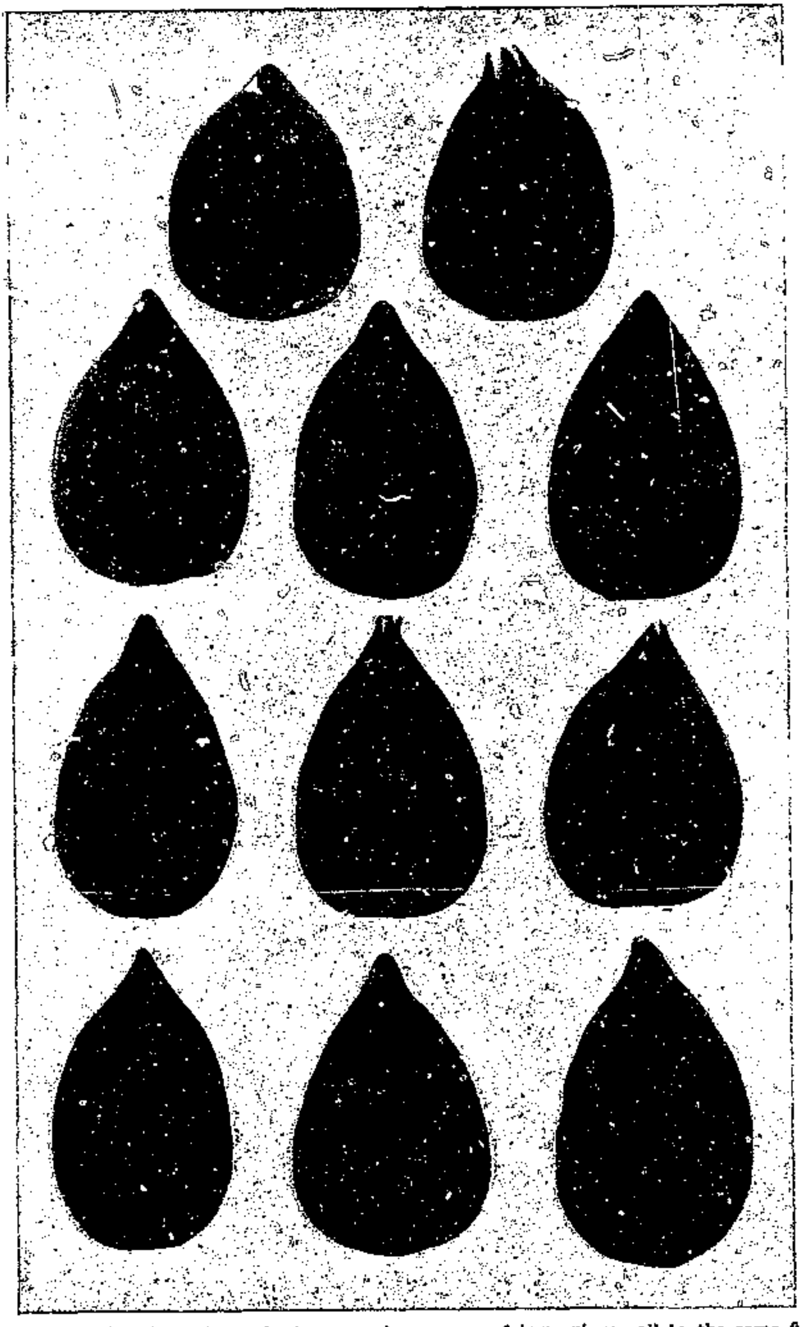

FIGURE 8.—Pima bolls from plants grown in an area of impervious soil in the same field from which the bolls shown in figure 7 were taken. (Natural size.)

TABLE 2.—*Average weight of seed cotton per boll and number of normal and aborted seeds from normal and crazy-top Pima and Acala plants, Salt River Valley, Ariz., 1930*

Variety and field	Average weight of seed cotton per boll		Average seeds per boll		Average aborted seeds per boll [1]	
	Normal	Affected	Normal	Affected	Normal	Affected
	Grams	*Grams*	*Number*	*Number*	*Number*	*Number*
Pima, field 7	3.3	0.8	16.9	6.1	2.4	3.2
Pima, field 8	3.2	1.5	17.5	10.1	.2	2.1
Acala, field 5	6.9	2.0	34.3	12.2	.6	2.8

[1] Ovules showing no development were not included.

It will be noted that the average weight of seed cotton from bolls affected by crazy top is from one half to one fourth that of normal bolls. The average number of seeds per boll ranges from 33 to 58 percent of the number in normal bolls, and the average number of aborted seeds is much greater in affected than in normal bolls.

EFFECTS ON CHARACTER OF LINT

While there is great variation in the kind of cotton sought by different manufacturers, certain qualities are desirable and some are objectionable to all. It is agreed that lots of cotton in which the fibers run even in length have an advantage over lots containing mixtures that differ greatly in staple length. It is also known that immature fibers give difficulty in the spinning process, tending to increase the waste and to make a product that is weak and "neppy." Hawkins (*12*) has shown that some of the neps are made up largely of thin-walled immature fibers that are knotted and tangled together. Uniformity in length of staple and ripeness of the fibers are qualities that are much more important than uniformity of grade, and it is an advantage for cotton growers to be familiar with the factors that influence length and uniformity.

Much has been recorded in cotton literature concerning the inferiority of fiber resulting from mixed or mongrelized stocks of seed, but only a few investigators have given consideration to soil variations or cultural conditions as factors that may seriously affect the quality and value of the lint. Kearney (*13*) found that the Egyptian type of cotton was sensitive to variation in the texture of the soil and to the presence of alkali salts, and that the quality of the lint was affected, as well as the size, appearance, and fruitfulness of the plants. Brown (*2*) reports cases where the lint from several upland varieties grown on poor land was on an average shorter in length and of poorer quality than the average of the same varieties grown on good land. Cook (*5, 9*) has given recognition to the effects of climatic and soil conditions on the quality of the lint and has advocated the classing of cotton in the field as a means of establishing uniformity of staple in the bales.

Experiments conducted in the Salt River Valley, Arizona, in 1923, by the United States Department of Agriculture, the Arizona Agricultural Extension Service, and local cotton organizations served to demonstrate the practicability of classing Pima cotton in the field so that the good lint could be kept separate from the poor and packed into bales in even-running lots. The application of some method for keeping separate the different classes of lint according to quality seems as well justified for upland varieties as for Pima. Although the upland lint is not put to such special uses as that of Pima, the greater degree of injury that it suffers under some of the unfavorable conditions that obtain in the irrigated areas makes it seem especially important that precautions be taken against lowering the value of the good fiber by mixing it with stress-damaged cotton.

To obtain more definite data on the relation of field conditions to fiber development, samples of seed cotton were collected from portions of six of the fields where the plants showed notable effects of water stress and also from areas where conditions were most favorable and the plants were least affected. Samples were also obtained from part of a field of Pima cotton where the plants were affected by crazy top and from another part of the same field where the plants were normal. One sample was taken from a field of Acala cotton where nearly all the plants were affected by crazy top, and, for comparisons with this, a sample was obtained from another field where the plants were normal. From these samples were determined the number of bolls per pound of seed cotton, the number of bolls per pound of lint, the weight of 100 seeds, the percentage of lint, and the lint index (*19*). These data representing the two conditions in eight fields are shown in table 3.

TABLE 3.—*Effect of water stress and the crazy-top disorder on the bolls of upland and Pima cotton*

Condition, variety, and field	Bolls per pound of seed cotton		Bolls per pound of lint		Weight of 100 seeds		Percentage of lint		Lint index	
	Unaffected	Affected	Unaffected	Affected	Unaffected	Affected	Unaffected	Affected	Unaffected	Affected
Water stress:										
Mebane:	*Number*	*Number*	*Number*	*Number*	*Grams*	*Grams*				
Field 1	73.2	122.2	220.5	336.6	12.4	10.0	33.2	35.3	6.2	5.7
Acala:										
Field 2	96.6	110.9	217.6	467.3	14.5	12.2	30.0	28.7	6.4	4.9
Field 3	57.4	139.9	175.0	441.3	15.0	11.4	32.8	31.7	7.3	5.3
Field 4	56.7	123.5	156.6	388.4	13.3	9.7	36.2	31.8	7.5	4.5
Crazy top:										
Acala:										
Field 5	65.4	227.8	231.1	629.2	13.6	10.7	32.2	36.2	6.4	6.2
Water stress:										
Pima:										
Field 6	130.2	200.5	467.1	795.6	13.2	12.0	29.8	25.2	5.6	4.0
Field 7	158.3	216.4	582.0	822.8	12.3	11.3	27.2	26.3	4.6	4.0
Crazy top:										
Pima:										
Field 8	142.0	204.1	473.3	1,106.0	12.7	11.3	30.0	26.6	5.5	4.1

It will be seen that the weight of the contents of bolls produced by stress-affected plants was from 30 to 60 percent less, and on crazy-top plants it was about 52 to 71 percent less than that on normally developed plants. The greatest difference occurred on the Acala plants, although it will be observed that the differences fluctuated considerably in the four fields of this variety. Without exception, the weight of 100 seeds and the lint index were materially smaller on stress-affected plants than on normal ones.

The lint percentage was greater where the conditions were the most favorable in all samples except those from the one field of Mebane and the field of Acala where crazy top occurred.

It is a common observation that the lint percentage or outturn at the gin increases as the lint becomes short and weak, which frequently happens at the end of the growing season. Such a result might be expected from a shortening of the fibers due to water stress, but the data suggest that under certain conditions of stress the weight of the lint is reduced to an even greater extent than the weight of the seeds. An explanation of this might be afforded by the following statement by Balls (*1*):

> If a boll has passed through severe weather in the flower (young boll) stage, the immediate effect will be diminished sprouting of the lint hairs with ultimately a low outturn as the consequence.

It will be noted that in each comparison the lint index is smaller, and in some cases considerably smaller, for the samples obtained from stress-affected or crazy-top plants than for those from normal plants. The fact that the lint index figures (the weight of lint on 100 seeds) are consistent in showing differences in the relative abundance of lint produced on the seeds of stressed and well-grown cotton, while the lint percentages are variable and misleading, further emphasizes the superiority of the lint index over lint percentage as an expression of abundance of lint.

From portions of the samples of seed cotton the fiber on individual seeds from different plants was combed out to full length, which made it possible to compare the extent of variations in length, abundance, strength, and uniformity of lint produced under the different conditions.

A comparison of the characters of lint of Acala as developed under favorable and adverse conditions is shown in figure 9. The combings shown in column *A* represent the type produced on a permeable soil of high water-holding capacity at the United States Field Station, Sacaton, Ariz. Those in column *B* are typical of the samples obtained from the most favorable soil in field 3, and those in column *C* show the range of variations exhibited by the samples from the impervious areas in field 3.

In this comparison it will be noticed that there is a decided lack of uniformity in the length of fiber from the stress-affected plants. The general tendency of stress, however, is to cause a shortening of the lint and a reduction in the quantity on the seed. On some of the seeds the shortening of the fibers at the base of the seed which give the so-called "butterfly" effect will be noted. In addition to these visible effects the lint was also found to be weak and "perished." No effort was made to compare the strength of individual fibers from the different samples, but the superior strength and quality of the lint from normal plants was easily discernible in "pulling the staple." A close similarity was observed in the effects on the lint and seed produced by ordinary stress conditions and by the crazy-top disorder.

Samples of combed lint and seed from Acala plants affected by crazy top and from normal plants in the same fields are shown in

FIGURE 9.—Acala cotton fiber grown under favorable and unfavorable soil conditions: *A*, Lint combings from plants grown under favorable conditions at the United States Field Station, Sacaton, Ariz., in 1926; *B*, lint combings from plants grown in impervious soil in the lower end of a field where irrigation water was impounded, near Casa Grande, Ariz.; *C*, lint combings from an area in the same field where the plants suffered more severely from water stress. (About one half natural size.)

figure 10. These combings, each of which represents a different plant, show that there are various degrees of injury suffered by the lint of upland cotton from this disorder, depending on the severity of stress conditions in the crazy-top areas. The fiber is less abun-

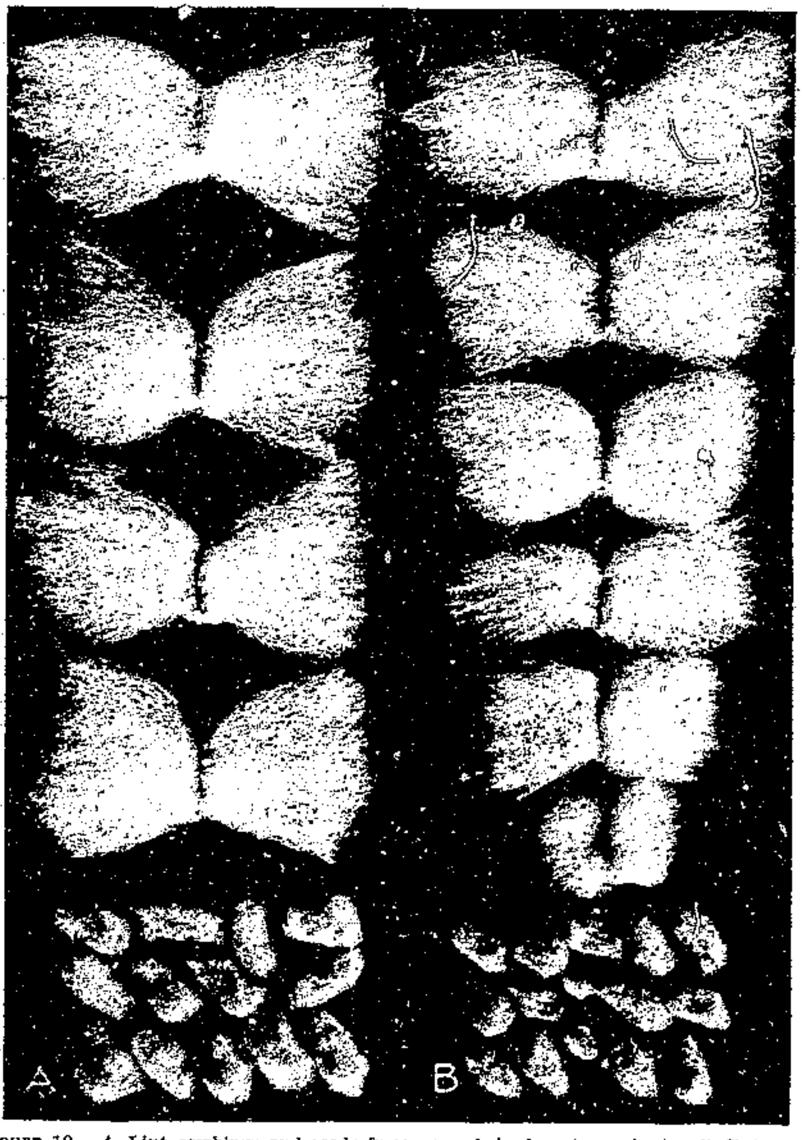

FIGURE 10.—*A*, Lint combings and seeds from normal Acala cotton plants; *B*, lint combings from adjacent Acala plants affected with the crazy-top disorder, under moderate stress conditions. (About four fifths natural size.)

dant on the seed of all the crazy-top plants and shows a "butterfly" arrangement on some of them. In the worst stages the fiber is reduced to little more than a fuzz. Though such cases may occur on individual plants, even under relatively favorable conditions, as in figure 10, all of the crazy-top plants have greatly damaged fiber where stress conditions are severe, as shown in figure 11.

FIGURE 11.—*A*, Lint combings and seeds from normal Acala cotton plants grown at the United States Field Station, Sacaton, Ariz.; *B*, lint combings and seeds from Acala cotton plants affected with the crazy-top disorder, under severe stress conditions. (About four fifths natural size.)

By use of the Baer sorter representative arrays were made of the fibers of one seed from a plant injured by crazy top and of one seed from a normal plant of the same variety. These arrays are shown in figure 12. The fiber from the diseased plants is shown as much shorter and less abundant than that from normal plants.

A comparison of combed samples of Pima seed cotton produced under favorable and unfavorable soil conditions showed that the quality of lint of this variety was also injured by stress, but not to the same extent as that of upland cotton. The combings shown in figure 13, *A*, were obtained from well-grown plants at the lower end of the field where the irrigation water penetrated deeply; and those in figure 12, *B*, are representative of those produced on stress-affected plants in an impervious or slick spot in the same field. It will be seen that there is little difference in the length of fibers under the two conditions, but the combings from the best plants show a greater abundance of lint per seed. The data in table 2 show that the differences in this particular field, as shown by the lint index, was in the proportion of 4 to 4.6. The lint from the stress-affected plants was weaker and lacked the luster and character shown in the lint from the well-grown plants.

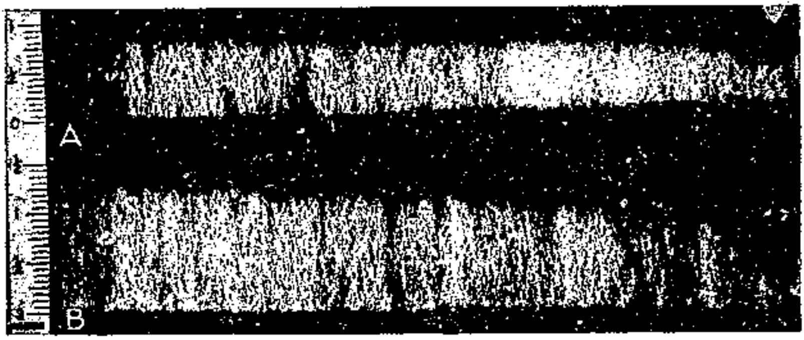

FIGURE 12.—Fibers from normal and from crazy-top affected Acala cotton plants; *A*, An array of fibers from one seed of a severely affected crazy-top plant; *B*, an array of fibers from one seed of a normal plant.

While the Pima lint in these particular comparisons was not greatly reduced in length, it is not uncommon to find short and extremely weak lint in some of the small bolls affected by water stress or by crazy top (fig. 14) that are found on plants of the Egyptian type. These "pinched" bolls which seldom open properly at maturity because of continued stress, are not confined to small stunted plants, but are frequently observed on large plants that are fairly productive. When periods of severe stress occur, such plants, probably because of the heavy load of fruit they are supporting, appear to be unable to sustain normal development in all of the bolls, and as a result the lint fails to attain full length or strength and many of the seeds are aborted.

Representative fiber arrays were made by the use of the Baer sorter in order to demonstrate some of the differences in the fiber from normal and from affected bolls, and these are shown in figure 15. For the most part the lint from the affected boll appears to have attained fairly normal development, but it was weak, and it will be noted that there are a greater number of short fibers than are shown in the array from the normal boll. It will be observed that the modal length of the fibers from the affected plant is much

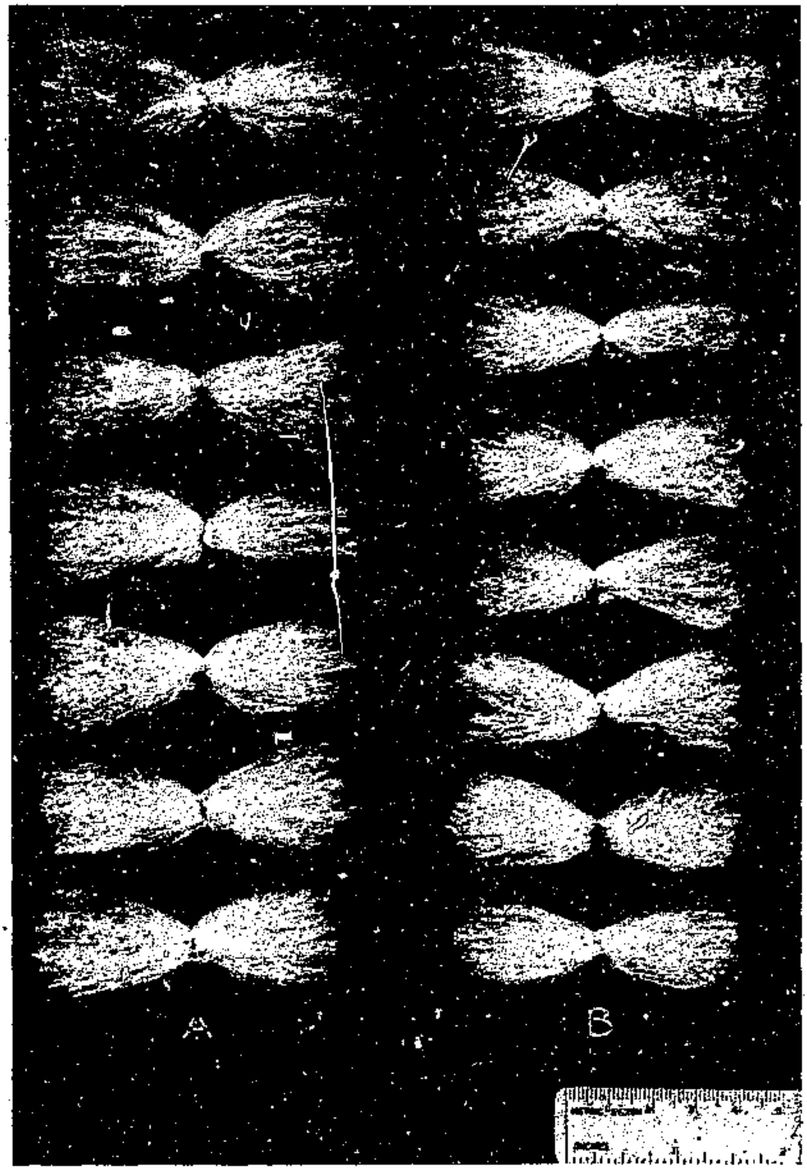

FIGURE 13.—Lint combings from normal Pima cotton plants and from plants in the same field that had suffered from water stress: *A*, Combings from normal plants at lower end of field where conditions were favorable for water penetration; *B*, combings from plants grown in an impervious area or slick spot. (About nine sixteenths natural size.)

FIGURE 14.—Normal and crazy-top bolls of Pima cotton. The two large bolls are from normal plants; the others are from plants affected with crazy top. (About natural size.)

shorter than that from the normal plant, and the longest fibers attained a length of only 1⅜ inches. This general shortening of the fibers indicates that the plant was affected by stress when the boll was very young, since it has been shown by Balls (*1*) that the length of lint is not materially affected by conditions after the bolls are about 21 days old. The lint from the affected boll was not only much shorter than that from the normally developed boll but was extremely weak and brittle.

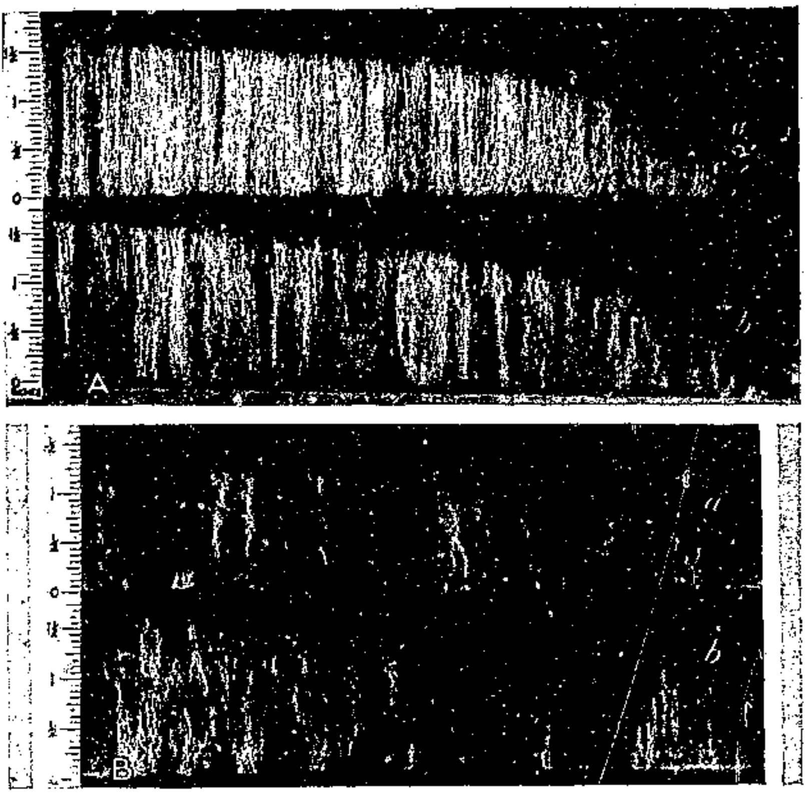

FIGURE 15.—Fibers from normal Pima cotton plants and from plants affected with crazy top: *A*, *a*, Fibers from one seed of a plant mildly affected with crazy top; *b*, fibers from one seed of a normal plant. *B*, *a*, Fibers from one seed of a plant severely affected with crazy top; *b*, fibers from one seed from a normal plant.

EFFECTS ON SEED

In the discussions on effects of water stress and crazy top on bolls and lint it was shown that the number of seeds per boll are greatly reduced. Table 3 shows that the weight of the individual seeds was also greatly reduced under unfavorable conditions. One of the common symptoms of degeneracy in most varieties of upland cotton is the sparse covering of fuzz or the naked condition of the seed produced on some of the plants. This condition is usually associated with short, weak fibers, although some superior naked-seed strains and varieties have been developed which produce lint of good quality. A study of the seed character of the Acala variety when developed under unfavorable conditions showed that many of the seeds produced by plants that had undergone severe water stress bore only a sparse covering of fuzz and some were nearly naked (fig. 16). This was especially true of the seed produced in the top bolls of the stressed plants (fig. 17).

Kearney and Harrison (*14*) showed that pronounced variation existed in the fuzziness of seed in bolls at different positions on Pima plants. They reported a strong tendency for the bolls on the lower fruiting branches to have fuzzier seeds than the bolls on the higher branches. Their suggestion that nutritional factors may be involved is given support by these investigations.

In figure 17 it will be noted that the seeds from bolls borne on the lower branches were more sparsely covered than normal Acala. The seeds produced in bolls on the higher branches are not greatly different from the seeds of some naked-seeded varieties. These seeds were planted on good soil, and the progeny plants produced seeds that were fully covered with fuzz.

The effect of the crazy-top disorder on the seeds differs somewhat from that of ordinary stress. A slight reduction in seed fuzziness is noted in some samples from crazy-top affected areas (figs. 10 and 11). One characteristic which is more pronounced in crazy top than in ordinary water stress is the abortion or interruption of the development of the seed after fertilization of the ovules. Some crazy-top affected bolls which show a high proportion of aborted seeds are shown in figure 18. When the severity of the disorder is carried a stage further the effects shown in figure 2, *A*, may result. Here so many of the seeds have been aborted and the lint on the others has become so shortened that the seeds remain separate from one another instead of being united to form locks.

EFFECTS ON SHEDDING

The work of several investigators (*1*, *2*, *15*) has indicated that a deficient moisture supply is one of the principal factors that influence the excessive shedding of buds and young bolls of the cotton plant. The behavior of the plants grown in impervious-soil areas under irrigated conditions points to the fact that an irregular supply of moisture is responsible for heavy shedding. The loss of young fruits from plants of the Pima variety is greater in impervious spots than in good soil, but with the upland varieties the difference in shedding is even greater. When subjected to severe stress many upland plants set no bolls whatever until late in the summer or in early fall after the period of high temperatures has passed. The yield from such plants is therefore greatly reduced, and, being late, may suffer injury from frost. Pima plants under similar conditions also shed heavily, but usually set a few bolls throughout the summer, although many of them may be small and poorly developed. Late in the season the Pima plants also endeavor to make up for the lost time by setting a heavy crop of top bolls, many of them borne on short axillary branches.

The shedding from plants affected with the crazy-top disorder is more complete than under conditions of normal water stress. In some fields large groups of plants may remain sterile throughout the season, although the rate of flowering is often higher than on normal

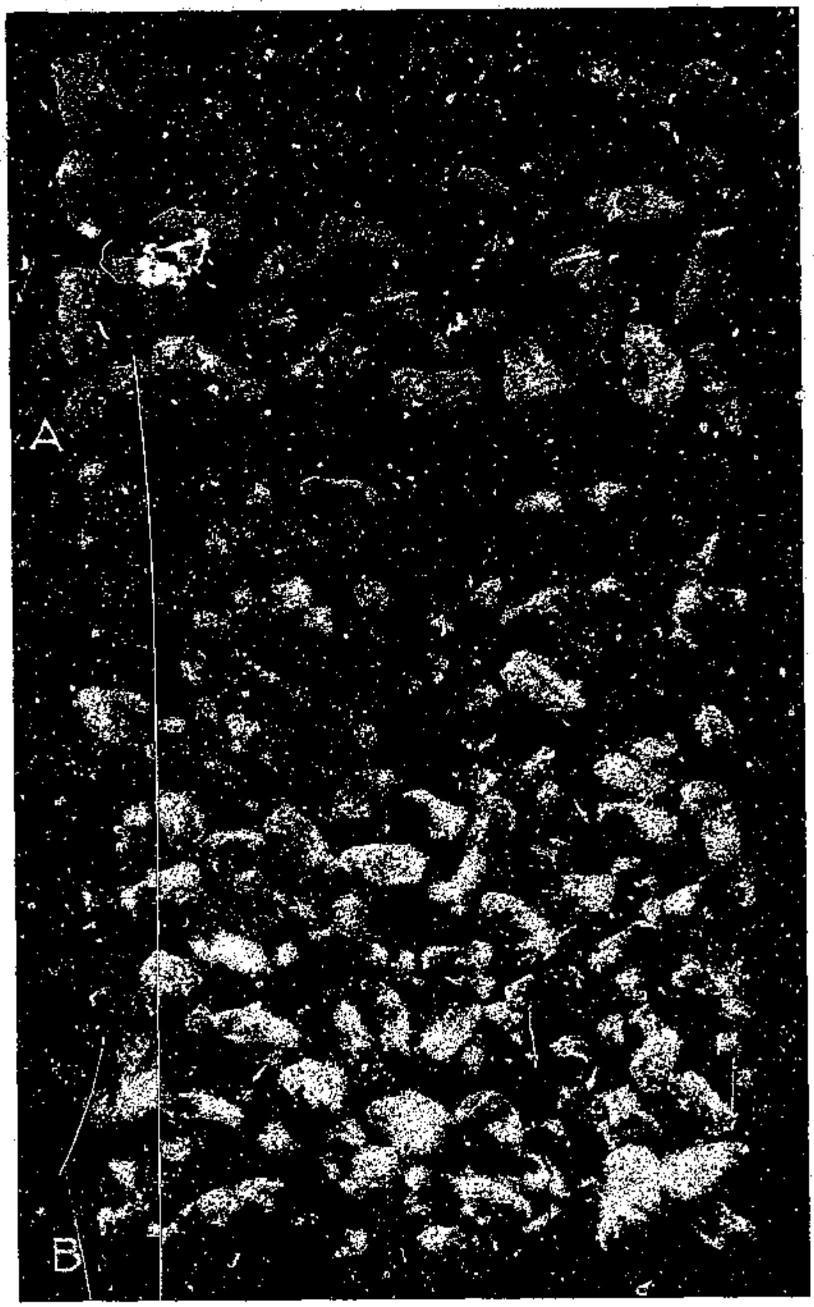

FIGURE 16.—Acala cottonseed produced under favorable and unfavorable soil conditions: *A*, Seed from plants grown in an area where water penetration was effective; *B*, seed from plants in an impervious area in the same field. (Natural size.)

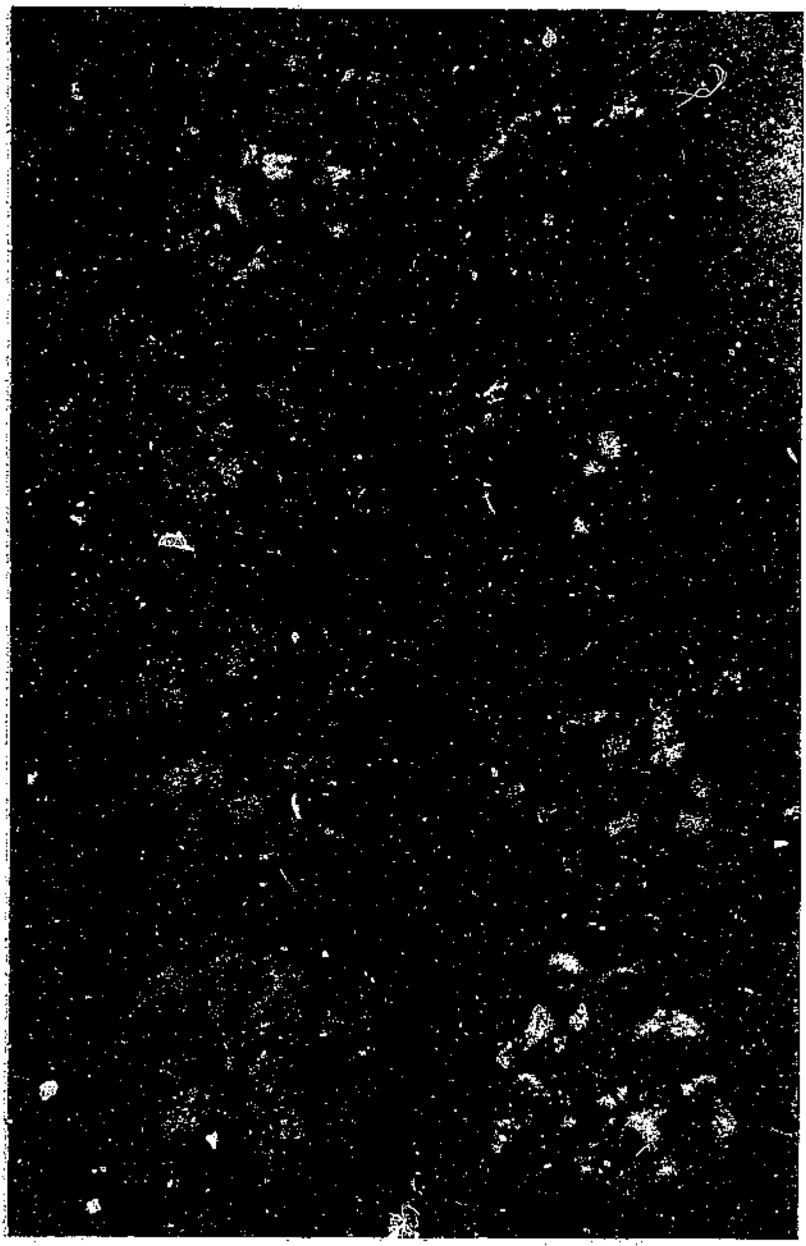

FIGURE 17.—Acala cottonseed from lower and upper bolls of four plants that suffered from ordinary water stress, showing less fuzz on later seeds; *A*, *a*, Seed from boll at axis node 11, branch node 1; *b*, seed from boll at axis node 24, branch node 1. *B*, *a*, Seed from boll at axis node 8, branch node 1; *b*, seed from boll at axis node 27, branch node 1. *C*, *a*, Seed from boll at axis node 10, branch node 1; *b*, seed from boll at axis node 28, branch node 1. *D*, *a*, Seed from boll at axis node 11, branch node 2; *b*, seed from boll at axis node 32, branch node 1. (Natural size.)

FIGURE 18.—Acala bolls from crazy-top affected plants, showing numerous aborted seeds, which are a result of this disorder. (About natural size.)

plants. A record of flowering and shedding of eight Pima plants affected with crazy top at Sacaton, Ariz., in 1929 showed an average of 117±10.4 flowers per plant, with an average shed of 59±3.7 percent of the young bolls. Ten normal plants nearby developed an average of 85.5 flowers per plant, of which 26.9 percent failed to set bolls.

The squares may shed before flowering, and an almost complete shedding during a prolonged period of stress may be responsible for a part of the abnormal behavior and appearance of crazy-top plants. With a temporary return of favorable conditions, such as follow an irrigation or a rainy period, the growth of these almost sterile plants is quickly revived, and this may force an additional growth of vegetative branches which contribute to the peculiar appearance of the crazy-top plants. The amount of early fruit that the plant has developed governs to some degree the extent of vegetative development later in the season. In figure 19, *A*, is shown an Acala cotton plant from which all of the flower buds were removed shortly after their appearance. It has a close resemblance to many of the almost sterile plants that appear in crazy-top areas and possesses some of the symptoms that are ascribed to that disorder. The other plant (fig. 19, *B*) grew only a few feet distant and is typical of the neighboring plants that were allowed to develop normally.

REMEDIES

It was the purpose of this study to analyze the various ill effects of unfavorable conditions on the irrigated cotton plant and to point out their importance, rather than to search for control measures. However, the possibilities for improving the conditions were made so apparent by the investigation that it seems advisable to discuss certain partial remedies which are entirely practicable for the growers to apply. The severity of the effects of water deficiency and crazy top on the fiber and their extensive occurrence in some of the irrigated valleys forces the conclusion that all other factors are secondary in importance to these in explaining the irregular and wasty character ascribed to some of the cotton grown in these valleys. The planting of gin-run seed, the mixing of varieties in the field and at the gin, the "running out" of seed stocks, and poor ginning are factors that may contribute to inferior quality, but even with the best seed and the best ginning, the crop may be unsatisfactory if the conditions of production are too unfavorable.

The practicability of separating the damaged and irregular cotton from the normal well-grown fiber after determining the quality of the cotton in the fields has already been discussed, and it is suggested as a means of improving the standard of all irrigated cotton.

In recent years some growers, alarmed by the declining yields in certain areas rather than by the inferior quality of the lint produced, have begun to adopt practices which tend to correct the damaging effects of an uneven distribution of irrigation water. Some have obtained good results from changing the direction of flow of the water so as to reduce the grade; others have realized benefits from releveling the uneven spots, leaching the soil with heavy applications of water, and rotating with alfalfa and other crops (*11*).

Investigations by King and Loomis (*16*) showed that cultural practices of this type were also effective in controlling and reducing the severity of the crazy-top disorder.

Recent investigations by McGeorge and Breazeale (*17*) have shown that a close correlation exists between impermeability and a low

FIGURE 19.—Effect of defruiting on Acala cotton: *A*, A defruited plant; *B*, an adjacent normal plant. The buds were removed to show the effect of removal of floral buds. Note the similarity between the defruited plant and those affected with crazy top, as shown in figure 4.

availability of phosphates. It was found, however, that the solubility of the phosphates in such soils was increased by leaching with water.

The evidence seems conclusive that any method or practice that effects a more uniform distribution of irrigation water, increases the water-holding capacity, and deepens the root zone in impervious areas is beneficial in controlling the injuries from stress and crazy top.

SUMMARY

The effects of unfavorable conditions on the cotton plant are especially pronounced in some of the irrigated valleys of the Southwestern States. As a result of the high temperatures that prevail in summer, the development of the cotton plant is modified in several ways when proper moisture relations are not maintained.

In some areas the impervious character of the soil, which prevents an even distribution of irrigation water, is a factor largely responsible for the irregular growth and development of the plants.

There are also many modifications of structures and abnormalities associated with the growth disorder called crazy top, which is prevalent in some of the irrigated valleys.

Under the influence of stress and crazy top much diversity appears in the plants, and fields in which such conditions prevail resemble the mixed fields that result from impure seed stocks. However, the abnormalities and modifications resulting from these conditions have not proved to be hereditary, although they closely resemble some characters that are generally known to be heritable.

Upland cotton plants showed a greater degree of diversity in the general type of individual plants and bolls when affected by stress than did Pima plants. Many off-type and misshapen bolls developed on upland plants of large size, as well as on those that had been stunted.

Some of the diverse types of plants that result from water stress can hardly be distinguished from some forms of crazy top, but the tendency to produce vegetative branches at the upper nodes of the main stem is one of the symptoms peculiar to crazy top.

The bolls from plants affected by water stress often are greatly reduced in size, contain a smaller number of seeds, and are frequently off-type as to variety, or are deformed. The bolls from crazy-top plants are affected in much the same way, but the injuries are often much greater.

A comparison of samples of fiber produced in areas where the plants suffered from water stress and crazy top with samples produced by normal plants in areas of good soil in the same fields showed that the lint developed under unfavorable conditions was usually weaker, less abundant, shorter, and more uneven in length than that developed under favorable conditions. Pima fiber showed less injury from stress and crazy top than upland fiber, but was weaker and less abundant on the seed. and, under some conditions, shorter than fiber produced under favorable conditions.

When developed under conditions of water stress the seeds of upland varieties are commonly reduced in size, and a wide range occurs in the amount of fuzz or linters covering the seed produced on different parts of the plant. The seed developed in the top bolls of stress-affected plants are frequently sparsely covered with fuzz or almost naked. while those developed in bolls on the lower branches have a much heavier coating of fuzz.

The seeds produced on plants affected with crazy top are usually reduced in size but have not the same tendency to nakedness as

those affected by ordinary stress. Under severe crazy-top conditions a large proportion of the seeds are aborted.

Shedding of buds and young bolls is more pronounced on plants that suffer from water stress than on those grown under favorable conditions. Plants affected with crazy top shed more completely than those affected by ordinary stress, and many of them are entirely sterile.

A system of determining the quality of the cotton in the field by field inspections and keeping separate the damaged fiber from the affected areas is suggested as a practicable means for raising the quality standards of irrigated cotton.

Cultural practices that effect a more uniform distribution of water in the soil, increase the water-absorbing capacity of the soil, and deepen the root zone have proved beneficial in controlling water-stress effects and crazy top.

Although the data here reported were obtained from impervious and crazy-top areas, similar reactions affecting the growth of the plants and quality of the fiber are to be expected in the best soil areas if good cultural practices are not followed, particularly in regard to irrigation. Care in working out the best cultural practices is perhaps of more importance with impervious or "crazy-top" soil than with good soil, but careless cultural methods if applied to good soil also bear a large measure of responsibility for the unfavorable reports on irrigated cotton.

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U.S. GOVERNMENT PRINTING OFFICE: 1933

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