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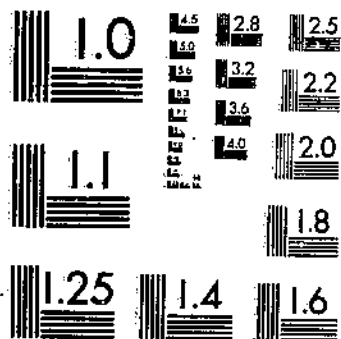
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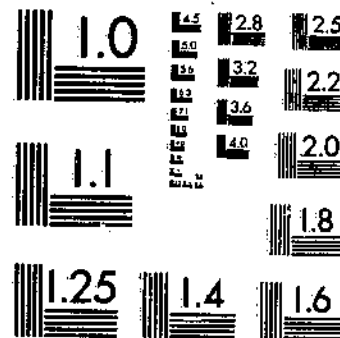
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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE EFFECT OF CRAZY TOP DISORDER ON
COTTON PLANTS AND ITS CONTROL
BY IRRIGATION MANAGEMENT

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CONTENTS

	Page		Page
Introduction.....	1	Chemical composition—Continued.....	
Occurrence of crazy top in Pima cotton at the seed farm, Sacaton, Ariz.....	3	Results.....	27
Description of symptoms.....	3	Field experiments with chemicals.....	27
Physiology and morphology.....	9	Irrigation experiments.....	31
Effects of crazy top on size of plants.....	9	Location, arrangement of plots, and pro- cedure.....	31
Comparison of the fruiting activities of normal and crazy top plants.....	10	Field test 1.....	31
Effects of crazy top on the structure of the flower.....	16	Field test 2.....	33
Effects of crazy top on the seed and lint of Pima cotton.....	10	Occurrence of crazy top.....	33
Budding and grafting experiments on plants affected with crazy top.....	21	Soil moisture.....	35
Topping experiments.....	23	Irrigation experiments in containers.....	38
Transplanting experiments.....	25	Relationship of water supply to incidence of disorder.....	38
Chemical composition.....	26	Summary.....	39
Preparation of samples.....	26	Literature cited.....	42
Methods of analysis.....	26		

INTRODUCTION

A growth disorder of cotton plants commonly known as "crazy top" and technically named acromania has been prevalent in parts of the cotton-growing districts of Arizona for several years. Cook (6)¹ was the first to describe the disorder and pointed out its similarity to some of the mosaic diseases. King and Loomis (16) reported that the extent of the crazy top injuries was closely associated with cultural conditions and showed evidence that improvement in the soil conditions caused a reduction in severity of the symptoms.

King and Loomis (16) recorded what they believed to have been the first occurrence that was recognized as a definite disorder. A small spot in which the plants were aberrant was observed by one of

¹ Italic numbers in parentheses refer to Literature Cited, p. 42.

the writers in a field of Pima Egyptian cotton near Scottsdale, Ariz., in 1919. Upland cotton was not grown commercially in the Salt River or Casa Grande Valleys at that time, but soon afterwards it was introduced and the same observer identified the disorder in a field of upland cotton near Casa Grande, in July 1922. By 1924 the disorder had become fairly common and from 1926 to 1934 it could be found to some extent in a large proportion of the cottonfields of these valleys. It is now one of the important problems of cotton production in these districts, and is of considerable economic importance.

In 1926, mild stages of the same disorder were recognized in the San Joaquin and Imperial Valleys of California. In the San Joaquin cotton districts the disorder had become more general by 1933, and although it was not severe enough to greatly reduce the yields it began to attract attention and give concern to some of the growers.

Preliminary studies on the crazy top disease disclosed that the prevention or cure of the disorder was not a simple matter. King and Loomis (16) published data indicating that alfalfa rotations were beneficial in reducing the extent and severity of crazy top. King (15) compared it with water stress in cotton, and presented some data on flowering and shedding of affected plants as compared with normal plants. Few measurements of the effects of the disease on the plant have been recorded. For the purpose of determining the extent of the injury to the affected plants through the derangement of the fruiting processes, detailed data were collected in 1931 and 1932 on the flowering and fruiting of aberrant Pima cotton plants. At the same time, the effects of the disorder on the rate of growth, the plant habit, the gross morphology of the flower, and on the fruit were noted. Some experiments also were conducted in budding and grafting of diseased and healthy parts of the plants in an attempt to determine the nature of the disease or the factors responsible for its development.

A limited investigation was made of the chemistry of plants affected with crazy top and of normal plants grown under similar conditions. In this study only a limited number of samples were analyzed, and only a few of the more essential elements were determined. While the data do not appear significant in making known the cause of the disorder, they appear valuable in a negative way in reducing the probability that the cause is associated with a deficiency of the more essential elements. They also add to the general information on the chemistry of the cotton plant, a subject which has received little study under irrigated conditions.

The writers and other investigators have noted from time to time the effects of various methods of irrigation on the disease. These observations indicated clearly that the severity of the disease, the tendency to recovery, and, in some cases, the incidence of the disease were influenced by the moisture supply. During 1933 and 1934 comprehensive experiments were conducted at Sacaton, Ariz., in an effort to determine the effects of some of these methods of irrigation on the development of the disorder. The results of these experiments add much to the information on the crazy top disorder and on the conditions that govern its occurrence.

The data obtained in the various studies of the disorder are reported and discussed in this bulletin under three general divisions: Physiology and Morphology, Chemical Composition, and Irrigation Experiments.

**OCCURRENCE OF CRAZY TOP IN PIMA COTTON AT THE SEED FARM,
SACATON, ARIZ.**

The seed farm at Sacaton, established in 1917 for the production of pure seed of Pima Egyptian cotton and other crops, is operated in conjunction with the United States Field Station. It is located on soil of the Mohave sandy loam type which contains considerable amounts of calcareous material known locally as "caliche" (9). From 15 to 20 acres of Pima cotton are grown each year. The crazy top disorder was first observed at the seed farm in 1921. It has occurred to some extent in all cotton grown since then. Almost all of the data presented in this bulletin were obtained from observations and experiments on the seed-farm Pima cotton.

The extent of the disorder has varied from year to year, but no measurements of it were made until 1931. In the seasons of 1931 and 1932 an average of 16.4 percent of the area planted to cotton was occupied by plants affected by crazy top. Figure 1 shows the location and extent of the disorder for the two seasons on section D on the seed farm. It is apparent from these diagrams that many of the crazy top spots in 1932 are not in the same positions as were the spots in 1931. On the other hand, there is evidence that the number and extent of the spots have some relationship to the individual "borders."² The behavior of the diseased plants in these plantings was characteristic. Typically, the plants remain normal and fruitful until late July and then become deranged rather abruptly with the appearance of the disorder. There is a tendency for the affected plants to occur in spots which vary greatly in size and are scattered throughout the field. Often all the groups "go crazy" at about the same time. In 1931, the first symptoms of the disorder were noted on July 18; and in 1932, on July 20.

DESCRIPTION OF SYMPTOMS

Cook (6) described the crazy top disorder in detail in 1924, but it seems desirable to record here some of the prominent characteristics. The first symptoms of the disease are characteristically abrupt and are discernible only in the new growth made by the plants. The previous growth usually appears normal. Heavy shedding of flower buds and young bolls usually accompanies or may slightly precede the appearance of the disorder.

In upland varieties, typical features of the abnormal growth, as described by Cook, include "reductions and distortions of leaf-blades, petioles, internodes, involucre bracts, and floral organs, with all stages of sterility from complete suppression of the floral buds to the development of small unsymmetrical bolls." Reduction in the size of the leaves is usually accompanied by partial suppression of the lobes of the leaf blade. The leaves may sometimes be aborted. There is no leaf discoloration. "Branching is very irregular, with fruiting branches largely suppressed or transformed into vegetative branches which also are very irregular in size" (fig. 2).

Late in the season some of the upland plants may resume flowering and fruiting and may produce normal or nearly normal leaves, but often there is no tendency to return to normalcy.

² For convenience the abbreviated term "border" commonly used by Arizona irrigators is used instead of "border strips" in referring to the area between levees.

In Pima Egyptian cotton, Cook (6) considered that abnormal branching and sterility of the affected plants are the chief features

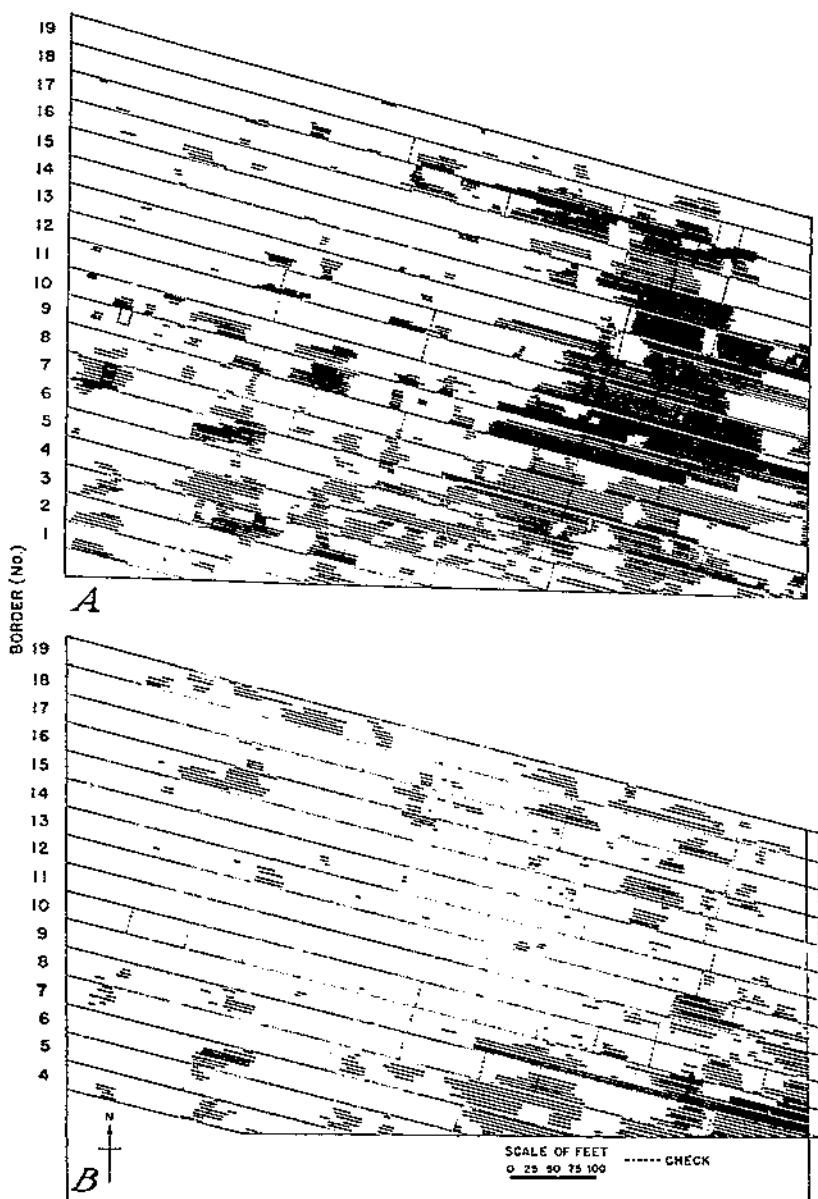


FIGURE 1.—Diagram showing distribution of Pima cotton plants affected with crazy top disorder in the 19 borders of section D at the seed farm, Sycaton, Ariz., (A) in 1931 and (B) in 1932. The continuous parallel lines indicate the levees separating the borders, as laid out for irrigation.

(fig. 3). One characteristic of crazy top in Pima is the regular "recovery" or the resumption of fruiting in late summer. Ordinarily,



FIGURE 2.—Irregular branching in the tops of upland plants infected with the crazy top disorder. The ascending branches are vegetative in character, some being transformed fruiting branches and others arising from axillary buds at higher nodes.

after the plants enter into this period of recovery they flower and fruit profusely, the diseased plants often setting more bolls than normal plants. However, these bolls are set too late to mature except when the first frosts are unusually late.

Fasciation or adhesion of branches occurs frequently in plants affected with crazy top. Due to the failure to form a normal abscission layer at the bases of the pedicels, many dead squares (flower buds) and young bolls that normally would have dropped off remain on the plants.

Subsequent observations by the writers have disclosed other effects of crazy top on the cotton plant. In Pima cotton the distor-



FIGURE 3.—Comparison of Pima cotton plants. Note that the central fruiting branches of the affected plant (right) are almost sterile, and some have changed into vegetative branches. The normal plant (left) matured a much earlier crop of bolls.

tion of the leaf blades is usually as great as in upland cotton, and severe distortion is nearly always accompanied by the complete suppression of the lobing. Such leaves are often quite round and may not be reduced in size. Severe crumpling and cupping of the leaves is also common in deranged Pima plants (figs. 4 and 5). It was first observed in 1933 that the epidermal hairs on the leaves of the abnormal growth on both upland and Pima plants are nearly always completely suppressed (fig. 6, *A* and *B*). Leaves produced before the appearance of crazy top, and those produced late in the season after recovery has set in, develop their hairs normally.

Very few flowers were produced in the early stages of the disease in the Pima cotton that was under observation by the writers. The flower buds are usually shed while quite young. As the season advances, the affected plants begin to produce a few flowers, but



FIGURE 4.—The effects of crazy top on leaves and fruiting branches of *Pinna* cotton plants. Note that vegetative branches occupy the normal positions of fruiting branches in the upper portion of the plant. Photographed August 30, 1933.

they are ordinarily much reduced in size, are paler in color, and show no petal spot or only pale spots greatly reduced in size (fig. 7). The anthers in such flowers commonly are defective, are reduced in number and size, and fail to produce pollen. The styles and stigmas are usually rudimentary and do not emerge above the staminal column. The ovaries and ovules appear to be normal, though they are sometimes smaller than average (fig. 8).



FIGURE 5.—Top of a Piima plant affected with crazy top. Note the excessive branching, the crumpled, distorted leaves, and the axillary squares with long pedicels.

In 1931, diagrams were made of a group of crazy top plants and of a group of normal plants on July 21, when crazy top was first distinguishable, and again on September 3 after recovery had begun. Typical representatives of these groups are shown by diagrams in figures 9 and 10. It will be seen from these diagrams that a fair bottom crop was produced by the crazy top plant prior to July 21, and at that time there was evidence of recent heavy shedding. During the same period the normal plant had shed very little. The diagrams of the plants on September 3 show that the affected plant continued to shed throughout the intervening period and that the normal plant had set a good crop, although it too had shed heavily soon after July 21.

PHYSIOLOGY AND MORPHOLOGY

EFFECTS OF CRAZY TOP ON SIZE OF PLANTS

Observers have noticed a tendency on the part of crazy top plants to grow taller than neighboring normal plants. In order to determine the extent of the differences in growth, if any, daily measurements were made for 30 days in 1931 and for 28 days in 1932 on the height of neighboring groups of 25 plants affected with crazy top and of

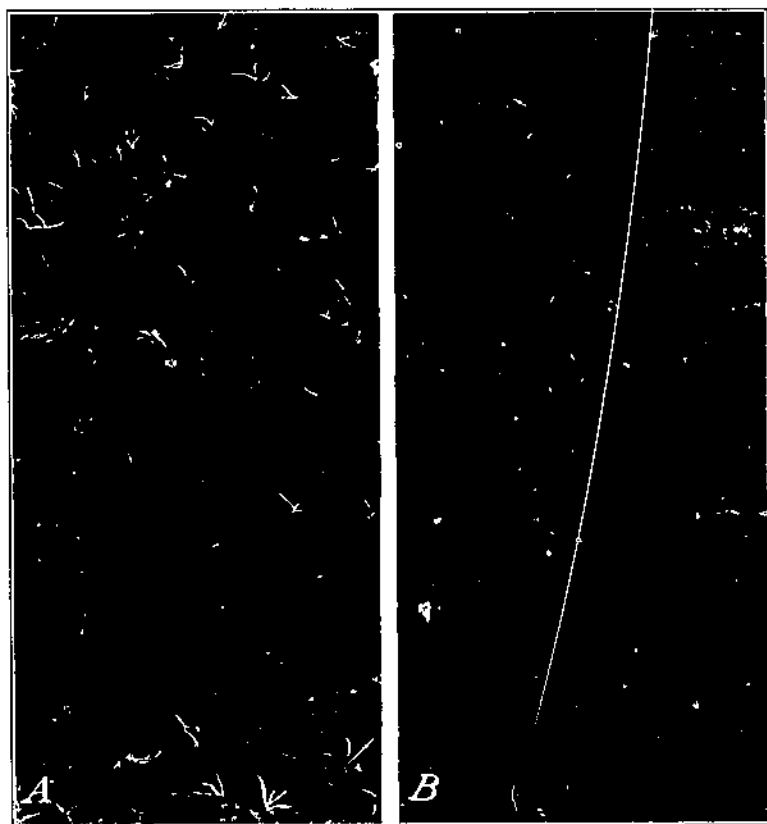


FIGURE 6.—Difference in development of hairs on normal and crazy top affected leaves of *Phoma cottoni*. A, section from under surface of a normal leaf showing numerous hairs. $\times 2$. B, section from under surface of a leaf affected by crazy top. Note the absence of hairs. $\times 2$.

25 normal plants. These plants also were measured at the end of the season after growth had ceased. Each year attempts were made to select aberrant and normal plants located near each other so that differences in soil, irrigation water, and other environmental factors determining growth rates might be eliminated as far as possible. The plants to be measured were marked as soon as it was possible to make a definite distinction between deranged and normal plants. Figure 11 shows by curves the average daily height of the groups in both seasons.

When measurements were begun soon after the first appearance of the disease in 1931 the average height of the 25 crazy top affected plants was almost 12 cm less than that of the normal plants, but on August 26 at the end of 30 days of daily measurements the average height of the affected plants was about 10 cm greater than that of the normal plants, and at the end of the season it was about 23 cm greater. In 1932 the aberrant plants averaged about 4 cm higher than the normal plants on July 26 soon after the disease first appeared, and when daily measurements were discontinued on August 22 they averaged 16 cm higher, and at the end of the season 18 cm higher than normal plants.



FIGURE 7.—A normal Pima cotton flower (center) and two flowers affected by crazy top. The flower shown in the center is typical of those developed on plants free from the disorder. The flowers on the right and left show typical effects of crazy top, with small petals and bracts, undeveloped anthers, and depressed stigmas.

Eaton (7) and (8) and King (15) have reported that partial or complete defruiting of cotton plants causes them to grow taller than the control plants, and it is not unlikely that the extreme sterility of the crazy top plants might be responsible for their extra vigor and more rapid growth.

COMPARISON OF THE FRUITING ACTIVITIES OF NORMAL AND CRAZY TOP PLANTS

In an effort to secure an accurate measure of the effects of crazy top on flowering and fruiting of Pima cotton, daily records were made of the number of flowers produced, the number of bolls shed, and the number of bolls retained on neighboring groups of crazy top and normal plants during the seasons of 1931 and 1932. Fifty diseased plants and fifty normal plants were under observation in 1931, while in 1932 there were 25 plants in each group. The normal plants studied were selected from locations as near the affected ones as possible. The records were started as soon as the effects of the



FIGURE 8.—Comparative morphology of flowers from normal Pima cotton plants and plants affected by crazy top: *A*, Bract, petal, and reproductive parts of a normal flower; *B*, bract, petal, staminal column, and ovary of an affected flower. Note in *B* the absence of petal spot and incomplete development of anthers and stigma.

disorder could be distinguished and were continued until the production of flowers had practically ceased. In 1931 this period was from July 22 to October 12, and in 1932 from July 25 to October 8.

The data of flowering, boll shedding, and boll retention are shown by curves in figures 12 and 13. The general similarity of the curves for the crazy top and the normal plants, respectively, in the two seasons is noteworthy.

In both seasons the crazy top plants in the end retained a great many more bolls than the normal plants, but only a small proportion of these were set before September 5, which is usually the latest date that will allow complete maturity of the bolls before frost. Usually,

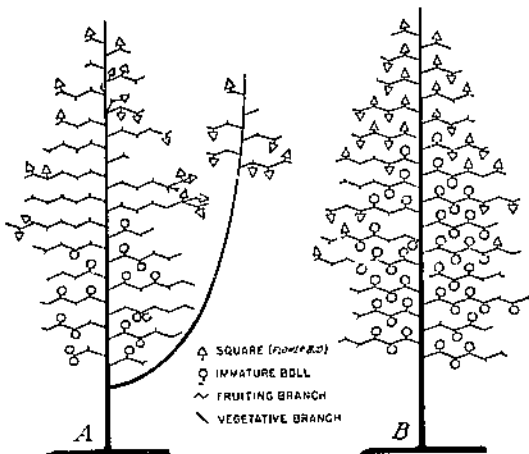


FIGURE 9.—Diagrammatic representation of a Pima cotton plant, showing first effects of crazy top disorder, and a nearby normal plant. The affected plant (A) shows a fair set of bolls on the lower branches, but excessive shedding on central branches. The normal plant (B) shows only moderate shedding. (Diagrammed July 31, 1931.)

too, the bolls set by crazy top plants during this period were small and abnormal. The peak of flower production on the normal plants came during late August and early September in both years, but on the diseased plants the peak came about September 15. The flowering curve for these plants rose very abruptly after September 6 in 1931, and after September 4 in 1932; and in each instance, the curve for the normal plants began to drop on almost the same day. The curves of boll retention agree very closely with the compar-

able flowering curves, and the same is true for the curves of shedding of the deranged plants. With the normal plants, however, shedding seems to have been fairly constant throughout the season. Table 1 is a summary of the flowering, shedding, and fruiting data for both seasons. It may be seen from this table that in 1931 the crazy top plants produced about 65 percent as many flowers as the normal plants from July 22 to September 5, but of these slightly less than 25 percent developed bolls, whereas a little over 75 percent of the flowers produced by normal plants during the same period developed into bolls. However, by the end of the 1931 season the aberrant plants had produced twice as many flowers as the normal plants and had set approximately 31 percent more bolls. In 1932, due possibly to the milder form of the disease, the differences were not so great, but the normal plants still retained appreciably greater numbers of bolls from July 25 to September 5 than the deranged plants. For the entire period covered by the observations the diseased plants retained 48.2 percent of their bolls in 1931 and 62.4 percent in 1932. The normal plants retained in these years 74.9 and 84.1 percent, respectively, of their bolls. The figures for the normal plants agree favorably with those reported by other investi-

gators in Arizona. The percentage of bolls retained by normal Pima cotton was reported by King (14) in 1919 at Phoenix to range from 73.4 to 82.2 percent. In 1920 Martin and Loomis (19) at Sacaton found that a mean of 88.8 percent of the bolls were retained. King, Loomis, and Varmette (17) also working at Sacaton, reported that in 1922, 82.5 percent and in 1923, 70.7 percent of the bolls were retained by normal Pima plants. Shedding records obtained by

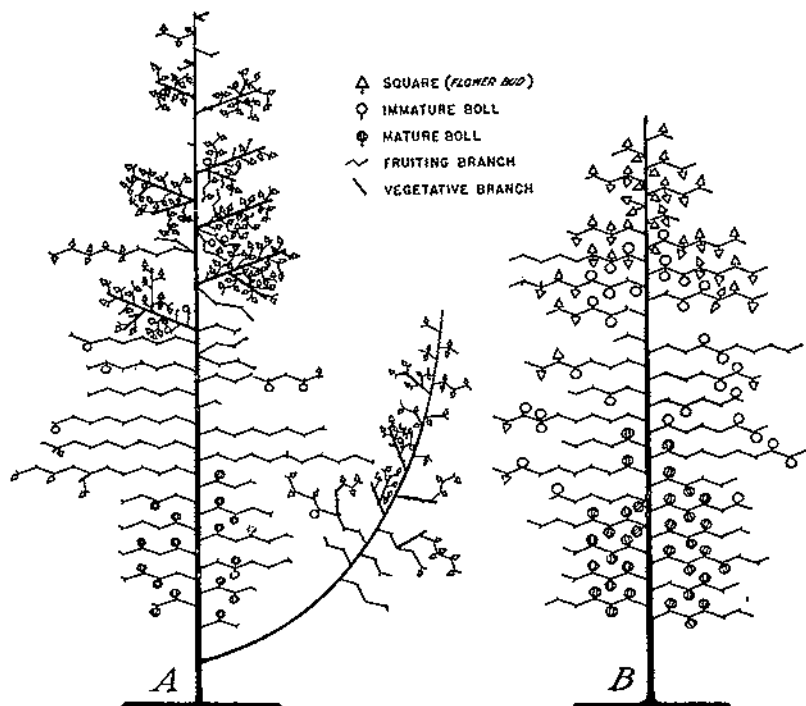


FIGURE 10.—Diagrammatic representation of the same plants (shown in fig. 9) on September 3, 1931. The affected plant (A) shows almost sterile central fruiting branches and an abnormal development of vegetative branches at the top, on the fertile branches of which are borne a large number of late squares. The single low vegetative limb shows a behavior similar to that of the main stem. The normal plant (B) shows that much shedding occurred from the central branches soon after the earlier diagram was made, but the branching structure and other features remained normal.

King (15) at Sacaton showed that 8 Pima plants with crazy top averaged 117 flowers per plant and retained 41 percent of the bolls, while 10 normal plants averaged 85 flowers and retained 73.1 percent.

TABLE 1.—Average number of flowers produced, bolls retained, and bolls shed per plant on crazy top and normal plants of Pima cotton at the seed farm, Sacaton, Ariz., in 1931 and 1932

Year and condition of plants	Plants	Flowers recorded prior to Sept. 5	Bolls retained from flowers produced prior to Sept. 5		Flowers to end of season	Bolls retained to end of season ¹		Total bolls shed
			Number	Percent		Number	Percent	
1931								
Normal.....	50	37.4	29.5	78.9	84.5	48.3	74.9	16.2
Affected.....	50	24.9	5.9	23.7	130.8	63.1	48.2	07.2
1932								
Normal.....	25	34.4	30.8	89.5	52.7	52.7	84.1	10.0
Affected.....	25	30.0	21.5	59.7	109.1	66.2	62.4	39.9

¹ Many of the bolls retained on plants affected with crazy top were too late to reach maturity.

The number of days between flowering and the shedding of the young bolls was recorded for each season. In 1931 the mean was almost the same for both the diseased and the normal plants, being 10.8 and 10.6 days, respectively. In 1932 the mean lengths of the periods were 10.9 and 9.7 days, respectively. Approximately the same figures for normal Pima cotton in Arizona were reported by

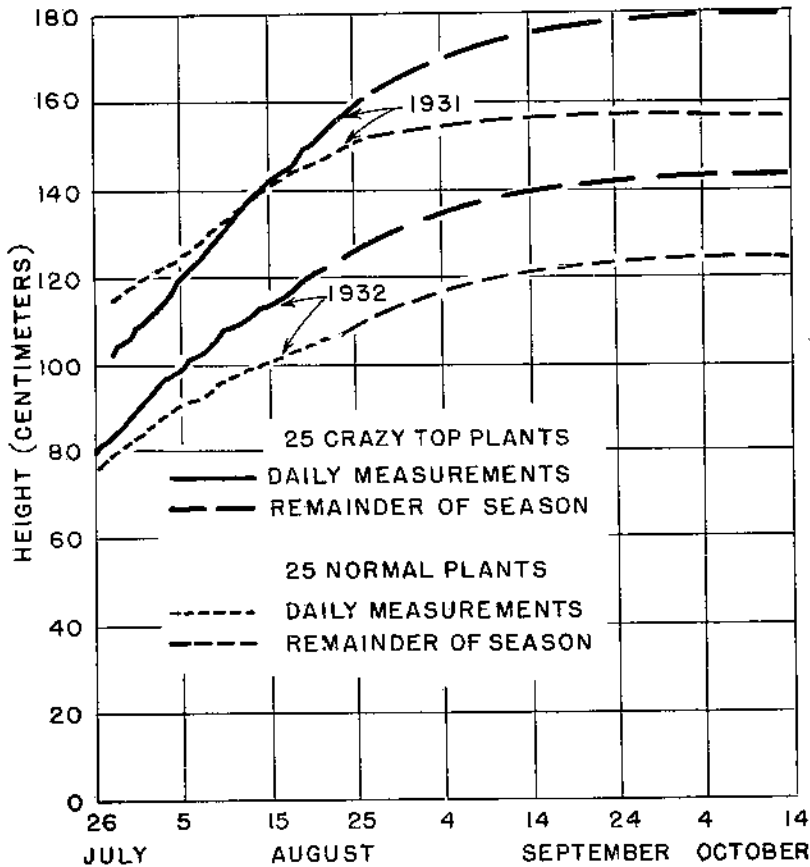


FIGURE 11.—Average growth of 25 normal Pima cotton plants and 25 plants affected by crazy top at the seed farm, Sacaton, Ariz., in 1931 and 1932. Daily measurements were made for only the first 30 days in 1931 and 28 days in 1932, and a final measurement was made at the end of the growing seasons. The remainder of the curves is interpolated.

other investigators. King (14) found the mean interval between flowering and shedding to be 10.3 days at Phoenix in 1919; Martin and Loomis (19) recorded 10.8 days as the length of the interval at Sacaton in 1920; King, Loomis, and Varmette (17), working at Sacaton, reported 10.1 days in 1922 and 9.1 days in 1923. Apparently, therefore, the interval between flowering and shedding of the young bolls by crazy top plants gives no indication that the factors responsible are different from those which influence shedding of bolls by normal plants.

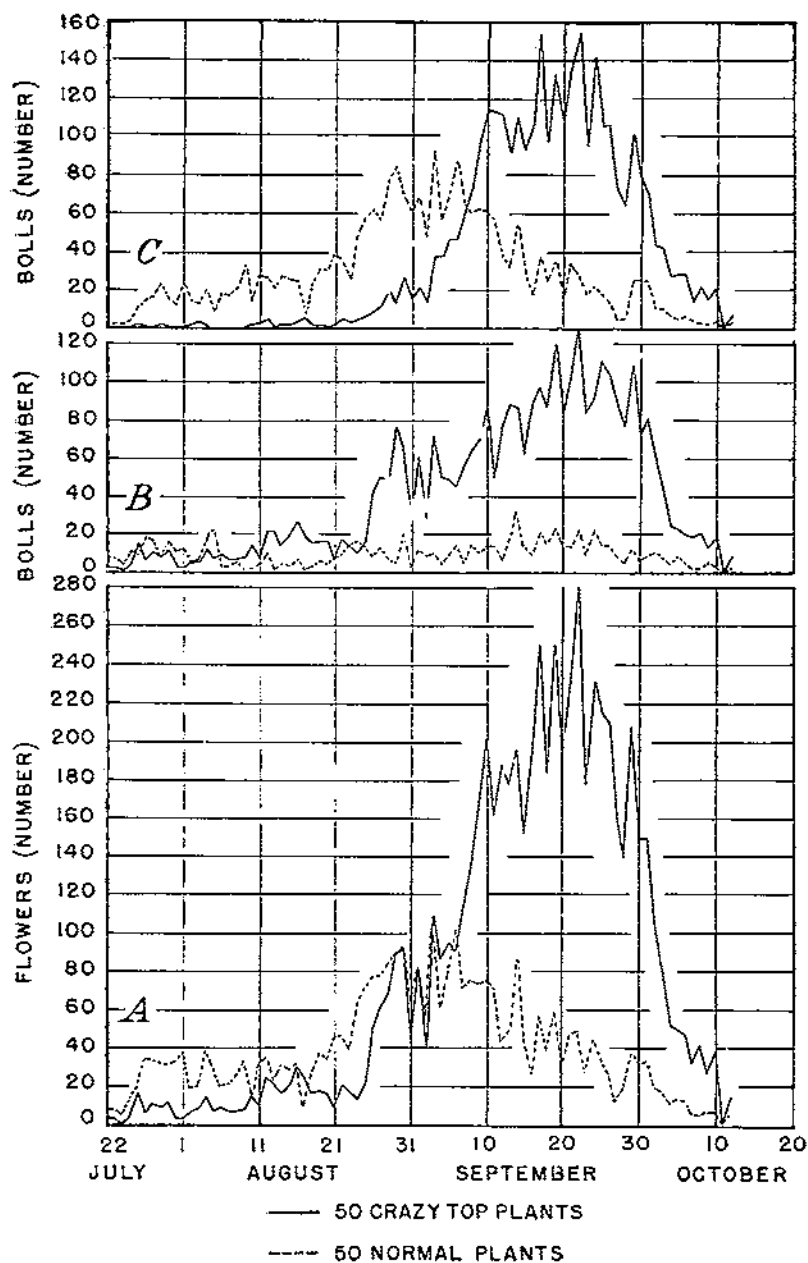


FIGURE 12.—Diagrams of daily flowering (A), boll shedding (B), and boll retention (C) on 50 normal and 50 crazy top plants of Pima cotton during part of the season of 1931 at the seed farm, Sacaton, Ariz.

EFFECTS OF CRAZY TOP ON THE STRUCTURE OF THE FLOWER

Cook (6) noted that the flowers of upland cotton plants affected by crazy top were sometimes reduced in size, and often had defective

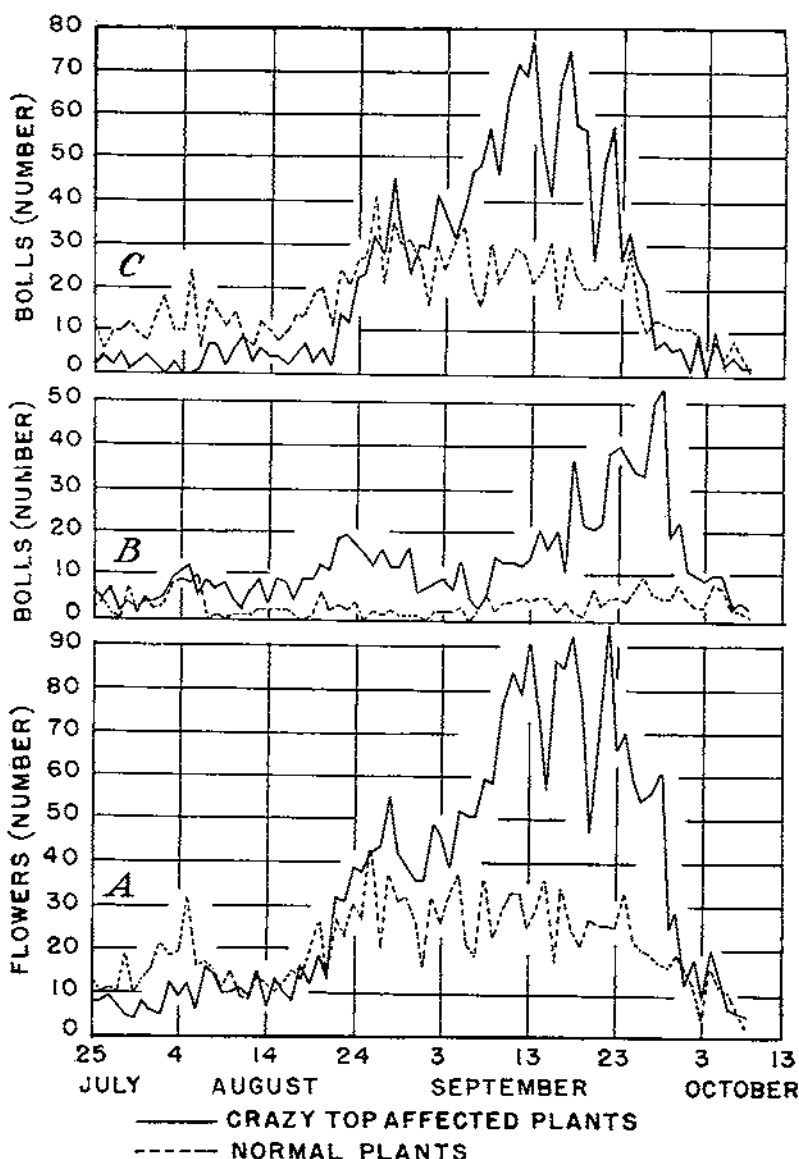


FIGURE 13.—Diagrams of daily flowering (A), boll shedding (B), and boll retention (C) on 25 normal and 25 crazy top affected Pima cotton plants for part of the season of 1932, at the seed farm, Sacaton, Ariz.

anthers. Since then the writers have observed that in Pima cotton flowers reduced in size, with defective anthers and pistils, and with the petal spot weak or entirely lacking are regular features of the disease in its more severe phases. Attempts were made in 1931 to

measure the extent of these abnormalities in the flowers. One procedure consisted of gathering at random 10 flowers from diseased plants and 10 flowers from normal plants once each week from July 27 to September 30. Then measurements were made of the length and width of the bracts, the length and width of the petals, the length of the staminal column, and the length of the style. At the same time the number of bracts, petals, carpels, and ovules were determined for each flower. The number of flowers with normal anthers was noted, and the petal spot of each flower was graded by referring to a series of standards according to the method used by Kearney (13). A grade of 0 represents the complete absence of petal-spot pigment and grade 10 represents the greatest intensity to be found in normal Pima. The length and width of the bracts were determined by taking the greatest dimensions of one representative bract from each flower. The length and width of the petals were obtained by averaging the greatest dimensions of two representative petals from each flower.

Table 2 is a summary of these measurements for the entire season. Each item recorded in this table is an average of the measurements of 10 flowers. The probable errors of the differences between the means in this table and in tables 3 and 4 were determined by the method of Student as modified by Engledow and Yule (10), which is suited especially for paired varieties.

Comparison of the means shows that the bracts of the crazy top flowers were somewhat smaller in both dimensions than those of the normal flowers. The petals of the crazy top flowers were reduced even more than the bracts, having averaged only about two-thirds the size of the normal petals. In the normal flowers the width and length of the petals were almost the same, being 6.3 cm wide and 6.5 cm long. In the crazy top flowers, however, the mean width was 3.7 cm and the mean length was 4.7 cm. During September the average size of the petals of the crazy top flowers increased noticeably.

Cook (6) pointed out that the interruption of the normal hereditary course in the expression of plant characters is one of the features of growth disorders in general. Apparently one instance of this behavior is the tendency on the part of plants affected with crazy top to produce flowers which do not possess the normal number of parts. It may be seen from table 2 that of the 100 flowers examined on plants affected with crazy top, 12 varied from the normal number of three bracts. Only one flower on a healthy plant varied in this respect. In the number of petals, normally five, 9 percent of the flowers from deranged plants and none of those from healthy plants varied; seven flowers from diseased plants and only one flower from a healthy plant varied from the normal number of three carpels.

The average grade of petal spot on the deranged plants reached its lowest point, 0.3, on August 10. From that date onward, with one exception, September 8, it increased steadily until in the final collection of September 30 it averaged 7.2. The mean for the season was 3.6. There was little variation in this character on the healthy plants, and the average for the season was 8.4.

Only 24 of the flowers from diseased plants produced mature pollen, and 22 of these were in the last three collections in September. Only 1 flower from a normal plant lacked pollen.

TABLE 2.—An analysis of the comparative morphology in Pima cotton of flowers from normal plants and from plants affected with crazy top, collected in samples of 10 each week for the period July 27 to September 30, 1931, at the seed farm, Sacaton, Ariz.

Date collected	Flowers with an abnormal number of—						Flowers with mature pollen		Mean—																	
	Bracts		Petals		Carpels				Length of bract		Width of bract		Length of petal		Width of petal		Grade of petal spot ¹		Length of staminal column		Length of style		Ovules			
	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected		
July 27	No.	No.	No.	No.	No.	No.	No.	10	0	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	Cm	No.	No.
Aug. 3	0	1	0	1	0	0	10	0	5.2	4.4	3.8	3.3	6.6	4.8	6.3	2.8	8.4	2.4	3.0	1.7	3.5	1.1	22.0	20.0		
Aug. 10	0	0	0	1	1	0	10	0	5.3	4.6	3.8	3.2	6.5	3.9	6.3	2.8	9.1	1.7	2.9	1.9	2.9	1.4	18.2	19.3		
Aug. 18	0	0	0	0	0	2	10	0	5.1	4.1	3.5	2.7	6.5	3.4	6.4	2.3	8.0	.3	3.1	1.6	3.4	1.0	20.5	18.1		
Aug. 25	0	0	0	0	0	1	10	0	4.7	4.1	3.2	2.9	6.3	3.7	5.9	2.5	8.7	1.5	3.3	1.9	3.6	.5	21.0	19.8		
Sept. 1	0	2	0	1	0	1	10	0	5.2	4.1	3.5	3.3	6.6	4.5	6.4	3.6	8.7	3.5	3.4	2.1	3.4	.9	19.0	16.4		
Sept. 8	0	1	0	2	0	0	10	1	5.7	3.9	3.7	3.3	6.4	4.7	6.0	3.6	8.0	4.7	3.4	2.3	3.3	1.1	19.9	16.7		
Sept. 15	0	2	0	3	0	2	10	1	5.1	3.9	3.8	3.3	7.3	5.4	7.1	4.3	8.5	3.7	3.5	2.2	4.1	1.7	17.7	17.0		
Sept. 22	1	1	0	0	0	0	9	4	4.8	3.8	3.6	3.0	6.7	5.9	6.5	5.2	8.0	5.4	3.2	2.6	3.3	2.2	18.0	17.9		
Sept. 30	0	1	0	0	0	0	10	8	5.3	3.8	3.7	3.1	5.4	4.6	5.4	4.4	7.8	5.5	3.2	2.8	3.0	2.2	19.3	18.6		
Sept. 30	0	4	0	1	0	1	10	10	5.0	3.9	3.0	3.3	6.6	5.8	6.6	5.2	9.1	7.2	3.4	3.0	3.5	3.0	10.3	17.8		
Mean for total collections									5.1	4.1	3.6	3.1	6.5	4.7	6.3	3.7	8.4	3.6	3.2	2.2	3.4	1.5	19.5	18.2		
Difference of means									1.08±0.07		0.48±0.03		1.82±0.17		2.62±0.20		4.84±0.45		1.63±0.09		1.89±0.14		1.24±0.26			
Difference of means + P. E.									15.4		16.0		10.7		13.1		10.8		11.4		13.5		4.8			

¹ See explanation of grade, p. 17.

The mean length of staminal column of the flowers from crazy top plants was only about two-thirds that of the flowers from normal plants, and in this character, also, there was an approach to the normal toward the end of the season. In average length the style was reduced even more than the staminal column, being less than half as long as on normal plants. In the first six collections the styles and stigmas were only rudimentary in the majority of the flowers from the diseased plants.

The number of ovules on normal plants averaged for the season 1.3 greater than the number on the diseased plants. No consistent variation from week to week in this character is discernible in the data for either group of flowers. After anthesis, abortion of seeds occurred to a greater extent on affected than on normal plants.

In another study of the effects of crazy top on the cotton flower 10 diseased plants were selected for observation. Beginning July 23, and continuing through September 30, all flowers produced by these plants were classified daily for size of corolla, intensity of petal spot, development of pollen, development of stigma and style, and variation in number of bracts or petals.

The grades for intensity of petal spot were determined as in the preceding study, while those for corolla size were based on a range in size from petals about 20 mm long for grade 1, to petals about 75 mm long for grade 10, with a difference of about 6 mm between each intervening grade. The data, summarized by weeks, are shown by diagrams in figure 14.

A comparison of these diagrams with the data in table 2 discloses very close agreement between corresponding items. Both indicate an increasing severity of the disorder as shown by the characters of the flowers until about August 15, and from then on there is evidence of improvement. The average size of the corolla of flowers from diseased plants during the period of observation was grade 6.7, which would be equivalent to a petal length of approximately 5.5 cm.

It is apparent from figure 14 that a high correlation exists between the size of the petal and intensity of the petal spot. During the 4 weeks when only sterile flowers were produced on the crazy top plants the petals were extremely small and almost devoid of spot.

The number of petals and the number of bracts were recorded on all of the 937 flowers produced by the 10 affected plants during the 10 weeks they were under observation. Of this number, 75, or about 8 percent, varied from the normal in the number of petals, and 151, or about 16 percent, varied from the normal in the number of bracts.

EFFECTS OF CRAZY TOP ON THE SEED AND LINT OF PIMA COTTON

In order to determine the effect of the crazy top disorder on the seed and lint of Pima cotton, a detailed study was made in 1932. Seven representative plants were selected from each of the normal and crazy top groups used in securing the flowering and shedding data reported above. The bolls of these plants were picked separately as they matured, and each was placed in a bag on which was recorded the date of the flower from which it developed, and the date of opening. The bolls set by the plants before crazy top became discernible also were picked, although no record was made of the date of the flowers.

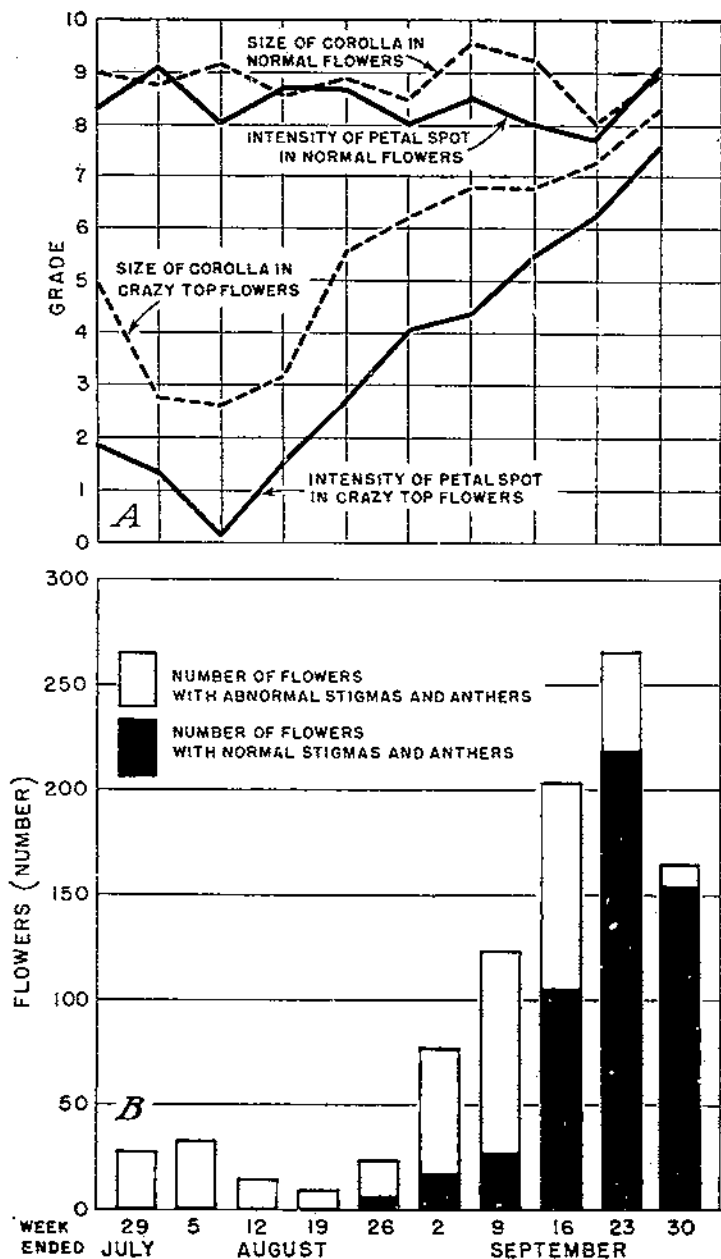


FIGURE 14.—Effects of the crazy top disorder on Pima cotton flowers produced July 23 to Sept. 30, 1931, at the seed farm, Sacaton, Ariz. *A*, Weekly summary of grades of size of corolla and intensity of petal spot on 10 normal and 10 crazy top affected plants. The grades indicated were determined as follows: Petal spot: Grade 0, no pigment; grade 10, most intense purplish red. Corolla size: Grade 1, very small, about 20 mm long; grade 10, largest, about 75 mm long. *B*, Weekly summary of the total number of flowers produced and of the number having normal and abnormal stigmas and anthers, on 10 plants affected with crazy top.

After the entire crop had been picked, the number of mature and of aborted seeds, the weight of the seeds and of the lint, the lint percentage, and the length of the lint were determined for each boll. Table 3 is a summary of these data grouped by the weeks in which the flowers opened. The data obtained from the bolls that were set before July 25 indicate that the disorder may have affected the normal development of the bolls on the lower and apparently unaffected parts of the plants. During the 3-week period from August 1 to 21, when the effects of crazy top were most severe, only four bolls were set by the diseased plants. The quality of the seed and lint in the bolls developed late in the season on these plants was not appreciably different from that in bolls from normal plants developed during the same period.

For the entire season, the average number of mature seeds per boll from affected plants was 2.44 less, and the number of aborted seeds approximately 1 more than in bolls from normal plants. The contents of affected bolls were on an average approximately one-fourth lighter in weight than the contents of normal bolls. The difference in lint percentage was negligible, evidently because, in the affected plants, the seed weight and the lint weight were reduced in nearly the same ratio. Perhaps the most important difference between the two groups of boll samples was in the length of lint; the lint from the affected bolls was 0.16 inch shorter than that from the normal bolls. The differences between the normal and diseased plants in seed and lint characters showed adverse effects of the disease and were statistically significant, as indicated by the probable errors of the differences, in every comparison except that of lint percentage.

BUDDING AND GRAFTING EXPERIMENTS ON PLANTS AFFECTED WITH CRAZY TOP

Several attempts have been made in the past to transmit the crazy top disorder from diseased to healthy plants. King and Loomis (16) were unable to infect healthy plants by the use of sap from various parts of diseased plants. Soil in which diseased plants had grown did not transmit the disease when packed around roots of healthy plants. Likewise, such soil when transferred to large metal containers failed to produce the disease.

At the suggestion of O. F. Cook, efforts were made in 1931 and again in 1932 to transmit the disorder by budding and grafting. In early August of 1931, a number of buds from diseased plants were placed on normal plants of Pima cotton, using the T or shield method of budding. Some of the buds came from the lower and externally unaffected parts of the diseased plants and some were from the upper, affected parts of the plants. All of the buds lived, but only five grew satisfactorily. Of these, three were from the lower, and two from the upper parts of the diseased plants. Regardless of origin, however, the growth was completely normal, and the plants used for stocks remained normal in all cases, including those on which the buds made no growth.

At the time the above experiment was performed, buds from normal plants were grafted on a number of plants severely affected by crazy top. The buds were placed near the tops of the plants well up into the diseased tissue. Again, all the buds lived, and 11 made satisfactory growth. There was no evidence of the presence of the disorder in the growth of any of these buds. In several instances, vegetative

TABLE 3.—Comparative development of seed and lint in bolls produced weekly on 7 normal plants of Pima cotton and on 7 plants affected with crazy top at the seed farm, Sacaton, Ariz., in 1932

Date flowers developed	Bolls		Mean per boll											
			Seeds		Aborted seeds		Weight of seed		Weight of lint		Lint		Length of lint	
	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected
	Number	Number	Number	Number	Number	Number	Grams	Grams	Grams	Grams	Percent	Percent	Inches	Inches
Before July 25.....	101	35	9.3	10.1	5.8	5.4	1.10	0.93	0.36	0.38	24.7	20.0	1.48	1.29
July 25-31.....	18	4	12.2	8.0	5.7	8.5	1.47	.73	.52	.27	26.1	27.0	1.61	1.37
Aug. 1-7 ¹	32	0	8.5		7.4		1.40		.37		25.2		1.54	
Aug. 8-14.....	43	1	12.0		7.1		1.43		.51		26.3		1.55	
Aug. 15-21.....	39	3	13.0	8.7	5.6	6.7	1.77	1.04	.62	.38	25.9	26.8	1.63	1.54
Aug. 22-28.....	71	47	14.7	9.0	4.7	7.8	1.79	1.03	.70	.42	28.1	29.0	1.64	1.46
Aug. 29-Sept. 4.....	73	57	14.8	10.9	4.8	6.1	1.83	1.31	.70	.50	27.7	27.6	1.65	1.49
Sept. 5-11.....	88	98	16.6	14.2	4.0	4.6	2.02	1.51	.68	.51	25.2	25.2	1.70	1.48
Sept. 12-18.....	94	125	17.5	14.4	3.3	4.1	2.00	1.37	.59	.44	22.8	24.3	1.60	1.33
Sept. 19-25.....	79	73	15.8	14.4	3.2	3.3	1.48	1.15	.41	.33	21.7	22.3	1.51	1.19
Sept. 26-Oct. 2.....	52	8	16.7	17.5	2.1	3.0	1.16	2.03	.36	.45	23.7	18.1	1.42	1.37
Oct. 3-9.....	9	4	17.1	16.7	2.3	1.0	1.02	.98	.36	.40	26.1	20.0	1.28	1.41
Total.....	699	455												
Mean.....			14.07	12.39	4.67	5.05	1.51	1.21	.52	.41	25.30	25.83	1.55	1.39
Mean (excluding period Aug. 1-14).....			14.83	12.39	4.15	5.05	1.56	1.21	.53	.41	25.20	25.83	1.55	1.39
Difference of means.....			2.44±0.475		-0.9±0.27		0.35±0.1		0.12±0.027		-0.63±0.52		0.16±0.026	
Difference of means ÷ P. E.....			5.1		3.3		3.5		4.4		1.2		6.2	

¹ Since only 1 boll matured from flowers that opened Aug. 1 to 14 on the affected plants no data are recorded. The data obtained from the bolls of normal plants which flowered during this period are included in the means for the season, but are not included in the means used for determining the differences. They are given to show that some influence of stress was operating even on young bolls of normal plants during this critical period.

branches of budded plants continued their abnormal growth while the cions were making normal growth. Neighboring plants which were crazy at the beginning of the experiment had not made more than the usual recovery by fall.

In 1932, larger numbers of buds were used and better growth obtained, but the results agreed with those of 1931. Out of a total of 25 normal buds placed near the tops of aberrant plants on July 25, 20 of them developed and made good growth which was apparently normal (fig. 15, *A*). Twenty-five of a total of twenty-nine diseased buds on normal plants put in at the same time made satisfactory growth. All were normal and the stocks remained normal (fig. 15, *B*). On July 26, 12 buds from diseased plants were placed on other crazy top plants and 8 of them grew. It is a surprising fact that the growth developed from these buds was quite normal in appearance, while neighboring control plants behaved in typical crazy top fashion (fig. 15, *C*).

Using a bottle-graft method, five normal seedlings were grafted to the main stems of crazy top plants on July 25 without injury to the terminal buds of the cions. The subsequent growth was quite vigorous, and entirely normal in appearance. A low vegetative branch on one of the stocks maintained a typical diseased behavior during the rest of the season. Seven similar grafts were made at the same time using normal plants as stocks and small diseased plants as cions. The cions apparently recovered and maintained a vigorous and normal growth throughout the remainder of the season. The stocks did not appear to be affected.

Since the phony peach disease may be graft-transmitted by roots only (11), a trial of that method was made with cotton. On October 5 and again in December roots from diseased plants were grafted onto the roots of normal plants, and buds from normal plants were inserted in the roots of diseased plants. Some plants in each group were cut to the ground and were overwintered in pots in the greenhouse, and the remainder were left in the field. Due to a severe winter, only the former survived. A number of normal and diseased plants for controls were overwintered in the same fashion. Of the plants that lived through the winter, 16 were normal, 6 were normal with root grafts of diseased plants, 3 had normal buds on diseased roots, and 12 were affected with crazy top. All were successfully transplanted to a plot of good soil at the United States Field Station in the spring of 1933. The subsequent growth from both normal and affected parts was quite vigorous and fruitful, and remained entirely normal throughout the season.

TOPPING EXPERIMENTS

In 1931 the writers found a few diseased plants that had lost their terminal buds, or the top few inches of the main stems, through injury. In such cases it is common for Pima cotton to send out one or more vegetative branches from nodes near the top of the injured stem. With upland cotton abortion of the terminal bud is a common symptom of the effect of crazy top. In the case of the diseased plants observed, the new branches were normal in appearance though uninjured neighboring plants remained typically abnormal.

In 1932 an experiment was conducted that afforded further information on the effects of topping on Pima plants affected with crazy top. On August 2, the terminal growth to the extent of about 5

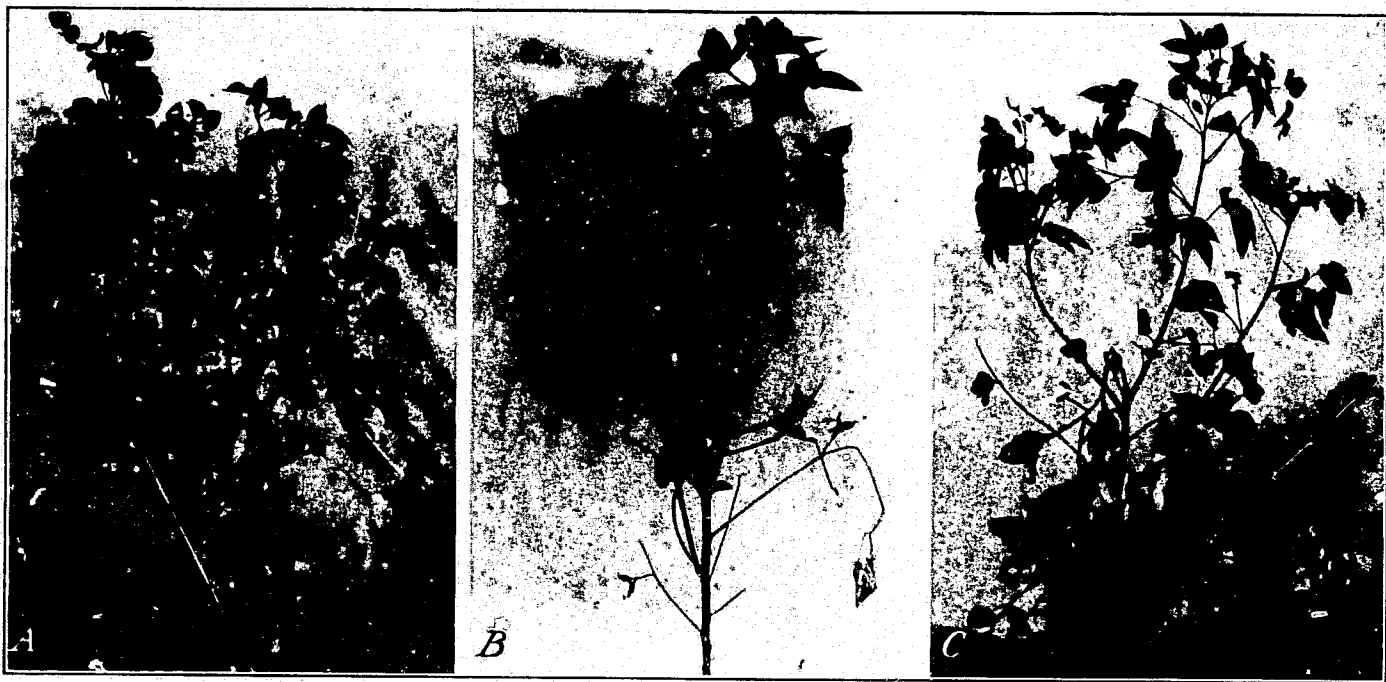


FIGURE 15.—Growth from cross budding between normal and crazy top affected Pima cotton plants. *A*, The twin branches at the right, developed from a normal bud inserted into an affected stock July 25, 1932. The vegetative limb at the left is from the stock, and shows effects of the disorder on leaves and upper branches. *B*, The branch at the right developed from a bud removed from a plant affected with crazy top and inserted in a normal stock. The branch at the left is from the original stock. Both branches are normal. *C*, The branch at the right on the large plant developed from a bud removed from a plant affected with crazy top and inserted in a stock affected with crazy top. The growth is normal. An affected branch from the original stock is seen at the left.

inches was broken from one group of diseased plants. At the same time, from another group, all of the aberrant growth was removed. One week later, and again 2 weeks later, other groups of plants received the same treatment. Most of the plants treated the first 2 weeks sent out new branches, but very little new growth was made in either group treated the last week. In all cases where new vege-



FIGURE 16.—A Pima cotton plant photographed October 21, 1932, showing the effect of "topping" in restoring normal growth characters. The terminal growth of the main stem was removed on July 21, 1932. The three newly developed upright branches have normal characters while older branches still show aberrant growth.

tative branches were produced they were invariably normal in appearance (fig. 16). Even in those cases where only a small part of the abnormal growth was cut off, the new growth was normal.

TRANSPLANTING EXPERIMENTS

In the hope that the reaction of transplanted crazy top plants might give evidence of the nature of the disease, King and Loomis (16) transferred four deranged plants to a productive soil. The one plant that survived made a complete recovery from the disease.

Further trials of transplanting were made in 1931. Four badly deranged plants were removed from the seed farm to a silty produc-

tive soil at the United States Field Station on July 23, and into the holes left by their removal were set four normal plants from the United States Field Station. Likewise, on the seed farm, four diseased and four normal plants were interchanged. All the plants lived and made several inches of growth before frost. The deranged plants recovered fully and set some bolls. All the normal plants remained unaffected.

CHEMICAL COMPOSITION

In view of the decided changes in the morphology of the cotton plant when affected by the crazy top disorder, it seemed important to determine whether affected plants differed from normal plants in chemical composition. It was believed that if such differences were shown they might furnish a clue to certain deficiencies or excesses in soil elements that might account for the abnormal behavior.

Since various parts of the plant differ greatly in chemical composition, it seemed desirable to know the composition of some of the organs during the period when the aberrant growth was under development.

Samples of leaves, stems, and squares were collected from the plants affected with crazy top and from nearby normal plants at various intervals during the seasons of 1930 and 1931 and prepared for analysis.

A majority of the samples were obtained from Pima plants grown at the seed farm, but a few samples from Pima plants and from plants of the Acala variety of upland cotton were obtained from fields containing areas of affected plants in the Salt River Valley.

PREPARATION OF SAMPLES

The leaves were collected from the upper portion of the plants, using fully developed but not old leaves. The stem samples were taken from the upper 8 inches of the main stalk after stripping off branches and leaves. The squares were taken from the upper fruiting branches, and represented ages from 10 to 20 days. The samples were exposed for several weeks in a drying room at air temperature until the weights were constant, after which they were ground and placed in tightly stoppered bottles.

The mean percentage of moisture in samples from Pima plants collected weekly for 7 consecutive weeks at the seed farm in 1930 was as follows. For leaves, squares, and stems from normal plants the percentages were 76.6, 79.7, and 83.0, respectively. For leaves, squares, and stems from diseased plants the percentages were 77.1, 79.1, and 85.1, respectively. The amount of moisture left in the samples after prolonged drying, as determined in part of the samples, averaged approximately 10 percent for leaves, squares, and stems. Since total moisture determinations were not made on all the samples the chemical constituents are reported on an air-dry basis.

METHODS OF ANALYSIS

For the most part the methods used were those recommended for plant materials by the Association of Official Agricultural Chemists as revised to July 1, 1924 (2). The total nitrogen was determined by the Kjeldahl method modified to include the nitrogen of nitrates.

The total ash was determined by igniting from 8 to 16 g of the material at moderate temperatures until the residue was nearly white. The mineral constituents were determined from the dissolved ash. Determinations were made of the sulphur, and ferric and aluminum oxides in a few of the samples, but the quantities were small and appeared to be of no significance and so are not recorded. Magnesium was determined in only a few samples.

The proportions of ash, nitrogen, phosphorus, chlorine, calcium, and magnesium in the samples of leaves, squares, and stems are given in table 4.

RESULTS

The differences in the quantities of the several constituents in normal and affected leaves of Pima cotton are not statistically significant except that it is indicated that there was a slightly greater quantity of calcium in the normal leaves (*D/E* 2.8). In the case of the Acala variety, however, a greater amount of nitrogen and chlorine is indicated in the leaves of affected plants. When regarded statistically the differences are highly significant (*D/E* 15.8 and 26.8, respectively).

In the analysis of squares from the Pima variety, those collected from normal plants showed a significantly higher content of total ash, chlorine, and calcium than those from affected plants.

In the stems from Pima plants the reverse was true. The affected stems contained significantly higher percentages of nitrogen, total ash, phosphorus, and chlorine than the stems from normal plants. It might be inferred from these scanty data that the stems of affected plants accumulate nutrients at the expense of the fruiting parts. It is characteristic for the branches of aberrant plants to develop luxuriantly, while the squares are shed freely until late in the season. The fact that a large proportion of the bolls retained by the affected plants show abnormal or incomplete development also would suggest faulty assimilation of nutrients.

While little significant information on the crazy top problem is furnished by these data, they contribute to the knowledge of the chemistry of the cotton plant produced under irrigated conditions. They show, as do earlier data, that there is a tendency for the ash constituents, particularly in the stems, to decrease as the plant grows to maturity. They also show, more pronouncedly, a decrease in the nitrogen of the plant parts as the season advances. It is apparent therefore that there is a more rapid assimilation of nutrients during the early development of the plant than in the later stages. With the exception of nitrogen in the leaves, these analyses show higher percentages of certain elements than are shown in analyses of plants made in the Southeastern States (3). This is especially true of calcium and chlorine.

FIELD EXPERIMENTS WITH CHEMICALS

The success attained in recent years in controlling diseases of such character as tobacco frenching, pecan rosette, little leaf of fruit trees, chlorosis of citrus, and other physiological diseases by the use of chemicals (1, 4, 5, 12, 20) suggested that the crazy top disorder might respond to such treatments. Some of these diseases respond to

TABLE 4.—Analyses of Pima and Acala cotton leaves, squares (flower buds), and stems collected at various periods during the fruiting seasons of 1930 and 1931 from plants affected with crazy top and from normal plants¹

[Most of the analyses were made by L. W. Towle, temporary field assistant in 1931]

Variety and place of collection in Arizona	Date of collection	Nitrogen		Total ash		Phosphorus		Chlorine		Calcium		Magnesium	
		Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected	Normal	Affected
Pima leaves from—		<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Seed farm, Sacaton	Aug. 16, 1930	3.14	4.48	7.91	9.86	0.27	0.32	0.66	0.68	2.07	2.70	0.33	0.41
Do	Aug. 23, 1930	2.97	3.36	9.15	13.20	.24	.26	.91	.86	2.35	2.48	.40	.41
Do	Aug. 30, 1930	3.52	2.92	10.27	10.37	.27	.27	.72	1.14	2.43	2.92	.40	.42
Do	Sept. 5, 1930	3.66	3.39	9.41	9.38	.22	.24	.89	.61	2.55	2.21	.46	.47
Do	Sept. 13, 1930	3.88	3.14	10.26	9.12	.23	.24	.71	.68	2.20	1.79	.43	.44
Do	Sept. 20, 1930	2.29		9.73	9.41	.25	.16	1.02	.77	2.14	1.97	.46	.45
Do	Sept. 27, 1930	3.12	1.65	10.51	8.63	.22	.16	1.04	.79	2.32	1.80	.48	.35
Do	Oct. 27, 1930	2.19	2.08	15.45	13.90	.14	.12	1.01	.57	4.62	2.95		
Do	do ²		1.66		16.25		.08		1.07		3.74		
Do	do ²		1.88		15.90		.26		.96		4.22		
Do	do		1.63		15.43		.10		.96		3.01		
Litchfield	Oct. 14, 1930	3.12	3.35	12.98	12.78	.18	.23	.83	.87	3.58	3.18		
Do	do	3.68	4.17	11.80	12.90	.25	.20	.70	.73	3.06	2.94		
Seed farm, Sacaton	July 31, 1931	1.68	4.27	10.23	9.20	.20	.26	.80	.72	2.22	1.85		
Do	Aug. 10, 1931	2.09	3.41	9.77	9.23	.16	.21	.89	.88	2.36	1.98		
Do	Aug. 18, 1931	1.44	2.80	12.23	9.46	.16	.20	1.24	.99	2.96	2.05		
Do	Aug. 24, 1931	3.24	4.11	12.34	12.86	.15	.17	1.05	1.47	2.78	2.82		
Mean ¹		2.86	3.02	10.86	11.64	.21	.20	.89	.87	2.69	2.68	.42	.42
Mean ²		2.90	3.32	10.86	10.73	.21	.22	.89	.84	2.69	2.41	.42	.42
Difference of means		0.42±0.19		0.12±0.29		-0.007±0.008		-0.05±0.04		-0.28±0.10		-0.0014±0.015	
Difference of means÷P. E.		2.2		0.41				1.2		2.8			
Acala leaves from—													
Peoria	Oct. 14, 1930	2.08	3.22	11.94	12.68	.14	.14	.68	1.44	3.65	3.19		
Do	Oct. 28, 1930	2.33	3.35	16.06	15.34	.14	.13	.64	1.26	4.56	3.29		
Litchfield	July 15, 1931	1.97	3.46	9.68	13.59	.21	.23	.45	1.08	2.27	3.13		
Mean		2.13	3.34	12.76	13.87	.16	.17	.59	1.26	3.49	3.20		
Difference of means		1.22±0.077		1.11±0.84		0.003±0.008		0.67±0.025		-0.29±0.34			
Difference of means÷P. E.		15.8		1.3				26.8		0.85			

chemicals containing certain of the essential elements, while others are influenced by the less essential elements like zinc, boron, and manganese. Valleau and Johnson (20) suggested that the symptoms of crazy top as described by Cook (6) suggested nitrogen deficiency. McGeorge and Breazeale (18) have reported evidence that unfertility of highly calcareous soils is often due to a lack of soluble phosphates.

Fertilizers high in nitrogen and phosphates were applied at ordinary rates during the years 1925 to 1930 to areas at the seed farm which had a tendency to produce crazy top plants, but these fertilizers appeared to have little effect in preventing or controlling the disorder.

In 1931 applications of ammonium sulphate were made at rates of 400, 600, and 950 pounds per acre to several areas on which the plants were showing initial symptoms of crazy top in July. The disorder was not checked on these areas, but the plants grew more vigorously and developed late in the season a greater number of bolls than affected plants in adjacent control areas. On May 29 of the same season treble superphosphate (20-percent phosphorus) in solution was injected into several areas which had produced affected plants the previous year. The rates were 1,500 and 2,500 pounds per acre. On July 23 other areas on which the disorder was beginning to appear were given a solution of treble superphosphate at rates of 1,000, 2,000, and 3,000 pounds per acre, applied with an injector. The disorder failed to appear in the areas treated in May or in adjacent untreated areas. No effects on the affected plants were noted on the areas treated in July.

In 1933 applications of ferrous sulphate (FeSO_4), zinc sulphate (ZnSO_4), borax, ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$), and manganous sulphate (MnSO_4) were applied late in June to some areas of Pima cotton at the seed farm where crazy top had appeared the previous year. Each chemical was applied to a different plot. On July 8 two other plots were treated, one with borax and the other manganous sulphate. After the appearance of the disorder each of three other areas of affected plants were treated with zinc sulphate, borax, and manganous sulphate. The number of pounds per acre of each of the compounds were as follows: Ferrous sulphate, 207 to 414; zinc sulphate, 1,245 to 4,148; borax, 6.6 to 7.5; manganous sulphate, 116 to 145. Except for one plot treated June 27 with ferrous sulphate at the rate of 414 pounds per acre, crazy top failed to appear in the areas which received the early treatments and was not in evidence nearby.

The treatments made in August showed no effects in checking or reducing the disorder. The only effects noted were that plants in some of the treated areas developed a darker green color than nearby untreated plants. The borax failed to show even this effect.

In 1934 further treatments with zinc sulphate were made at various periods during the summer at rates of 900, 1,563, and 3,000 pounds per acre. In one of the areas that received frequent irrigation, treated at the rate of 3,000 pounds per acre just prior to an irrigation, many of the plants were killed or injured. At the same time in another area receiving the same amount of zinc sulphate preceding the first irrigation after a stress period, no injury attributable to the chemical was apparent. Some injury was noted in one area treated at the rate of only 1,500 pounds per acre. As in 1933 the treatment failed to show any influence on the crazy top disorder.

IRRIGATION EXPERIMENTS

LOCATION, ARRANGEMENT OF PLOTS, AND PROCEDURE

Since observations had shown that the severe phases of the disease were associated with unfavorable soil and moisture conditions, it seemed reasonable that valuable information might be obtained from variations in the irrigation management.

The area selected for the field irrigation experiments is located at the seed farm of the United States Field Station. The soil was classified by the Bureau of Chemistry and Soils as Mohave sandy loam. It is highly calcareous and has a tendency to become cemented and impervious on drying. Crazy top had occurred in previous years on the area under the experiment, and was observed to some extent in every cotton planting made at the seed farm during the period 1922 to 1933.

The irrigation experiment as conducted in 1933 and 1934 comprised two different tests. The objective of the first test was to determine whether withholding of irrigation water at various times throughout the season influenced the incidence of the disorder; and the purpose of the second was to ascertain whether the occurrence of the disease was influenced by different methods of applying irrigation water.

FIELD TEST I

The 1933 test was carried out on three strips or "borders" designated by plot numbers 12, 15, and 19. These were about 28 feet wide between the water-control dikes and 880 feet long. They were further divided into 16 plots or basins of equal size by the construction of cross dikes every 55 feet. A separate supply ditch was prepared the full length of each border so that each of the 16 basins could be irrigated as a single unit. Water was applied at the rate of about 4 acre-inches per irrigation. In 1934 the test was conducted on only two borders, numbered 11 and 13, both of which had been practically free from crazy top in 1933.

The 48 plots in 1933 and the 32 plots in 1934 were grouped into four series and designated A, B, C, and D. A different irrigation treatment was applied to each series, making 12 replications for each in 1933 and 8 in 1934. The irrigations were so timed as to provide adequate moisture at all times except as it was desired to check slightly the development of the plants by withholding water. Toward the ends of these periods of water deficit the plants on many of the plots remained in a pronounced state of wilt for several hours of the day (fig. 17).

In 1933 it was thought desirable to apply water every 5 days after July 20 to insure adequate water for the plants on this type of soil. The results indicated that this period could be prolonged, and in 1934 water was applied every 7 days where adequate quantities were desired.

The development of plants on the A series in 1933 was checked by withholding water from June 1 to July 20 except for a single irrigation on June 30. In 1934 the A series received no water from May 28 to July 11. On series B checking was effected in 1933 by withholding water from June 23 to July 20, and in 1934 from June 26 to July 31. The water shortage period for series C in 1933 was from July 20 to August 17 and in 1934 from July 24 to August 21. On series D only

short intervals were allowed between irrigations, so that adequate moisture was available in the root zone for continuous growth throughout the season.

In order to obtain some knowledge of the moisture conditions in the soils of the plots under the different treatments, soil samples were taken from representative plots at frequent intervals for moisture determinations.

In 1933 soil samples were taken in 1-foot horizons to a depth of 4 feet in five or six different plots of each series. From the plots in

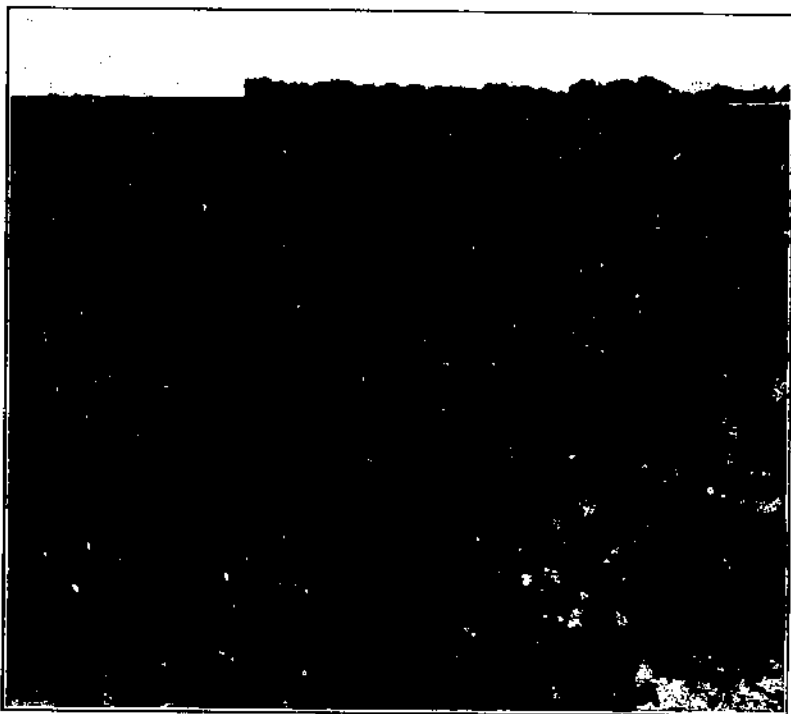


FIGURE 17.—Extremely wilted condition of Pima cotton plants in one of the plots under treatment B at end of water-deficit period July 31, 1934. In most of the plots the plants had not reached this extreme degree of stress before irrigation was resumed.

series D, soil-moisture samples were taken on the day after irrigation. Likewise, from the plots in series A, B, and C, samples were taken only on the day after irrigation except during the various stress periods when they were taken on the same days as those from series D plots. Sampling was begun June 14, and was continued until August 9 in series A and B where crazy top had already appeared and where a condition of adequate soil moisture had been reached again. In series C, sampling was continued throughout August and in series D, to August 24.

In 1934 the procedure differed from that of 1933. Only one representative plot in each series was sampled for soil moisture. Except during the stress period, samples were taken on the day before and 2 days after irrigation. During the stress period, in series A, B, and C the samples were taken only once a week, on the day preceding the

irrigation of series D. Sampling was begun June 4 and continued through August 30.

The dates of irrigation for the four series of plots are given in table 5.

TABLE 5.—*Dates on which irrigation water was applied to four series of plots of Pima cotton to note the effects of various irrigation treatments on the incidence of the crazy top disorder at the seed farm, Sacaton, Ariz., in 1933 and 1934*

Series A		Series B		Series C		Series D	
1933	1934	1933	1934	1933	1934	1933	1934
	Apr. 10		Apr. 10		Apr. 10		Apr. 10
	May 2		May 2		May 2		May 2
May 13	May 16	May 13	May 16	May 13	May 16	May 13	May 16
	May 28		May 28		May 28		May 28
June 1		June 1	June 5	June 1	June 5	June 1	June 5
		June 13	June 12	June 13	June 12	June 13	June 13
		June 19	June 19	June 23	June 19	June 23	June 23
June 30 ¹		June 23	June 26	June 30	June 26	June 30	June 30
	July 11 ²			July 7	July 7	July 7	July 7
	(1)			July 13	July 11	July 13	July 13
July 20 ²		July 20 ¹	July 31 ²	July 20	July 24	July 20	July 20
(1)		(1)	(1)	Aug. 17 ²	Aug. 21 ²	(1)	(1)
				(1)	(1)		

¹ Every 7 days thereafter.

² End of water-deficit period.

³ Every 5 days thereafter.

FIELD TEST 2

In the comparison of irrigation methods in 1933, borders 8 and 11 were divided into check basins 25 by 28 feet in dimensions, and water was applied to these at 5-day intervals during July, August, and September. Borders 6 and 13 were flooded frequently, by the conventional border system, the water being checked by a few cross dikes at intervals of about 150 feet. In 1934 the small basins were not used, but border 14 was divided into 18 basins 28 by 50 feet in dimensions, and 15 of these were irrigated every 7 days after May 28.

In another division of the farm known as section B, borders 6 and 10 in 1934 were divided into 11 basins, each 28 by 50 feet. Border 6 was irrigated every 7 days and border 10 every 14 days.

In order to obtain a record of the distribution of the diseased plants under the different treatments, the aberrant plants were mapped according to their location in the rows. In 1933 the diseased areas were mapped on August 29 and on October 5. In 1934 they were mapped on September 25.

OCCURRENCE OF CRAZY TOP

After the irrigation system was under way and the fruiting season had begun, the experimental plots were inspected daily to detect the first symptoms of crazy top. In 1933, the first crazy top growth was definitely identified on July 26 on six plots of the A series and three plots of the B series. This was 6 days after the irrigation of these series, following a 20-day interval without water for series A and a 27-day interval without water on series B. On August 4 the disorder was in evidence on nine plots of the A series and nine of the B series, and 1 week later 11 of the 12 plots in each of these two series were affected. In some of the plots almost all of the plants were affected; in others, only a few plants showed aberrant growth.

The plants on the 12 plots of series C were normal to July 20 and throughout the enforced period of water deficit from July 20 to August 17. Following the irrigation of August 17 the plants made rapid growth, but the new growth did not show crazy top symptoms until after September 1, and then only in a few plots. By October 1, however, plants on eight plots of the C series showed some crazy top growth, but since the plants had almost completed growth for the season, the crop was affected but little.

On the D series of plots, which received water at frequent intervals throughout the season, the plants showed no evidence of crazy top at any time.

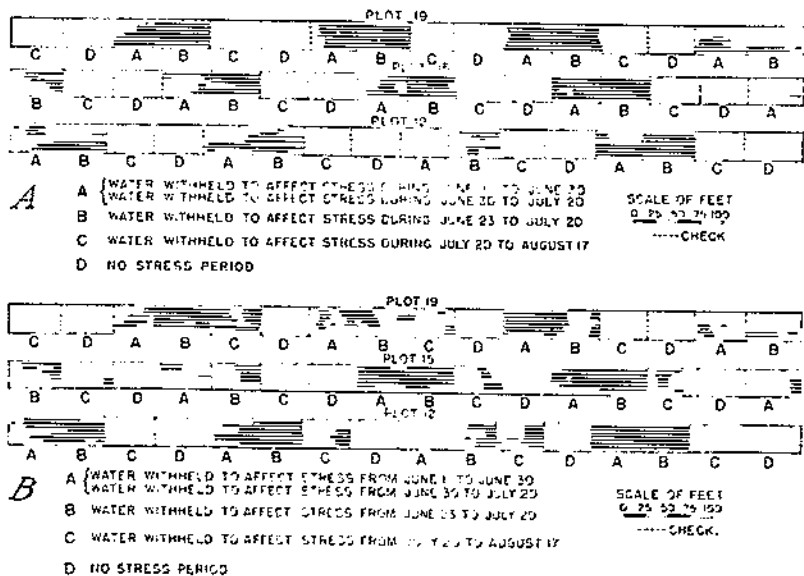


FIGURE 18.—A, Location on August 29, 1933, of Pima cotton plants affected with the crazy top disorder in three border strips to which four different irrigation treatments were applied at the Sacaton seed farm. A relationship will be noted between the location of the diseased plants and the plots (A and B) which received inadequate irrigation water early in the summer. B, Crazy top affected plants on the same border strips on October 5, 1933. It will be noted that the disorder had made its appearance on seven plots of the C series which received adequate irrigations except for a 28-day period, July 20 to August 17. (For convenience, these diagrams and those of figs. 24 and 25 are drawn in horizontal form, although the borders represented lie diagonally in the field, as shown in fig. 1.)

The distribution of the affected plants in the plots under the various treatments on August 29 and October 5, 1933, is shown in figure 18, A and B.

In 1934 the first definite crazy top growth was identified on July 24 in all but one of the eight plots in series A. This was 13 days after the period of water shortage.

On August 14 the first symptoms of the disorder were observed on some of the plants in all of the eight plots in the B series. The plants in the C series, as in 1933, showed a rapid revival of growth in response to irrigations following the period of water shortage ended August 21, but there were no symptoms of crazy top until the latter part of September when a few plants could be found with slightly abnormal terminal growth.

The plants in the D series, which were provided with adequate water to prevent wilting or checking of growth, showed no signs of

crazy top at any time. The plants were moderately fruitful, and bolls were set at a fairly constant rate.

Figure 19, *A, B, C,* and *D,* shows the typical appearance of the plants under the four treatments on October 16, 1934.

SOIL MOISTURE

Figure 20 shows by diagram the percentage of moisture in the soil in each of the four series of plots for test 1 at certain intervals in 1933 and 1934. In 1933 only the data from those locations where the plants became diseased are included in the diagram for series A and B, but in series C and D the data for all samples are included. Thus, six plots from series A and D and five plots from series B and C are represented. In 1934 samples were taken from only one plot in each series. The variations in the water-holding capacity of the soils at the different locations of sampling possibly account in part for the higher average moisture content of the series A and B plots at the end of the stress period in 1933 than in 1934. The moisture content of the series D plots was fairly constant and at all times adequate for the plants.

In 1934 only the data obtained from sampling after irrigation and during the stress period are included. From the diagram it may be seen that the moisture content in each of the plots was less than 5 percent by the end of the stress period. At this stage, in most cases the plants were near permanent wilting. The moisture content of the series D plot was always adequate and moisture penetration following irrigation was always good.

In test 2, 1933, none of the plants in basined plots 8 and 11 were affected with crazy top (fig. 21). The disorder did not appear in border 6 (not shown in figure) which was under the treatment of frequent flooding but occurred in one spot on border 13 which was under similar treatment. This spot, extending



FIGURE 19. Characteristic development of Pima cotton plants at maturity under differential irrigation treatments in crazy top investigations at the seed farm, Stanton, Ariz., October 16, 1934. *A,* Plants affected with crazy top influenced by a water deficit period from May 28 to July 11. Treatment *A.* Note the evidence of early abnormal development in the branching structure. *B,* Plants affected with crazy top influenced by a water deficit period from June 20 to July 31. Treatment *B.* *C,* Plants under the treatment of late summer water deficit, July 21 to August 31. Treatment *C.* *D,* Plants supplied with adequate irrigation water throughout the summer. Treatment *D.*

across four rows for a distance of 45 feet, was higher in elevation than the surrounding soil and for this reason could not be irrigated effectively. The first symptoms were noted in this spot on August 18.

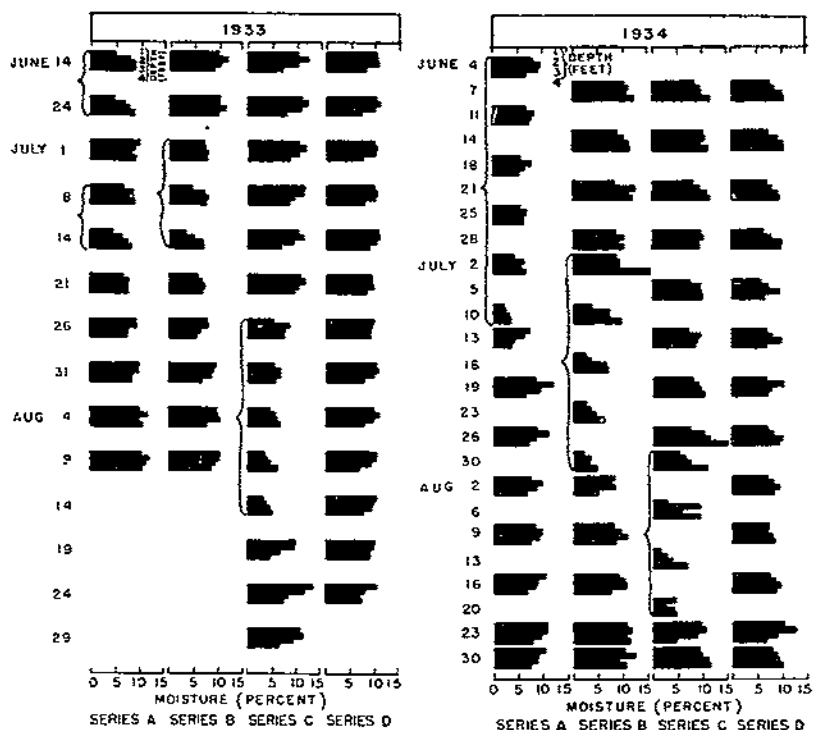


FIGURE 20.—Moisture in percentage of dry weight in soil samples taken to a depth of 4 feet from plots in the irrigation test 1 at the seed farm, Sacaton, Ariz., in 1933 and 1934. The samples represented by the data symbols to the right of braces were taken at intervals during the time water was withheld from the plots to effect stress.

In 1934 no crazy top developed in any of the 15 out of the 18 plots of basined border 14, which were irrigated every 7 days (fig. 22), nor did it occur in any of the 11 basins in border 6 of section B, not shown

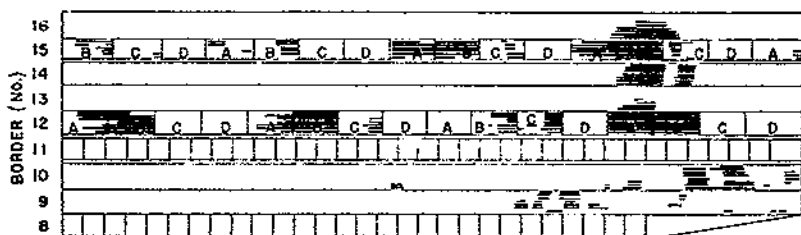


FIGURE 21.—Arrangement of plots and location of Pima cotton plants affected by crazy top on nine borders at the seed farm in 1933. (Borders 12 and 15, under the differential irrigation treatment shown in fig. 18, are included.)

in figure, where the water was applied at weekly intervals. It did appear, however, in 5 of the 11 basins on border 10 of section B, to which water was applied at intervals of 14 days.

It is apparent from the maps that the plants affected by the crazy top disorder are restricted to areas where they were subjected to stress at some period during the season by an enforced water shortage.

At the first mapping of affected plants in the four different irrigation treatments on August 29, 1933, none were observed in the C series of plots in which the plants were almost mature before being subjected to stress. When mapped on October 5 the terminal growth on some of the plants in the series was slightly abnormal, but the general branching structure was not affected as in series A and B. In 1934 all of the plants in the C series were recorded as free from the disorder at the time of mapping on September 25, though aberrant growth developed on a few plants later. In both 1933 and 1934 the plants on the D series which received adequate irrigation throughout the season reached maturity much earlier and produced more cotton than those in series A and B. Plants in the two latter series set only a few early bolls, but developed a large number of late bolls, many of which failed to mature before frost. The plants in most plots of the A and B series attained greater height and developed a much larger number of vegetative branches in the tops than did those in the C and D series.

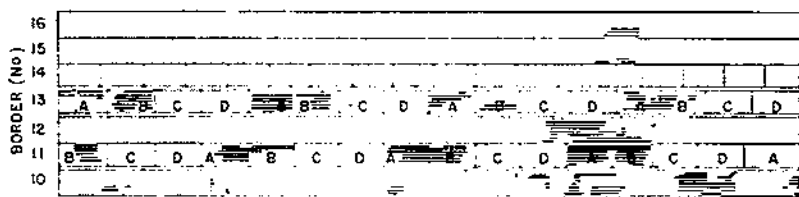


FIGURE 22.—Location on September 25, 1934, of Pima cotton plants affected by the crazy top disorder in seven border strips of section D at the seed farm, Scenton, Ariz. The locations of diseased plants on these borders in 1933 is shown in figure 21. Borders 11 and 13 received four different irrigation treatments, while border 14 received adequate water throughout the season as did the D plots of borders 11 and 13. A relationship will be noted between the location of the diseased plants and the plots which received inadequate irrigation water early in the summer.

Figures 21 and 22 show that the location of the spots of affected plants in one season bears little or no relationship to their location in succeeding seasons. In 1933 borders 12 and 15 contained the greatest number of affected plants as a result of the periodic water shortage on three-fourths of the area. In 1934 these borders were flood-irrigated at frequent intervals throughout the season and very little crazy top occurred. In 1934 the greatest number of affected plants occurred on borders 11 and 13 in which three-fourths of them were subjected to periodic water shortage. In the previous year border 11 was irrigated frequently in small basins and no plants were affected. Border 13 was irrigated by flooding at short intervals and plants were affected in only one small spot that was too high to irrigate effectively.

In these experiments the method of applying water in check basins to effect uniform distribution and deep penetration of moisture was advantageous, but it was apparent that in preventing the disorder the method of application was not as important as proper frequency of irrigations. In several cases where plots received an accidental irrigation from shallow flooding, thus unintentionally shortening the period of water deficit, the stress was alleviated to such an extent that no crazy top occurred during later development.

The behavior of the plants under the treatments in these experiments indicate that prevention of crazy top on soils of this type is

entirely practicable by management of irrigations so as to prohibit a checking of plant growth during the summer months.

IRRIGATION EXPERIMENTS IN CONTAINERS

As a supplement to the field experiment of 1933, an irrigation experiment was conducted with a number of plants grown in large iron barrels or drums filled with soil.

The soil for 14 barrels was obtained from an area at the seed farm on which crazy top had occurred the previous year. Two other barrels contained soil of an alluvial type known as Gila fine sand obtained from an area at the experiment station on which crazy top had never occurred. Eight different irrigation treatments were applied using 2 barrels for each. Treatments A, B, C, and D were the same as used in the field plots, except that more frequent irrigations were necessary to prevent wilting of the plants. In treatment E the plants were irrigated frequently but inadequately until August 5. After that date they were irrigated adequately. In treatment F applications of water were frequent, but not adequate prior to July 15, and after that were of such frequency and quantity as to prevent distress. Treatment G was similar to treatment B but was applied to the alluvial soil that had no crazy top history. In treatment H the applications were sufficient to maintain a moderate but fairly continuous growth.

The first crazy top symptoms appeared about August 5 on the plants under treatments A, B, and E. In the first two treatments it occurred in new growth, developed in response to an irrigation following a prolonged period of shortage, and in E under conditions of frequent but inadequate amounts of water. At the end of the growing season, plants in all containers of these three treatments showed the disorder. The disorder affected the plants in only half of the containers under treatments C, F, and H. The plants under treatment D remained entirely normal throughout the season. The plants under treatment G, which were grown in the alluvial soil, did not show the disorder after water shortage as did those similarly treated under B in the highly calcareous seed-farm soil.

In 1934 an experiment somewhat similar to that of 1933 was conducted with cotton plants grown in iron drums. The crazy top disorder did not affect all of the plants that were stressed from water shortage, but in all cases where it occurred, the soil was of the highly calcareous seed-farm type, and the water supply had been inadequate at some period during early development. The growth behavior of the plants in two of these drums seems worth recording. One drum that had been treated so as to produce crazy top in 1933 and one that had been treated so as to keep the plants normal in 1933 were planted again in 1934 without disturbing the soil except to cover the seed. The irrigation treatment was reversed so that the one with crazy top in 1933 received adequate irrigations. The plants in this drum remained normal in 1934. The other which contained normal plants in 1933 received very little water in late June and early July 1934, and the plants developed crazy top shortly after irrigation was resumed late in July.

RELATIONSHIP OF WATER SUPPLY TO INCIDENCE OF DISORDER

It is apparent from the plant reactions both in the field and tank experiments that the occurrence of crazy top on highly calcareous

soils is related to the water supply. The checking of growth from a lack of soil moisture, particularly in the early part of the fruiting season, is shown to have a direct relationship to the incidence of the disorder. Plants whose development is never checked from shortage of moisture apparently are not subject to the disorder.

The changes in the general structure of the plant, characteristic of crazy top, originate immediately following the restoration of moisture to the soil after a prolonged stress period. While under ordinary field conditions the aberrant growth may sometimes begin in almost epidemic fashion, the investigation shows that it may begin at any period that the water-stress influence is applied after the branching structure is well started. The structure of the central branches, and even of some of the lower branches, may be affected if the water deficit occurs early in the summer concurrently with high temperatures.

This behavior does not preclude the conception that the disorder may be of the mosaic or virus character as Cook (6) has suggested, but the analogy becomes less close as more information tends to associate it with the physiological diseases.

The facts that the disorder was not induced by water shortage in alluvial soils and has not been observed commonly in areas of alluvial or easily permeable soil, indicate that water shortage and resulting interrupted growth are not the only factors involved.

SUMMARY

This bulletin reports the results of an investigation of the various effects of the crazy top disorder on the cotton plant. The study involved principally the changes effected by the disorder on the morphology of the Pima cotton plant, particularly on the floral parts. Data are given on the effects of the disorder on the physiological processes related to stem growth, flower production, and boll shedding. Results of experiments on budding, grafting, and topping are reported.

Data are given on the chemical composition of parts of normal and crazy top affected plants, and a report is made on the results of field experiments with chemicals and fertilizers.

The results of experiments to determine the effects of various irrigation practices on the occurrence and control of the disease are reported.

Plants affected with crazy top attained greater height than nearby normal plants, probably as a result of their greater sterility.

In 1931 more than 75 percent of the young bolls from flowers produced July 22 to September 5 on one group of affected plants were shed, while only 25 percent were shed from nearby normal plants. By the end of the season, however, the affected plants had produced an average of about twice as many flowers as the normal plants, and set approximately 35 percent more bolls, many of which were too late to mature before frost. In 1932 the affected plants retained an average of 62.4 percent, and normal plants 84.1 percent of their bolls.

The bracts and petals of flowers from affected plants were on an average much smaller than those from normal plants, the affected petals averaging about two-thirds the size of normal petals, their width having been reduced to a greater extent than their length. Variations in the number of bracts, petals, and carpels (or boll locks) occurred to a greater extent in affected flowers than in normal flowers.

The intensity of color of the petal spot in affected flowers varied with the advance of the season and the severity of the disorder, but in normal flowers it showed but little change. The least color was shown in the affected flowers collected on August 10, 1931, and after that date the petals gradually recovered their normal spot color. The average grade of petal spot for affected flowers was 3.6 and for normal flowers 8.4.

With a few exceptions no pollen was produced by affected flowers collected weekly during the period July 27 to September 3, 1931, but after September 3 there was a marked increase in the number of flowers producing pollen.

During the period when the disorder was at its height the styles and stigmata of affected flowers were reduced to mere rudiments. For the season the mean length of the staminal columns of affected flowers was only about two-thirds of that of normal flowers, and the mean length of the style was about one-half of that of normal flowers.

A large proportion of the bolls which reached maturity on crazy top affected plants showed injurious effects of the disorder, even some that were partly developed before the first disease symptoms were noted on the plant. In affected bolls the mean number of mature seeds was 2.44 less and the number of aborted seeds 0.9 more than in normal bolls. The mean length of lint for the season in affected bolls was 0.16 of an inch shorter, and the mean weight of lint was 0.12 g less than in normal bolls.

Buds cut from crazy top plants and inserted in normal plants developed normal branches, and the results were similar when buds from normal plants were transferred to affected plants and when buds from affected plants were transferred to affected plants.

Normal seedlings grafted to the main stems of crazy top plants continued to produce normal growth, while low vegetative branches on the stock maintained their aberrant growth.

Cross grafting of roots from normal and diseased plants and insertion of buds from normal plants into the roots of affected plants at the end of the season resulted in the development of only normal growth the next year after the plants were overwintered in the greenhouse and transplanted to a favorable soil.

Growth produced after artificial topping or removal of the aberrant growth from affected plants early in August was normal in appearance.

An interchange of normal and affected plants by transplanting diseased plants to an area free from crazy top and transferring normal plants to the holes from which the others were removed, resulted in recovery of the diseased plants and continued normal development of the normal plants.

The chemical composition of leaves from affected Pima plants as determined by partial analysis was not greatly different from that of leaves from normal plants, except for an indication that calcium was slightly higher in normal than in affected leaves. In the few samples of Acala leaves that were analyzed the affected leaves contained higher proportions of nitrogen and chlorine than normal leaves.

The squares collected from affected plants were lower in total ash, chlorine, and calcium than squares from normal plants, but the stems of affected plants contained significantly higher percentages of nitrogen, total ash, phosphorus, and chlorine than the stems of normal plants. These facts suggest that imperfect translocation of nutrients

to the immature fruits of affected plants may influence the excessive shedding of squares and bolls and the poor development of the bolls that are retained.

It was apparent from the chemical data that there was a tendency for the ash constituents and nitrogen to decrease as the plants approached maturity.

In the ash of both normal and affected plants there was a greater proportion of important elements, particularly calcium and chlorine, than are shown by most analyses of cotton plants in the Southeastern States.

In field tests on the effects of fertilizers on crazy top, ammonium sulphate failed to check the disorder, but the plants treated grew more vigorously and produced a greater number of bolls late in the season than nearby plants that were not treated. Superphosphate (treble superphosphate, 20 percent phosphorus) applied in various amounts in solution with an injector showed no effects on the disorder nor on the growth and production of normal plants. Applications of ferrous sulphate, zinc sulphate, borax, and manganese sulphate to crazy top areas both before and after the appearance of the disorder were ineffective in controlling the disorder or preventing its occurrence. In some tests heavy applications of zinc sulphate caused injury to the cotton plants, especially when the plants were in a vigorous condition of growth.

During the years 1933 and 1934 four irrigation treatments were applied in several replications to four series of plots of Pima cotton to determine the effects of periodic water shortage on the occurrence of the crazy top disorder.

In 1933 the disorder began to appear late in July, but at that time only in plots of the A and B series that had been inadequately supplied with water for prolonged periods during June and early July. On August 1 a large proportion of the plants on 11 of the 12 plots in both of these series were affected with the disorder.

In 1934 the disorder appeared July 24 on seven of eight plots of series A that received no water from May 28 to July 11, and by August 14 it had appeared on all of the eight plots of series B that received no water from June 26 to July 31.

In a series of 12 plots in 1933 and 8 plots in 1934 which were abundantly supplied with water except for a period of 28 days late in July and early August, the disorder made a delayed appearance in a few plots but did not seriously affect the production of the plants.

In another series comprising 12 plots in 1933 and 8 in 1934, which received frequent and adequate irrigations throughout the fruiting season, the plants remained free from the disorder.

With cotton plants grown in iron barrels containing a highly calcareous soil, withholding water until the plants were stressed resulted in the appearance of crazy top in the new growth following the application of water. However, the disorder failed to appear on plants under the same treatment grown in barrels containing a sandy alluvial soil.

A reversal in irrigation treatments of cotton plants in containers during two consecutive seasons resulted in a reversal of crazy top occurrence. Plants provided with adequate water in 1934 remained free from crazy top in a drum containing the same soil in which plants were affected in 1933. In another drum, plants grown in the same

soil in which no plants were affected in 1933 developed the disorder when water was applied after a prolonged period of water shortage.

The results obtained in the irrigation experiments show that the incidence of crazy top was related in some way to the checking of the growth from water shortage and the resumption of growth when abundant moisture was restored.

It is not indicated, however, that water shortage is the only factor involved in bringing about the abnormalities characteristic of the disorder.

The information suggests the practicability of preventing crazy top on soils of this character by applying irrigation water with sufficient frequency to prohibit a checking of plant growth during the summer months.

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