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SUGAR-CANE ROOT DISEASE INVESTIGATIONS

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SUGAR CANE ROOT DISEASE.

By F. S. EARLE.

For several years past attention in Porto Rico has been so centered on the damage caused by the sugar cane Mosaic or Yellow Stripe disease that there is danger of overlooking the even more serious losses caused every year by the so-called root disease. This trouble is always with us. There is not a cane field in the Island that is not more or less affected by it. It is the cause of the dying out of the cane in so many fields that necessitates such frequent replantings. If it were not for root disease we would be today cutting twenty or thirty ratoon crops from each planting of cane as was done in the early days of the cane industry on this Island, and is still being done on virgin lands in eastern Cuba and in Santo Domingo. The expense of these frequent replantings is by no means the only loss caused by root disease. It is safe to say that one form or another of the troubles known under this collective name is causing a loss of tonnage on every acre of cane now growing in Porto Rico. Few cane planters who really understand these facts will question the statement that this is by far the most serious problem that confronts the cane growers not only in Porto Rico but on old lands in all parts of the sugar-cane-growing world. Unfortunately the question is very complex and obscure. There is probably no other plant disease of equal importance about which so little is really known and concerning which such erroneous ideas have long passed current in plant-disease literature. Some chance discoveries recently made in connection with studies of the cane mosaic have thrown new

light on this most important subject and it seems opportune at this time to attempt a review of the entire problem.

SYMPTOMS.

The symptoms of root disease are sufficiently well known to most cane planters, yet they are not easy to accurately define. In the earlier stages they amount to little more than the slowing down of the normal growth of the cane. They are exactly the symptoms that would be expected when cane is planted on old worn-out lands without proper fertilizers. In other words, they are the preliminary symptoms of mal-nutrition, a lack of vigorous growth and a paling or slight yellowing of the leaves from the dark-green characteristic of cane in full vigor. These symptoms will be accentuated in dry weather, especially if this follows a period of excessive rains or in spots that have suffered from insufficient drainage. Bad drainage always intensifies the trouble from root disease. If drouth continues the leaves will begin to roll up during the middle of the day on the worse-affected spots. Later the lower leaves will die prematurely but will usually still hang to the stalk not falling like normally matured leaves. The old leaf sheaths near the ground will often be found to be matted together and cemented to the stalk by a conspicuous white, mould-like fungus mycelium. Still later the tips and margins of the remaining living leaves will be seared and brown and the general color becomes quite yellow. When rains come this diseased cane may regain its color and continue to make some growth but it never regains full vigor. As maturity of the crop approaches another phase of the trouble presents itself. The terminal bud on the more feeble stalks dies and this is followed by the rotting of the soft terminal tissues. This "top rot" is well known and is often incidentally referred to in cane-disease literature but it has never been satisfactorily explained. Of course, a top rot, especially in young cane when it is usually referred to as "dead heart" is often caused by injuries from the moth borer (Diatræa). A top rot of young overshaded suckers is also often caused by the fungus *Sclerotium Rolfsii* which is everywhere present in cane fields. The top rot referred to above, however, comes from neither of these sources, but in the opinion of the author is the direct result and culmination of the symptoms that have so long been known under the collective name of "root disease." Soon after the dying of the top the black pustules of the fungus *Melanconium* appear on the stalk, usually

beginning at the top of the stalk, following up the work of the top rot, but sometimes first appearing near borer injuries or on sun-scalded areas, and "rind disease" finishes the work of destruction by completely rotting the stalk unless harvesting quickly follows the appearance of top rot. The losses sometimes following from top rot and rind disease, which is now to be considered as the final manifestation of "root disease," are clearly shown by the notes (see page 18) on the variety experiment at Santa Rita when as early as December 10, before most of the mills had begun grinding, some of the more susceptible varieties were a total loss and where in the 90 plots of the standard Rayada the estimates showed an average of 29.4 per cent of top-rot stalks. Finally, after a severe case of root disease the cane stubble fails to ratoon, or at best ratoons very poorly. Such stools must be dug out and replanted if a ratoon crop is expected. This replanting of ratoons is carefully attended to in Porto Rico where it is part of the usual plantation routine. In Cuba it is frequently neglected with the consequence that great vacant areas soon appear at the worst diseased spots in the field. These are locally known as "sabanas" and they increase in area from year to year till the field is finally abandoned and plowed up.

The symptoms of root disease may then be summarized as follows:

1st. A slowing down of growth and lack of vigor accompanied by a more or less pronounced yellowing of the leaves.

2nd. The rolling up of the leaves at mid-day during periods of drouth.

3d. The premature dying of the lower leaves which remain hanging on the stalk and usually by the cementing of the leaf sheaths by a white fungus mycelium.

4th. A leaf burn causing the dying and browning of the tips and margins.

5th. Top rot, the dying of the terminal bud, followed by a soft stinking rot of the soft growing tissues.

6th. Rind disease, the appearance on the stalks of *Melanconium* and other fungi causing the rotting of the stalk.

7th. Failure to ratoon.

HISTORICAL.

During the first half of the last century the cane variety variously known as Caña Blanca, Bourbon or Otaheite, came to be grown very extensively in practically all of the tropical sugar-producing countries. It is a variety particularly well adapted to the rich

porous soil of newly cleared forest or so-called virgin lands, where it grows with great rapidity, giving a heavy tonnage of cane which yields a good percentage of sugar and which has unusually good milling qualities. Unfortunately, however, its root system is not adapted to the conditions found in old compacted soils. In one sugar-producing country after another this variety has given down, often with an apparent suddenness that has caused a serious crisis in the sugar industry, and it has been necessary to replace it by kinds better adapted to the compacted condition of old partially exhausted soils and more resistant to the complex troubles usually known under the name of Root Disease. Such a crisis occurred in the islands of Mauritius and Bourbon as early as 1846. In Porto Rico the outbreak in the Mayagüez district of the so-called epidemic of 1872 was clearly a manfestation of root disease. Similar crisis have occurred in Jamaica and other of the British West Indies. In Java the problem was complicated by the presence of the Sereh disease and the Yellow Stripe or Mosaic but the present custom of taking no ratoon crops but replanting the field annually has clearly largely come from the effect of root disease. In Cuba the abandonment of the Caña Blanca has been equally complete on all of the older cane lands, but as such a great area of virgin land was available for new plantings no sudden crisis resulted from a forced change of varieties. Fields of Caña Blanca (Otaheite) may still be found on the new lands of Eastern Cuba, but even here it is being rapidly replaced by the Crystalina. In Porto Rico this variety which was once so universally planted has practically disappeared except in certain loamy irrigated soils of unusually good texture on the south coast and in limited areas of the richer hill lands of the interior. Even here it does not ratoon well but usually has to be replanted every year. The entire question of varietal resistance to root disease is so important that it will be discussed under a separate heading.

Wakker in Java seems to have been the first investigator to assign a definite cause to sugar cane root disease (Arch. V. Java Suikerindus, 1895). He found a small gill-fungus or mushroom growing on the trash at the base of diseased stalks which he considered to be the cause of the trouble. He named and described this fungus as *Marasmius sacchari* n. sp. His work has been accepted and followed by most subsequent investigators and to this day the terms root disease and Marasmius disease are used interchangeably in most publications on cane diseases.

During the years 1899–1902 Albert Howard was investigating sugar cane and other plant diseases for the Imperial Department of Agriculture of the West Indies with headquarters in Barbados. He seems to have been the first to identify our West Indian Root Disease as being identical with the trouble in Java. He found and identified *Marasmius sacchari* Wakker, and carried out a series of experiments that convinced him that it was the true cause of the trouble. In this he has been followed by Lewton-Brain, Bancroft, Tempany, Stockdale and other pathologists who have been connected with the British West Indian Department of Agriculture.

During the years 1904–1906 root disease was investigated in Cuba by Cook and Horne. They found an abundant white mycelium involving the bases of the old leaf sheaths, but during this period found no fruiting bodies of the *Marasmius*. (Estac. Agro. de Cuba Bull. 7, 13, 1907.) They did find, however, the fructifications of another Hymenomycetus fungus, *Peniophora* sp., which they suggested as a possible cause for the disease. This was not supported by experimental evidence.

In Circular 18 Horne refers to this fungus again as probably being *Hypochnus sacchari*. In the second report of the Cuban Station (Inf. Ann. Esta. Agr. de Cuba 2:81–, 1909, Horne again discusses root disease. He reports the finding of abundant fructifications of *Marasmius sacchari* Wakker in the fall of 1908 not only at the base of cane suffering from root disease but also on Johnson grass, Para grass and Guinea grass. He inclines to attribute the root disease to this fungus rather than to the *Peniophora* but again gives no experimental proofs.

In Hawaii in 1905 Lewton-Brain published as Bul. 2 of the Sugar Planters Experiment Station a paper entitled "Preliminary Notes on Root Disease in Hawaii." At this time he had not found fruiting bodies of Marasmius, but he considered the disease as identical with the West Indian root disease with which he was familiar in Barbados. The following year Marasmius fruiting bodies were found in connection with the root disease. These were named *Marasmius Sacchari var Hawaiiensis* by Cobb. (Sugar Station Bull. 5:214, 1906). In this same publication, which is entitled "Fungus Maladies of the Sugar Cane," Cobb describes at great length a stink-horn fungus which he calls *Ithyphallus coralloides* n. sp. and to which he ascribes the principal roll as cause of the root disease. The whole question was discussed and illustrated most elaborately but without one word

of proof to establish the causative relation of this fungus, which is one of the last that could reasonably be expected to be a parasite. Cobb's work has not been confirmed by other investigators, so this profusely illustrated paper may be dismissed as one of the curiosities of pathological literature.

In 1908 R. H. Fulton discussed root disease in Louisiana (Expt. Sta. Bull. 100). He ascribed it to a *Marasmius,* but to a different species which was determined as *M. plicatilis* Wakker.

In Porto Rico this disease has been extensively studied by both J. R. Johnston and J. A. Stevenson during the time of their connection with the Insular Experiment Station. In their joint paper on Sugar Cane Fungi and Diseases of Porto Rico (Jour. Dept. Agri. Porto Rico 1–(4) 1917) they enumerate and describe *Marasmius sacchari* Wakker, *Himantia Stellifera* Johnston sp. Nov., *Odontia saccharicola* Burt, *Odontia Sacchari* Burt and some other Hymenomycetous fungi as occurring at the base of cane stalks and apparently in connection with root disease, but they say (p. 189) "The exact status of root disease with respect to the parasitism of *Marasmius, Himantia, Odontia* or possibly other forms is uncertain, and while it is generally held that *Marasmius* at least is a true parasite, really definite evidence is lacking. Studies under controlled conditions must be carried out working with pure cultures of the fungi which has not yet been possible."

Stevenson in his more recent papers has used the term "Deterioration" to cover part of the symptoms that have been above described and has attempted to separate them from what he calls "Root Disease." This he considers as being caused by parasites, but as quoted above he does not consider it as proven that either *Marasmius* or the other conspicuous Hymenomycetes connected with the disease are its true cause.

In the *Hawaiian Planters Record* for July, 1919, Mr. H. L. Lyon has published a paper entitled "A Preliminary Report of the Root Rot Organism." In this paper he describes and figures an organism which he does not name but assigns to the *Chytridineæ* which he considers "the primary cause of the Lahaina disease (of cane) and pineapple wilt throughout these islands and perhaps in other tropical countries as well." The vegetative stage of this organism consists of small naked plasmodia either rounded or irregular and elongated, which occur two or more together in the same root cell. These plasmodia are believed to fuse and to then form either a sporangium or

a resting spore since these are uniformly found only one in each host cell. The sporangia soon give rise to motile zoospores. The resting spores are thick-walled globular bodies. They were kept under observation for several months but it had been impossible to induce them to germinate. They occur in the soft tissues of the root often near the growing point. When the presence of this organism causes the death of a root it is soon completely destroyed by secondary organisms.

The above hasty review of the literature of Root Disease is in no sense intended as a complete bibliography, but it is believed that it covers all of the different views that have been published regarding this disease, or as perhaps it had better be called this complex of diseases. It should be added that white grubs (*Lachnosternum*) and other root-eating insects often produce somewhat similar symptoms, the results to the cane being much the same whether the roots are killed by fungi or are eaten off by insects. A certain amount of such root insect injury is doubtless often included under the general name of root disease. Mealy bugs too (*Pseudococcus*) are very abundant in most cane fields and aid in creating that state of debility that accompanies the first stage of root disease.

The technical studies on certain organisms connected with root disease that are reported on another page of this publication by Mr. Matz represent a distinct advance in our knowledge of this most important complex of diseases. When Mr. Matz came to the Insular Station a little over a year ago the present writer took every occasion to impress on him the overshadowing importance of root disease as a sugar-cane problem and pointed out the entirely inadequate treatment of the question in plant-disease literature. He personally collected and brought to the laboratory much of the material on which these studies are based and has watched every step of the investigation with closest interest. He therefore feels competent to discuss the results and to express a decided opinion on the following points:

1st. *Marasmius* is at best a very feeble parasite. It may overrun new healthy roots or other organs without killing them. The same may be said of the so-called "stellate fungus" and of the other Hymenomycetes that form a conspicuous white mycelium on cane trash and at the base of cane stalks.

2nd. The killing of the roots which is so marked a feature in "root disease" is usually caused by various species of *Rhizoctonia* and sometimes by a species of *Pythium*. These are the well-known

causes of the damping off of seedlings and cause heavy losses in tobacco and vegetable seed beds but they have not before been connected with a disease of cane.[1] This seems most remarkable in view of the fact that some one of these species has been isolated from almost every diseased cane root from which cultures have been made and that in every case they have promptly killed every cane root on which pure cultures have been planted. Nothing could be more convincing than that these heretofore unsuspected species and not *Marasmius* and its allies are the true root-killing agents. We can only conclude that previous workers have done little in the way of making cultures from dying cane roots or they could have hardly failed to have detected these fungi which are so easily isolated and grown in artificial cultures.

This very satisfactorily clears up what may be considered as root disease proper, viz., the actual killing of the roots. The conditions under which this occurs and its relations to cultural practices will be discussed in another paragraph. The above organisms are all facultative parasites, and as such may be controlled at least to some extent by cultural methods.

3d. The finding of a strict parasite within the vascular bundles of cane suffering from root disease was an entirely accidental and unexpected result from some anatomical studies of cane tissues made in connection with the investigation of the sugar-cane Mosaic (see Journ. Dept. of Agr. Porto Rico, Vol. III, 4, Oct. 1919). At first it

[1] Since the above was written Hawaii Federal Station Press Bulletin 54 (issued December 9, 1919) has been received. It is by C. W. Carpenter and is entitled "Preliminary Report on Root Rot in Hawaii." In this interesting paper Mr. Carpenter attributes the root rot of cane, Taro, bananas and rice and the wilt of pineapples in Hawaii all to the action of a species of Pythium which he considers as probably P. DeBaryanum. In discussing Lyon's paper he expresses the opinion that the resting spores found by the latter in cane and pineapple roots are in reality the oospoers of this *Pythium*. Oospores have been produced abundantly in Mr. Matz's cultures here of *Pythium* from diseased cane roots. They certainly strikingly resemble the bodies figured by Lyon but they are always accompanied by a conspicuous mycelium. Furthermore, they germinate readily. These facts make us doubtful whether or not Carpenter and Lyon are discussing two distinct organisms. Mr. Carpenter's paper, however, corroborates Mr. Matz's conclusion that *Pythium* is one of the active agents in killing cane roots.

A review of additional literature not accessible when the above note and paragraph was written shows that Pythium has long been konwn to attack cane roots. In discussing the Sereh disease in Java. Dr. M. Treub in 1885 (Med. Slands Plant, Buitenzorg 2: 30–35, 1885) refers at some length to *Pythium* on the roots as a possible cause. In 1896 Dr. J. H. Wakker in a paper entitled De Schimmels in de Wortels van Het Suikerriet (Med. Proefs. Oost–Java (n. series) 21,) gives a fine plate and a long discussion of *Pythium* as the cause of the killing of cane roots. The more conspicuous *Marasmius* seems, however, to have attracted his attention more strongly as it has that of most subsequent investigators and no subsequent mention of *Pythium* as a cane fungus has been found in the literature until that of Carpenter as mentioned above.

was thought that this organism might have some connection with the mosaic disease since it was originally discovered in the tissues of an advanced case of mosaic. Later, however, it was found not once, but very many times and from widely different localities in cane that was suffering from root disease but that was absolutely free from mosaic. The evidence is conclusive that this organism is connected with the former disease but not with the latter.

Its life history has not been fully worked out. The vegetative stage consists of a yellow plasmodium which occupies the larger vessels of the vascular bundles often completely filling them for considerable distances. Infected bundles may be easily detected with a hand lense, or even with the naked eye, in either cross or longitudinal cuts on account of their peculiar orange-yellow color. This is quite distinct from the reddening of the bundles that so often accompanies any mechanical injury. These plugged bundles are more abundant near the base of the cane, especially in the part which develops below ground, but they have also been found in the roots, and they can often be traced for long distances up into the cane, occasionally, in mature cane, almost to the terminal bud.

This plasma is multi-nucleate. After a time each nucleus surrounds itself with a rounded mass of the cytoplasm and begins to divide first into two, then into four, and finally into a mass of dense granules. At the same time a cell wall is being formed and the result is a globose, thick-walled resting spore. The cell wall is smooth and hyaline, but the content is so densely granular that the spore is dark and opaque. They are produced in great numbers and remain imbedded in the cytoplasm, which finally becomes somewhat hardened and gum-like. So far these spores have resisted all attempts to germinate them. The remainder of the life-history can therefore only be conjectured. It seems most probable that when these infected canes and cane stubbles rot in the soil these resting spores are liberated and in their own good time germinate probably by the formation of motile zoospores. These probably find their way into new cane roots and thus start the infection of other canes. It is evident also that when infected canes are cut up and used as seed for new plantings that the disease could be propagated in the new field by the continued growth of the original plasma.

If the above hypothesis is correct and these resting spores do break up into motile zoospores the organism would have to be classed among the *Myxomycetes* or Slime moulds. The only recognized

genus to which it could be referred would be *Plasmodiophora*. It differs from the known species of this genus in the much larger size of the spores and in the fact that it causes no enlargement or distortion of the cells of the host. It seems best to withhold a final opinion as to its name and systematic position until its life history has been more fully determined.

The resting spores of this organism are so very similar to those figured and described by Lyon for the supposed Chytridiaceous fungus discovered by him as a cause of root disease in the Hawaiian Island that it was at first assumed that we had found the same organism. This, however, can hardly be the case. We have found nothing resembling the sporangia and definitely formed plasmodia which he figures. The resting spores of his organism occur singly in the parenchyma cells of the young roots and the epispore is irregularly thickened. Our organism is in the vascular bundles, not the parenchyma. The plasmodium is indefinitely continuous, often for a distance of many centimeters. The numerous resting spores have a smooth cell wall of equal thickness throughout. It seems clear that this organism belongs in the Slime moulds and not in the *Chytridiaceæ*. It is, however, remarkable that two such similar but distinct organisms are causing serious damage to sugar cane in different parts of the world and that both had so long escaped detection.[1]

It is not possible as yet to express a fixed opinion as to the damage being done by this vascular bundle parasite, nor as to its exact roll in the complex we are considering under the name of "root disease." It is not probable that it is an active agent in the actual killing of roots. In fact, it is quite certain that this is not the case. The actual root killers are facultative parasites and as such their action is largely inhibited when the cane is in full vigor. The bundles fungus is doubtless one of the many contributing causes to lack of vigor and thus may be indirectly responsible for loss of roots. Whether its action is merely mechanical, simply resulting in the plugging of the bundles it occupies, or whether it may secrete injurious substances we do not know. If the former, an occasional plugged bundle will cause little or no harm, but if many of the bundles are invaded the result would inevitably be the rolling up and withering of the leaves and finally the death of the terminal bud. It seems probable, therefore, that this bundle fungus is core-

[1] See note on page 10.

lated with the baffling condition known as "top rot" rather than with "root rot" proper.

Whatever the damage it may be doing it is widely scattered in Porto Rico, having been found in every cane-growing district where a search has been made for it. It is interesting to note that the old Caña Blanca (Otaheite or Lahaina) is particularly susceptible to it. It was found to be very abundant in the few stalks of this kind that have survived in the experimental plots at the Mayagüez Station where it had been interplanted among the other kinds as a check and where it practically all failed to ratoon at the end of the first year. This particular field, by the way, is said to be the one where the famous epidemic of 1872 first made its appearance. This may be only a coincidence, but it at least suggests this as one of the factors in that outbreak.

The habit of growth of this fungus makes it certain that it has been widely transported in seed cane. It therefore probably has a wide distribution in all cane-growing countries. It should certainly be carefully searched for by all investigators. Its presence indicates the great unwisdom of taking seed cane from old, neglected fields where it is quite certain to be more abundant than in new plantings. It also probably explains the better results usually obtained from planting "top seed" since it is comparatively rare for this organism to reach the top joints of the cane. Where the entire cane is used for planting the butt cut should certainly be rejected since this is much more likely to be infected.

4th. The above discussion throws light on the much-discussed problem of "top rot."[1] It seems entirely probable that this bundle inhabiting, *Plasmodiophora*-like organism is the original cause of "top rot," aided, of course, by the root-killing fungi and the other factors of "root disease" that unite to lower the vitality of the cane. The writer is well aware that no positive proof has been given as to the casual agency of the bundle fungus in producing "top rot." He only wishes to point out the strong probability that this is the fact.

In cases of "top rot" the withering leaves of the terminal bud spindle soon show numerous, scattered, minute black specks which

[1] Since the above was written the Gumming disease or Sugar Cane Gomosis has been found in Porto Rico. (See J. Matz, Insular Station Circ. 20, 1920.) This also causes a top rot, but such cases can be distinguished by the flow of gum from cut surfaces of the stalks.

under the microscope prove to be the fruiting bodies of some fungus. As noted by Stevenson in his discussion of "wither tip," (Jour. Dept. Agr. Porto Rico 1: 207.) This usually is found to be either *Sphærella sacchari* Speg. or *Periconia sacchari* Johnston.

At about the time that these fungus specks become visible a stinking bacterial rot occurs in the soft tissue about the growing point. This rot only involves the soft tissues. Sometimes the disease is checked at this point, the rotted top falling away while the joints below remain sound, the lateral buds soon pushing into new shoots. More often, however, the black pustules of "rind disease" appear on the joints below the rotten tip and this soon completes the destruction of the stalk.

Clearly these bacteria and fungi so uniformly associated with "top rot" are saprophytes and agents of decay but it is very probable that they are also facultative parasites and are able to attack cane tops that have been weakened by other causes without waiting for death to occur. This point needs further study. Whether the fungi or the bacteria or both are real killing agents has not been determined. In any event it seems certain that they cannot attack cane that is in full vigor and health.

Many references occur in the literature to a supposed bacterial top rot of cane but no proof exists that there is a specific disease of this nature apart from the fact that bacteria are always present in the soft, rotting tissue.[1] The whole subject needs much careful investigation. The above discussion is intended to be suggestive rather than final.

5th. In the prceeding paragraph the statement is made that "rind disease" usually sets in to complete the work of destruction caused by "top rot," the predisposing causes for this last condition being here held to be "root rot" and the presence of the bundle inhabiting *Plasmodiophora*-like organism. The "rind disease" here referred to is assumed to be caused by *Melanconium sacchari* Mass. The discussion of this fungus in plant-disease literature has been involved with many needless and really inexcusable errors. It seems clear that this fungus has nothing to do with either *Trichosphæria, Thielavioposis, Diplodia* or *Colletotrichum,* although eminent mycolo-

[1] Mr. Noel Deerr has informed the writer that a contagious bacterial top rot exists in Demorara but his studies regarding it have not been published.

gists have frequently expressed a contrary opinion. This is a very common saprophyte, growing everywhere on dead cane trash. It is not an active parasite but can attack enfeebled cane tissue before it is quite dead. It often follows borer injuries but in these cases seldom is able to pass the nodes being confined to the one injured joint. Where canes have been so weakened by "root disease" that they have fallen a victim to "top rot" the vitality is so lowered that the *Melanconium* is usually able to quickly invade and destroy the entire cane.

Varieties differ greatly in their power of resisting "rind disease," the Otaheite or Caña Blanca being particularly susceptible. This question will be further discussed in a subsequent paragraph.

To what extent the "red rot" caused by *Colletotrichum falcatum* Went. has been confused with "rind disease" it is not easy to determine, especially since they often occur together, in which case this fungus is likely to be overlooked, being obscured by the more conspicuous *Melanconium*. Apparently, *Colletotrichum* is not as injurious here as in many other cane-growing countries. It is, however, known to occur and Stevenson reports the presence of three other unnamed forms of this genus as occurring on sugar cane in Porto Rico. Their distribution and economic importance should be given careful study.

6th. *Failure to ratoon.*—Cane suffering from the advanced stages of "root disease" (including "top rot" and "rind disease") seldom ratoons well and in many cases fails entirely, thus causing the necessity for the early abandonment of the planting. This represents an even greater financial loss than the yearly shortage in tonnage. It may be considered as the final culmination of this series of disasters. It completes the picture of the complex of trouble as we now understand them that are grouped under the comprehensive name of "Sugar Cane Root Disease."

THE RESISTANCE OF CANE VARIETIES TO ROOT DISEASE.

Ever since root disease was first recognized it has been noted that different varieties were very differently affected by it, some being very susceptable while others were comparatively resistant. The old favorite Otaheite, Caña Blanca, Bourbon or Lahaina as it has been variously called, has always suffered more severely than any other

kind in general cultivation. It seems to be particularly susceptible to all phases of this complex of maladies. Its root system is delicate, and while well adapted to rich porous lands that are well supplied with humus it quickly succumbs to the attacks of *Rhizoctonia, Pythium* and other root-killing fungi when the soil becomes old and compacted. It was never a strong ratooner and on unfavorable soils it often completely fails to ratoon even after the first cutting. In addition it proves to be a favored host for the vascular bundle fungus that has been above described and the stalks are particularly susceptible to the *Colletotrichum* red rot and to the *Melanconium* rind disease. One or another of these troubles or a combination of them has caused its failure and abandonment in practically all cane-growing countries. The opinion has been widely expressed that this variety was degenerating. The facts, however, do not support this idea. Where all conditions are favorable it grows with its old-time vigor. It is simply a susceptible variety only adapted to a narrow range of conditions. It is the old, long-cultivated soils that have deteriorated and not the Otaheite cane.

It was the failure, often the sudden and disastrous failure, of this old favorite that first forced serious attention on other kinds and that has lead in so many countries to the extensive production of new seedling varieties. Many of these new kinds have come to be extensively planted. In fact, the sugar industry of many regions is now based almost entirely on some of these new kinds. Their success has been almost entirely due to their resistance to root disease. It is a remarkable fact that among the multitude of new kinds produced and tested so few have surpassed or even equaled the old standard varieties in sucrose content and purity. New kinds are everywhere pushing out the old standard kinds, Otaheite, Crystalina, Rayada and Morada (purple), not because they are richer, better milling canes but because they are more resistant to root disease and so give better tonnage for a longer series of years.

Much attention has been given to this subject in the British West Indies and the reports from the different agricultural stations there are filled with notes on the resistance or susceptibility to the root disease of different varieties in different localities and different seasons. In the publications of the Porto Rican Stations casual mention can be found regarding the resistance of various kinds but no comprehensive study of the question seems to have been made under

our local conditions. A coöperative planting of 171 varieties made at Santa Rita, Guánica, in the irrigated district on the south side of the Island, for the purpose of testing their resistance or susceptibility to the Sugar Cane Mosaic, has been reported on in Bulletin 19 of the Insular Station. At the time of the last inspection reported in this bulletin, August 10, 1919, it was evident that some kinds were not doing as well as others aside from the effects of the mosaic infection.

It was suspected then that root disease was also at work, but as yet it was only in the preliminary stages, no signs of "top rot" or "rind disease" having appeared. Subsequent visits showed that the combined effect of the root disease and the mosaic were going to result in heavy losses from "top rot." It is not considered that the mosaic was in any sense a primary cause of this top rot. Its presence was simply one more factor in lowering vitality of the cane. Some white grubs (*Lachnosterna*) were also present and helped to secure the total injury which ended in disaster for most of the kinds in these plots.

Rhizoctonia had been isolated from cane roots from this field early in the season and it was found that many of the canes were infected by the vascular bundle parasite. On December 10, 1919, about the time when Central Guánica is usually actively grinding the *gran cultura* plantings, a final inspection was made and the per cent of "top-rot" stalks in each row was estimated. It will be remembered that every third row in these plots was planted with Rayada seed infected with Mosaic in order to insure the equal exposure of the other kinds to that disease. There were 90 of these Rayada plots. The per cent of "top rot" was estimated in each of these. In 8 of them it was placed as low as 5 per cent. One was a complete loss, 100 per cent. The average of the estimated loss on the 90 plots was 29.4 per cent, so that figure is given in the following table. Twenty-six kinds had been cut for seed and had ratooned, so notes could only be taken on the condition of the ratoons. It is to be presumed that most of these kinds would have shown good resistance to the root disease had they been standing. Most of the top-rotted canes had developed rind disease and were fast becoming a total loss. The average condition of the field was deplorable, though it was planted on very fine land and had had the best of irrigation and cultivation.

Table Showing Resistance and Susceptibility to Root Disease in the Santa Rita Variety Experiment.

Name of variety.	Estimated per cent top rot.	General conditions.
Cavengerie	Cut for seed	Stand and condition ratoons only fair.
Crystalina	20 per cent	Poor.
Fortuna seedling	4 per cent	Very good.
Karandali (Calancana)	Vacant	
Kavangire	No top rot	Decidedly best condition and heaviest tonnage.
Otaheite	70 per cent	Very poor.
Rayada	29.4 per cent	Average poor.
S. Seedling (= B-3412)	5 per cent	Very good.
White Transparent (= Crystalina).	20 per cent	Fair.
Yellow Caledonia	Mostly dead from Mosaic.	Two remaining stools very good.

BARBADOS SEEDLINGS.

Name of variety.	Estimated per cent top rot.	General conditions.
B-109	Cut for seed	Stand of ratoons fair, condition good.
B-208	10 per cent	Fairly good.
B-376	20 per cent	Fair.
B-1355	10 per cent	Good.
B-3390	Vacant	
B-3412	10 per cent	Fair.
B-3578	5 per cent	Very good.
B-3669	Mostly dead	Poor.
B-3859	Cut for seed	Ratoons only fair.
B-3922	5 per cent	Fair.
B-4028	Vacant	
B-4596	No top rot	Very good.
B-6048	No top rot	Only two hills fair.
B-6292	20 per cent	Fairly good.
B-6450	4 per cent	Very good.
B-6536	15 per cent	Fair.
B-7168	Vacant	

DEMERARA SEEDLINGS.

Name of variety.	Estimated per cent top rot.	General conditions.
D-109	20 per cent	Fair.
D-117	15 per cent	Fair.
D-357	30 per cent	Fair.
D-433	Cut for seed	Ratoons only fair.
D-504	Vacant	

Table Showing Resistance and Susceptibility to Root Disease in the Santa Rita Variety Experiment—Continued.

CENTRAL FAJARDO SEEDLINGS.

Name of variety.	Estimated per cent top rot.	General conditions.
F. C. 79	5 per cent	Very good.
F. C. 84	5 per cent	Good.
F. C. 86	4 per cent	Good.
F. C. 88	10 per cent	Fair.
F. C. 90	5 per cent	Good.
F. C. 95	Cut for seed	Ratoons, stand fair, condition good.
F. C. 97	10 per cent	Good.
F. C. 98	Only two stools living	Poor.
F. C. 99	60 per cent	Very poor.
F. C. 101	5 per cent	Good.
F. C. 104	Cut for seed	Ratoons only fair.
F. C. 103	5 per cent	Good.
F. C. 110	30 per cent	Very poor.
F. C. 114	40 per cent	Poor.
F. C. 129	5 per cent	Good.
F. C. 131	5 per cent	Good.
F. C. 133	Cut for seed	Ratoons good stand and condition.
F. C. 136	30 per cent	Poor.
F. C. 137	Only one stool living	Fair.
F. C. 140	5 per cent	Fair.
F. C. 148	40 per cent	Poor.
F. C. 155	Only two stools living	Fair.
F. C. 158	5 per cent	Good.
F. C. 163	10 per cent	Good.
F. C. 170		Fair.
F. C. 171	30 per cent	Fair.
F. C. 174	40 per cent	Poor.
F. C. 178	Cut for seed	Ratoons only fair.
F. C. 188	2 per cent	Good.
F. C. 193	2 per cent	Very good.
F. C. 194	5 per cent	Good.
F. C. 197		Fair.
F. C. 199	Cut for seed	Ratoons good stand and condition.
F. C. 200	100 per cent	Complete loss.
F. C. 202	Cut for seed	Ratoons only fair.
F. C. 204	Cut for seed	Ratoons only fair.
F. C. 205	Only one stool	Fair.
F. C. 214	No top rot	Very good.
F. C. 225	10 per cent	Fair.
F. C. 226	5 per cent	Fair.

Table Showing Resistance and Susceptibility to Root Disease in the Santa Rita Variety Experiment—Continued.

CENTRAL FAJARDO SEEDLINGS—Continued.

Name of variety.	Estimated per cent top rot.	General conditions.
F. C. 230	10 per cent	Fair.
F. C. 231	40 per cent	Poor.
F. C. 233	50 per cent	Poor.
F. C. 239	Cut for seed	Ratoons only fair.
F. C. 246	10 per cent	Fair.
F. C. 249		Fair.
F. C. 260	50 per cent	Poor.
F. C. 277	Cut for seed	Ratoons good stand and condition.
F. C. 279	20 per cent	Poor.
F. C. 280	10 per cent	Fair.
F. C. 281	5 per cent	Good.
F. C. 292	50 per cent	Poor.
F. C. 299	30 per cent	Poor.
F. C. 303	10 per cent	Fair.
F. C. 305	Only one stool living	Fair.
F. C. 306	40 per cent	Poor.
F. C. 308	5 per cent	Good.
F. C. 312	5 per cent	Very good.
F. C. 317	5 per cent	Good.
F. C. 322	Cut for seed	Ratoons good stand and condition.

GUANICA CENTRAL SEEDLINGS.

Name of variety.	Estimated per cent top rot.	General conditions.
G. C. 47	4 per cent	Good.
G. C. 127	No top rot	Very good.
G. C. 149	2 per cent	Very good.
G. C. 425	10 per cent	Good.
G. C. 426	5 per cent	Good.
G. C. 434	5 per cent	Good.
G. C. 469	2 per cent	Good.
G. C. 490	20 per cent	Fair.
G. C. 493	4 per cent	Good.
G. C. 606	Cut for seed	Ratoons poor stand, fairly good condition.
G. C. 629	60 per cent	Very poor.
G. C. 698	20 per cent	Fair.
G. C. 701	Cut for seed	Ratoons full stand, fair condition.
G. C. 888	2 per cent	Very good.

Table Showing Resistance and Susceptibility to Root Disease in the Santa Rita Variety Experiment—Continued.

GUANICA CENTRAL SEEDLINGS—Continued.

Name of variety.	Estimated per cent top rot.	General conditions.
G. C. 908	15 per cent	Good.
G. C. 928	10 per cent	Good.
G. C. 949	20 per cent	Fair.
G. C. 1060	4 per cent	Good.
G. C. 1180	30 per cent	Fair.
G. C. 1246	10 per cent	Good.
G. C. 1254	2 per cent	Very good.
G. C. 1313	Cut for seed	Ratoons good stand, fair condition.
G. G. 1332	10 per cent	Good.
G. C. 1346	10 per cent	Fair.
G. C. 1358	30 per cent	Poor.
G. C. 1441	10 per cent	Good.
G. C. 1454	100 per cent	Complete loss.
G. C. 1480	10 per cent	Good.
G. C. 1482	95 per cent	Very poor.
G. C. 1484	10 per cent	Fair.
G. C. 1485	20 per cent	Fair.
G. C. 1486	Cut for seed	Ratoons good stand and condition.
G. C. 1486 (2nd lot)	4 per cent	Very good.
G. C. 1487	50 per cent	Poor.
G. C. 1489	50 per cent	Very poor.
G. C. 1495	20 per cent	Fair.
G. C. 1504	Cut for seed	Ratoons poor stand, only fair condition.
G. C. 1508	30 per cent	Poor.
G. C. 1509	10 per cent	Fair.
G. C. 1511	20 per cent	Poor.
G. C. 1513	Cut for seed	Ratoons good stand, fair condition.
G. C. 1515	10 per cent	Good.
G. C. 1517	5 per cent	Good.
G. C. 1518	Cut for seed	Ratoons good stand and condition.
G. C. 1519	20 per cent	Poor.
G. C. 1521	Cut for seed	Ratoons only fair stand and condition.
G. C. 1522	2 per cent	Very good.
G. C. 1523	60 per cent	Very poor.
G. C. 1524	50 per cent	Very poor.
G. C. 1526	50 per cent	Very poor.
G. C. 1527	4 per cent	Good.

Table Showing Resistance and Susceptibility to Root Disease in the Santa Rita Variety Experiment—Continued.

GUANICA CENTRAL SEEDLINGS—Continued.

Name of variety.	Estimated per cent top rot.	General conditions.
G. C. 1530	50 per cent	Very poor.
G. C. 1531	95 per cent	Lost.
G. C. 1533	50 per cent	Poor.
G. C. 1534	50 per cent	Very poor.
G. C. 1535	10 per cent	Poor.
G. C. 1536	80 per cent	Very poor.
G. C. 1537	10 per cent	Poor.
G. C. 1538	3 per cent	Good.
G. C. 1539	No top rot	Very good.
G. C. 1540	1 per cent	Good.
G. C. 1541	30 per cent	Poor.
G. C. 1542	100 per cent	Complete loss.
G. C. 1544	4 per cent	Good.
G. C. 1545	Cut for seed	Ratoons full stand, fair condition.
G. C. 1546	30 per cent	Poor.
G. C. 1547	50 per cent	Very poor.
G. C. 1548	4 per cent	Good.

JAVA SEEDLINGS, P. O. J.

Name of variety.	Estimated per cent top rot.	General conditions.
Java 36 P. O. J.	Cut for seed	Ratoons stand perfect, condition best.
Java 228 P. O. J.	20 per cent	Very good.
Java 234 P. O. J.	Cut for seed	Ratoons stand perfect, condition best.

PORTO RICO SEEDLINGS.

Name of variety.	Estimated per cent top rot.	General conditions.
P. R. 68	20 per cent	Poor.
P. R. 208	20 per cent	Fair.
P. R. 209	50 per cent	Poor.
P. R. 210	10 per cent	Good.
P. R. 226	10 per cent	Fair.
P. R. 260	Cut for seed	Ratoons only fair stand and condition.
P. R. 270	50 per cent	Poor.
P. R. 292	5 per cent	Very good.
P. R. 317	5 per cent	Fair.
P. R. 318	10 per cent	Good.

In discussing the above table it must be borne in mind that practically all of this cane, excepting only the Kavangire, was heavily infected with Mosaic, which by lowering its vitality had greatly contributed to this disastrous result. It is considered, however, that this has only accentuated the effects of the root disease and has brought out with unusual clearness the resistance or susceptibility of these different kinds. The 26 kinds cut for seed in September were those considered most promising by the Agricultural Staff of Guánica. Had they remained standing they would doubtless all appear in the resistant lists. It is known from two seasons' observations at the Mayagüez Experiment Station that Java 36 and Java 234 are almost equally as resistant to root disease as the Kavangire. These three clearly make a class apart in their almost complete immunity to root disease and in their great ratooning power. It will be noted that the Kavangire is of straight North Indian blood while the other two are hybrids with another North Indian cane, the Chunnee, as staminate parent. The so-called Egyptian cane (see Bulletin 19, p. 15) is probably Java 105 P. O. J., and if so is another of this set of hybrids. It promises to be equally resistant with the others but unfortunately it was not included in this experiment: we therefore have—

LIST 1.—*Varieties practically immune to root disease.*

Kavangire	Java 105 P. O. J. "Egyptian".
Java 36 P. O. J.	Java 234 P. O. J.

Of the remaining broad-leaved canes there are only four which showed no cases of top rot.

LIST 2.—*Highly resistant varieties, showing no top rot.*

B. 4596	G. C. 127
F. C. 214	G. C. 1539

LIST 3.—*Resistant varieties showing general good conditions and only 2 per cent to 5 per cent of the top rot.*

B. 3578	G. C. 1254
B. 6450	G. C. 1486
F. C. 79	G. C. 1491
F. C. 193	G. C. 1522
F. C. 312	Java 228 P. O. J.
Fortuna Seedling	P. R. 292
G. C. 888	Sealey Seedling

The kinds cut for seed and which would probably have fallen in either 2 or 3 follow, as—

LIST 4.—*Varieties cut for seed, probably resistant.*

B–109
B–3859
Cavangerie
D–433
F. C. 95
F. C. 104
F. C. 133 * *
F. C. 178
F. C. 199 * *
F. C. 202
F. C. 204
F. C. 239
F. C. 277 * *
F. C. 322 * *
G. C. 606
G. C. 701 *
G. C. 1313 *
G. C. 1486 * *
G. C. 1504
G. C. 1513 *
G. C. 1518 * *
G. C. 1521
G. C. 1545 *
P. R. 260

Those marked with an "*" in the above list show a complete stand of ratoons, those with "* *" have a complete stand and show superior vigor.

These lists include the only kinds that would have made a satisfactory commercial crop under the trying conditions of this experiment. The others grade all the way from a 15 per cent or 20 per cent reduction in crop to a complete loss. But for its extreme susceptibility to Mosaic disease Yellow Caledonia would assuredly have been found in one of these lists since it has very considerable resistance to root disease. This table should have a great practical interest for every cane grower in Porto Rico since it illustrates so forcibly the supreme importance of selecting the proper variety for planting in order to avoid very serious possible losses. It is seldom that circumstances combine to produce such striking results as were given by this experiment, but on the other hand there can be no question but that root disease is exacting a heavy toll in practically every cane field in the Island.

One of the most impressive lessons from this experiment is the outstanding superiority in resistance of the canes of North Indian parentage. Kobus in Java seems to be the only cane breeder who has realized and taken advantage of this most important fact. The continued indiscriminate breeding of new seedlings of the ordinary broad-leaved tropical type of canes does not seem to be leading to any advantage. Crossing a vigorous North Indian cane like Kavangire on the Crystalina which represents the best of the rich-juiced, broad-leaved tropical canes should lead to much more favorable re-

sults. Such crosses could be easily made by simply planting the two kinds in adjoining rows since the Crystalina is usually sterile to its own pollen. The present writer is only temporarily in Porto Rico. It is unlikely that he will ever have the opportunity to undertake cane breeding, but he strongly urges this cross on the attention of those who do continue in this work.

REMEDIAL MEASURES AGAINST ROOT DISEASE.

It is clear from the discussion under the last heading that the planting of resistant varieties is likely to prove the most effective remedial measure. It is also clear that the varieties descended from the slender, narrow-leaved North Indian canes show greater resistance to this complex of troubles than the stouter, sweeter, broad-leaved tropical kinds, though many of these last show very satisfactory resistance.

Making a complete change in variety is often difficult and it may be costly. It always takes considerable time. It must be admitted, too, that none of the resistant kinds so far tested are really equal to Crystalina and Rayada as desirable milling canes. It is of great practical importance, therefore, to consider what other remedial measures are possible and how satisfactory they have proven in actual practice.

It must be remembered that so far as we know all of the organisms that cause injuries in connection with this disease, with the one exception of the vascular bundle fungus, are facultative parasites. That is, they cannot attack tissues that are in vigorous growth but only those that have become weakened from some cause or that have reached such a state of over maturity or senility that the vital processes are lowered. All of the root killers and all of the organisms found in the dead tops and in rind disease and red rot belong in this category. It is a fact of general knowledge that diseases caused by facultative parasites are as a rule best controlled by improved cultural methods. Cane-root disease is no exception. The more abundant use of properly balanced fertilizers; careful attention to drainage where needed as well as the avoidance of unnecessary ditching; most important of all in Porto Rico, sufficient cultivation with implements to keep the soil open and porous and to prevent crusting; and the use of irrigation when soil or climate conditions demand it will go far to prevent the enormous losses now caused by this complex of diseases. On the contrary, the factors

that contribute most largely to these losses are lack of fertility, lack of suitable drainage, hard, compacted, unworked soils, severe drouths, and injuries from insects or other diseases such as white grub, mealy bug or Mosaic. The author's experience in Porto Rico is limited, but he has observed innumerable instances in Cuba on old lands so exhausted that cane plantings run out after two or three light cuttings, where a reasonable annual application of fertilizer and good cultivation has not only resulted in considerably increased crops at the first cuttings but has prolonged the life of the fields from two or three to eight or ten years. He has published in Circular 19 (Oct., 1905) of the Estación Agronómica de Cuba a photograph showing on the one side a vigorous field of ratoons going to their fourth cutting and on the other a grass field with one lone remaining stalk of cane. Both lots were planted at the same time. The one only showing grass was not fertilized, the other received 500 pounds per acre of a complete chemical fertilizer when planted but it had not been fertilized since, the residual effect of the one application still keeping the cane in comparatively good health and vigor while the unfertilized cane had entirely disappeared. This was undoubtedly an unusual case but it clearly illustrates the point under discussion, which is that a large percentage of the annual losses from root disease are easily preventable by following the simple agricultural practices mentioned in Circular 17 of this Station.

Unfortunately, the finding of a true parasite, the vascular bundle fungus, shows that not all of the losses can be prevented in this simple manner. Our studies so far do not indicate how serious a factor this may prove to be in the general complex, but it is entirely unlikely that it can be controlled by cultural methods. In the variety experiment at Santa Rita, the results of which have been already discussed, this organism was frequently found. The disaster which overtook that field notwithstanding fairly good cultural conditions seemed to depend on the complication with the severe infection of Mosaic disease rather than on the presence of this organism. The Mosaic disease by its influence in reducing vitality and inducing premature maturity is a factor exactly fitted to promote injury from root disease.

Aside from the selection of resistant varieties and the use of reasonably good cultural methods, one other point requires attention, and that is proper selection and handling of seed cane. The bundle fungus is undoubtedly transported and planted in the seed. There

is less danger of this where top seed is planted and less danger when young plant cane is used than with old ratoons. In planting the entire cane for seed as in *gran cultura* the butt-cut should be rejected, as this is more likely to carry the bundle fungus and besides the bottom leaf sheaths are likely to be matted by the mycelium of *Marasmius* and other undesirable fungi. The seed cane, too, should be inspected and the butts should be cut off in the field where cut. The common practice of hauling the cane to the side of the new field and doing this work there is objectionable since it leaves the infected butts and discarded canes on the border of the new field with every chance for infecting it.

Dipping seed cane in Bordeaux mixture will have little or no effect in preventing root disease. This treatment serves to protect the seed piece from the entrance of the pineapple-rot fungus (*Thielaviopsis*) or other rot-producing organisms. It can have no effect on the bundle fungus and will have little or no effect in preventing root killing by *Rhizoctocnia, Pythium* or other facultative parasites.

SUMMARY.

1st. Root disease as here understood is a complex including phases often known as Root Rot, Wither Tip, Top Rot and Rind Disease. These phenomena are caused by a number of facultative parasites, none of which attack actively growing vigorous tissues. There is also a heretofore unknown true parasite inhabiting the vascular bundles. *Rhizoctonia* and *Pythium* are the usual root-killing agents rather than *Marasmius* and *Himantia*.

2d. Cane varieties differ greatly in their resistance or susceptibility to Root Disease. The Otaheite or Caña Blanca is very susceptible. North Indian canes like Kavangire and those with part North Indian parentage are very resistant or practically immune.

3d. Remedial or preventive measures include—

A. The planting of resistant varieties.

B. Better cultural methods to overcome facultative parasites.

C. Proper seed selection and handling.