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DISEASES OF TARO IN HAWAII AND THEIR CONTROL

With Notes on Field Production

by

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INTRODUCTION

In Hawaii taro is grown either submerged (wetland taro) on muck or heavy clay soil, or nonsubmerged (upland taro) on clay loam or sandy loam soil. Wetland taro is produced in valleys which extend from sea level to the base of the mountains, with irrigation water obtained from the uplands; upland taro grows at the higher levels, usually in regions of 70 inches or more of rain per annum. Most of the taro in Hawaii is produced under wetland culture.

The plant, *Colocasia esculenta* Schott, adequately described by Whitney et al. (*10*),[1] is subject to a number of diseases which attack either the corm and root or the leaf, and cause appreciable losses. Many of these diseases are best controlled by a proper understanding and appreciation of the culture and care of the plant. Wetland taro is particularly subject to corm and root diseases, but upland taro is singularly free from subterranean attacks. Of the two serious leaf spots, one is apparently limited to upland taro, the other is severe on wetland taro but occasionally attacks upland taro in rainy areas or seasons.

PRODUCTION AND CARE OF TARO

Wetland Taro

The Soil

Taro is cultivated in square or rectangular patches of varying sizes, each patch surrounded by a dike which contains appropriate openings for the entrance and exit of the irrigation water. Taro growers drain and plow their land as soon as possible after harvesting and leave the soil exposed, without submergence, for 3 weeks to 1 month before running in the irrigation water, followed by puddling of the soil and planting.

The Irrigation Water

Water is generally admitted into the well-plowed taro patch and left standing for 1 to 3 weeks in order for the soil to become puddled. After the taro is planted, the water is shut off until the plant has formed roots and produced 4 or 5 leaves, a period of several months. Sometimes the soil has become so dry that large

[1]Reference is made by number *(italic)* to Literature Cited, p. 29.

cracks appear in its surface. This causes breaking of roots and is probably harmful. When water is finally run in, it is allowed to fill the patch to a depth of 2 to 3 inches; the outlets and intakes are then regulated by crude wooden slats to permit a steady movement of water through the patch. The positions of the water inlets and outlets are important, for thus is adequate water movement regulated with a minimum of water consumption. The speed of movement varies according to the grower's ideas on water management and the amount of water available for irrigation. The use of water to the best advantage can only be learned by experience. The water should be passing through the planted patch at a fair rate of speed, and there should be no "dead" spots where the water can stagnate. When water is scarce, it may be retained in the patch but should be changed as often as possible. Good water movement means good aeration of the soil, which in turn affects the susceptibility or resistance of the taro plant to corm and root diseases.

Every taro farmer believes that water transporting soil, from erosion due to heavy rains in the mountains, makes taro corms rot. A more acceptable explanation would seem to be that the mud "forces" or "flushes" the taro, which then becomes more susceptible to the attacks of microorganisms.

Five to 7 months after planting, the water is usually shut off and the patch, after being allowed to drain, is weeded and fertilized. A week or so later water is again run into the patch. According to accepted practice, water must never be drained off the soil after the taro is 8 months old, or rot will set in at once.

Planting

There are two methods of planting wetland taro—the Hawaiian method and the Oriental method. The former *(puepue Kolea)* is seldom practiced today, except in rapidly disappearing Hawaiian valley communities. It consists in setting five or more plants, one in the center and the others surrounding it, in a slightly raised mound of soil, with the hills 3½ to 4 feet apart from center to center. The five plants are not necessarily planted at the same time. This type of culture was well adapted to the life of the Hawaiian people and insured a constant supply of food with a minimum of labor.

The Oriental type of planting (Hawaiian=*lalani*) is an adaptation from the Chinese method of planting rice. The taro *huli*[1] are set in rows 18 inches to 2 feet apart, the plants spaced 16 to 18 inches apart within the row. Patches *(lo'i)* are planted in their entirety by the Oriental, who is more desirous of selling the produce than growing taro for home consumption. The number of *lo'i* planted at one time is usually determined by supplies of labor and of *huli*.

The time of planting was a matter of some importance to the Hawaiian; possibly by planting at certain phases of the moon he insured an adequacy of rain in succeeding weeks. The Oriental plants taro at any time, although he believes that a crop planted during the cool months of the year, specifically November to March, is more severely affected by corm and root diseases than one planted between April and September.

Fertilization

The Hawaiians understood the need of occasional fertilization of taro and either planted weeds in the taro patches, trampling in the subsequent plant growth, or collected grasses and *honohono (Commelina nudiflora)* and buried them in the soil prior to planting. In certain parts of the territory, for example Keanae Valley on Maui, Hawaiian as well as a few Chinese taro growers still follow these old practices. The average Oriental taro farmer uses an abundance of commercial fertilizer, however.

The forms and correct proportion of nitrogen, phosphorus, and potash in a fertilizer for taro are uncertain, as are the time of application and the quantity of fertilizer necessary. Sedgwick (*8*) states that 500 pounds per acre of a 6-10-8 fertilizer (composition not stated) should be applied before planting, and that 2 to 3 weeks after planting 160 to 180 pounds per acre of sodium nitrate should be spread around the young plants. The station (*3*) reports that McGeorge found taro fertilized with 1,150 pounds per acre of a 6-9-8 formula (ammonium sulfate, superphosphate, and sulfate of potash) to give higher yields than unfertilized taro, and as good yields as plants receiving 1,250 pounds per acre of an 8-9-8 formula (nitrate of soda,

[1]Planting material, consisting of one-eighth to one-fourth inch of corm with one or more buds, cut from the apex of the corm at harvest time; the leaves are removed and the petioles cut back, leaving 6 to 12 inches of the basal portion. *Huli* are planted in submerged soil by forcing the cutting 2 to 3 inches below the surface of the soil, previously puddled. On upland soil, conventional implements are necessary.

superphosphate, and sulfate of potash). The recovery of poi from the raw taro was 57.6 percent when nitrate of soda was applied in combination with superphosphate and sulfate of potash, whereas there was 74.6 percent recovery when ammonium sulfate served as the source of nitrogen. Unfertilized taro gave 74.7 percent recovery. No difference was found in percentages of poi recovered or yields from taro fertilized 10 days before planting, 1 day before planting, and 2 months after planting.

MacCaughey and Emerson (7) state that F. A. Clowes, formerly with this station, recommended 1,000 pounds per acre of a 6-9-8 fertilizer (ammonium sulfate, superphosphate, and potassium sulfate) as adequate for taro. No time of application is mentioned.

A local fertilizer company has two ready-mixed fertilizers which they recommend to taro growers. One contains sulfate of ammonia, raw rock phosphate or superphosphate, and potassium sulfate in a 6-9-5 formula; the other, the same constituents in the more concentrated formula of 8-12½-6. Nitrate of soda has been shown by this company to produce leafy taro with small corms.[1]

A number of fertilizer tests with taro were installed at this station[2] in 1935-36 to determine the effect of different fertilizer combinations, applied at different times, on yield of taro and presence or absence of corm diseases. The results were disappointing; to all intents and purposes, yield and percentage of disease were not influenced by the fertilizer combinations tested.

Many growers believe that phosphorus is necessary to the growth of taro, and that it is intimately related to resistance of the corm to root rot. The source of the phosphorus seems to be immaterial, some growers using raw rock phosphate and others, superphosphate.

There seem to be three periods at which fertilizer may be applied: (a) Before planting, (b) 2 to 3 months after planting, and (c) 6 to 8 months after planting. Some growers make one, some two, and some all three applications, the number usually being determined by the appearance of the plants, the condition of the market, and the amount of labor available. When labor is scarce, fertilizer is applied 6 to 8 months after planting, in combination with weeding practices. The amounts of fertilizer vary from 1,000 to 2,000 pounds per acre; such rates are probably higher than actually necessary.

[1]Verbal statement to the writer.
[2]In cooperation with F. A. I. Bowers, formerly principal agricultural aide in agronomy.

The taro *huli* begins to form roots 8 to 12 days after planting. For the next 3 to 5 months the plant produces top growth only, with corm formation and enlargement taking place subsequently. Most of the roots of wetland taro are buried deep in the submerged soil, and relatively few roots per plant are surface feeders. To benefit the plant, the fertilizer must reach these buried roots, and it is very doubtful if this can be achieved when the soil is saturated with water. If the fertilizer is applied before planting, it seems probable that a root system of adequate absorbing capacity is not formed before the nitrogenous fraction is washed out of the patches. Since a large amount of reserve food is present in the base of the *huli,* it should not be necessary to fertilize the young taro plant. The proper time of fertilization is believed to be 5 to 7 months after planting, just prior to corm development.

Before fertilizer is applied, the patch should be drained and the soil permitted to dry. After the fertilizer is scattered by hand, little or no water should enter the patch for 1 to 2 weeks. Taro responds rapidly to fertilization, especially to nitrogen; by watching the foliage of the plants, the grower can determine whether or not the fertilizer is reaching the root system. When response has been noted for about a week, the irrigation water should again be turned into the patch.

Liming the Soil

Sedgwick (*8*) and Carpenter, according to station reports (*4*), were of the opinion that taro soils were acid and that acidity was a contributing factor to rot; therefore they recommended liming. Kelley (*5*), however, states that the application of lime for the purpose of ameliorating heavy clays "seems to be of doubtful benefit." Since taro rot has been found in Hawaii on soils high in calcium carbonate, the author agrees with this conclusion, although some growers appear to have derived benefits from intercrop liming of the soil. Two to 4 tons of burnt lime per acre are customarily applied, before planting, and should be well plowed into the soil. The use of lime is discussed in more detail later (page 15).

Upland Taro

The culture of upland taro, unlike that of wetland taro, is similar to the culture of many nonsubmerged crops.

Soil and Rainfall

The type of soil is of little importance in the production of upland taro, for the plant grows equally well on light or heavy soil. Of more importance is the amount of rainfall the plant receives, unless irrigation water is available and cheap. As mentioned previously, taro will not produce a good crop unless the rainfall is 70 inches or more per annum; if less than this amount obtains or the rainfall is seasonal, upland taro *must* be irrigated and the soil kept moist continuously.

Planting

Upland taro may be planted in furrows or on ridges between furrows, or in staggered holes, 2 to 3 feet apart. Irrigation is facilitated by furrow planting. Where the land is sloping, taro should be planted on the contour to prevent soil erosion and disturbance of the root system.

Taro is a poor competitor with weeds, especially during the early months of its growth, and the soil should be properly plowed and harrowed prior to planting. Cultivation between and around growing plants is not recommended, for most of the roots, unlike those of wetland taro, are surface feeders and are easily injured. For the same reason, chemical weed killers should not be used.

The time of planting upland taro is immaterial unless a rainy season characterizes the particular locality, when planting should be prior to advent of precipitation. Upland taro usually matures 4 to 6 months earlier than wetland taro, depending on the variety and on the elevation.

Fertilization

A fertilizer trial was installed in Kona by the agronomy division of this station in 1936-37. The variety, *Lehua Palaii,*[1] was harvested at 15½ months. Fertilizer was applied immediately before planting, broadcast in the furrow, and 6 months after planting, as a side dressing. The second application contained only nitrogen, in the form of ammonium sulfate. Phosphorus was applied as superphosphate and potash as potassium sulfate.

[1]Variety names used in this circular conform with names suggested or preferred by Whitney et al. (*10*).

Results from this single test indicated that potash is probably more important for maximum growth of upland taro than nitrogen or phosphorus.

DISEASES OF THE CORM AND ROOT

Cultivation of wetland taro by the Hawaiians was highly organized, for they recognized that, in order to produce healthy taro, it was necessary to rest their *lo'i* between crops. In most villages there were taro specialists or *kahuna* who concerned themselves intimately with selection of good *huli,* preservation of soil fertility, time of planting and harvesting, and water management.

The land was owned by the Hawaiian, or by his chief, and it was to his benefit to produce adequate food for his family, and also for his neighbor when the latter encountered hard times, or *pilikia.* In later years the Caucasians came to own this land, either by outright purchase or by intermarriage with the native chiefs or their relatives, and the word rent appeared. Rentals increased as new agricultural ventures utilized the available land, and, unless taro prices were high, the grower found it increasingly difficult to rest the land between crops. In the early decades of the nineteenth century the Oriental ex-rice grower appeared, bringing with him the cultural practices of his former livelihood, the faculty of tireless labor, and the ability to exist on relatively little. He planted the taro more closely than did his predecessor, and invariably discontinued drying and resting the soil. Often there was an unbroken procession of crops over a 10- to 15-year period.

Continuous cropping and submergence, and possibly the closer interplant spacing, produced anaerobic conditions in the soil very devitalizing to the growth of the corm and its root system. In the presence of a soil-borne fungus, the roots were killed or damped-off, and the corm was more or less destroyed by what is here termed pythium rot.

Pythium Rot

Pythium rot is the transformation of the normally firm flesh of the corm into a soft, mushy, often evil-smelling mass, unfit for human consumption. Handy (*2*) reports that the natives called the disease *pala* or *palahe*. Associated with rot of the corm is a damping-off of the root system, often a cause of decreased yields and occasionally the reason for outright death of the plant. Taro is believed to be the only plant attacked by this disease: according to Sedgwick (*8*) rice and bananas can well be employed in rotation with taro when the latter becomes diseased.

Losses due to pythium rot have been found to range from less than 10 percent to 100 percent, with 25 percent as a conservative average. A good yield is 200 to 300 bags of taro per acre, selling for 75 cents to 2 dollars per bag (100 pounds), depending on supply and demand. Assuming a 25-percent loss from the depredations of the disease with taro selling at 1 dollar per bag, the monetary loss amounts to 50 to 75 dollars per acre. When one remembers that taro requires 14 to 16 months to mature and that cultural costs and land rentals are high, losses from disease are often of great significance to the farmer. Fluctuating prices due to instability of the local market intensify his problems.

Symptoms

The rotting of the taro corm is the most spectacular phase of the losses caused by this disease, but destruction of the root system cannot be ignored. Often a corm suffers little or no rotting, but most of its feeding roots are dying or absent except for a small fringe near the apex of the corm. Root destruction may be so pronouncd that the plant, no longer anchored in the mud of the taro patch, topples over and floats on the surface of the irrigation water, held in place by the surviving roots. Damage to the root system causes a reduction in the yield of the plant, the amount of reduction depending on the extent of the damage. *Huli* taken from diseased plants are weak and of poor quality. If most of the corm has been destroyed by rot, the base of the *huli,* that is, the uppermost portion of the old mother corm, is low in reserve food, or is diseased.

According to Sedgwick (*8*), "Diseased plants may be readily distinguished from healthy ones by the form and general appearance of the leaves. The whole plant becomes stunted, the leaf stalks are shortened, the leaf blades become curled or crinkled, and instead of being a deep healthy green are yellowish and spotted." Diseased plants can easily be removed from taro soil by hand, while it is extremely difficult to remove a healthy plant without first breaking off the roots.

Lateral cormlets or suckers *(oha)* are produced by the basal third of the mother tuber *(kalo)*, to which they normally remain attached. When the *kalo* rots, the *oha* are freed, develop root systems of their own, and remain clustered around the cavity left by the demise of the mother corm. These orphaned *oha* may possess a basal rotting initiated from the mother tuber.

Diseased corms show rot of varying color, from whitish-yellow through shades of gray and blue to dark purple, usually starting at the base of the corm (fig. *1, A*) and progressing upward until the whole corm may be affected. Occasionally the disease starts at the side of the corm, 2 to 3 inches above the base (fig. *1, B*). The extreme tip of the corm, which is the suberized remnant of the original *huli,* is infrequently attacked. The skin of a diseased corm usually remains intact, though softened, until complete disintegration of the interior of the corm has taken place; then the skin also disintegrates.

When the corm is cut open, a sharp line of demarcation can usually be seen between healthy and diseased tissues (fig. *1, C*). The diseased are discolored and softened, the healthy are white or pinkish, depending on the variety of taro, and very hard and resilient. Healthy corms are ovoid or oblong while diseased corms are sometimes parallel-sided or bottle-necked.

Healthy taro roots are creamy white or pinkish depending on the variety, tough, and turgid, whereas diseased roots are darkened, flaccid, and dying or already dead over the greater portion of their length (fig. *1, A*). Between healthy and diseased portions along the length of a root exists the same sharp line of demarcation found within the corm. Lateral roots are absent, or darkened stubs attest their former presence. Further decay of the corm and roots is common and is usually accompanied by a foul-smelling, sour odor characteristic of putrefying tissues.

Cause

The cause of pythium rot is a fungus, an as yet unnamed species of the genus *Pythium,* which lives in the soil of the taro patch and attacks the roots and corms of the taro planted therein. Between crops the fungus lives on the partially or completely decayed tissues of taro roots, leaves, petioles, and corms which were thrown back into the patch by the grower at harvesting.

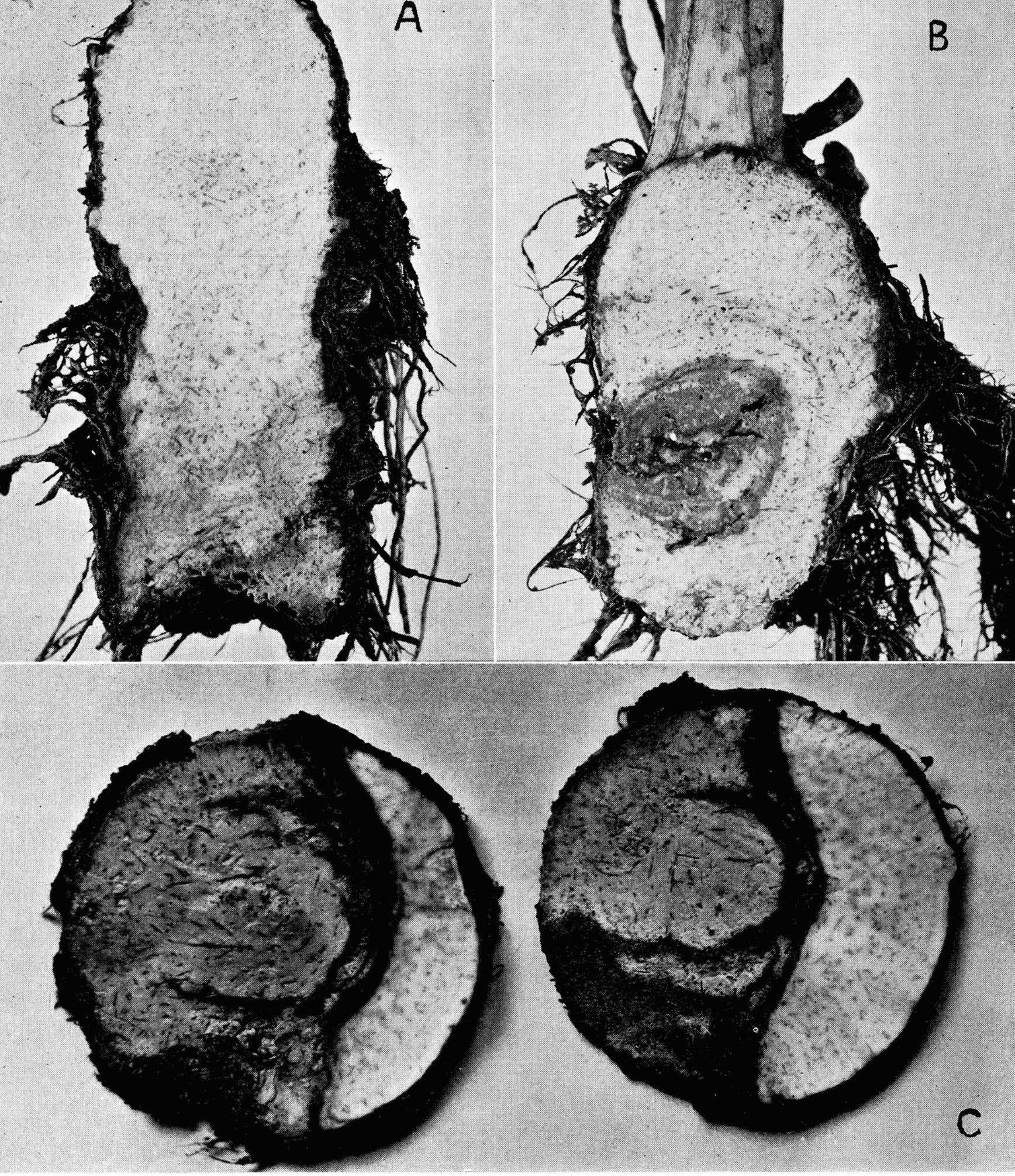


Figure 1.—Pythium rot of the taro corm and roots: A, rot that has started from the base of the corm and is progressing upward (note that most of the roots are blackened or entirely absent and that the corm is characteristically parallel-sided); B, rot that has started at the side and also at the base of the corm—the lower quarter of this corm is already completely softened; C, cross-sections of diseased corms, showing color differences and sharp line of demarcation between healthy (white) and diseased regions

The fungus may also live for several days on the surface of *huli* piled on the banks of the taro patch or transferred from locality to locality by growers. Freshly cut *huli* are commonly covered with moist burlap; this increases the chance of survival of the fungus by preventing desiccation.

Even though the soil is heavily infested with *Pythium*, losses may be relatively slight, for the concurrence of certain conditions in the soil seems to be necessary for the appearance of the disease in destructive form. These are: Abundant moisture accompanied by a fairly high temperature, low biological activity and poor physical condition of the soil, and the presence of toxic materials. The nutrition of the taro plant is said to influence susceptibility, but the writer has been unable to find any confirming evidence. The pH of the soil seems to have little direct effect on the amount of pythium rot.

That temperature plays a role in the development of the pythium-rot complex in Hawaii is illustrated by the fact that the rot is, in general, most severe and, once established, develops with greatest rapidity in warm regions or localities distant from the mountain source of the water supply. In Hawaii irrigation water for taro originates at the heads of the valleys, from natural precipitation on mountain ridges 2,000 to 6,000 feet above sea level. The temperature of water within taro patches situated close to the head of a valley has been found to be 4 to 6 degrees (F.) colder than the water in patches in the middle or at the mouth of the valley. The same is true of soil temperatures. Within individual taro patches, differences of 1 to 3 degrees have been found for water or soil temperatures; these differences are determined largely by the rapidity of water movement over the soil. In an infested patch, rot is always severest where water movement is slow.

It is generally believed that soils high in organic matter, especially decaying plant parts, are favorable to root rots. Taro soil is full of roots, left in the soil when the corm is pulled, and diseased corm material returned to the patch by the grower. Sedgwick (*8*) believed that the presence of rot was partly due to soil conditions, particularly lack of drainage. He says, "The center of a taro patch is usually the lowest and the most poorly drained, and very often the disease occurs in the center of the patch while the taro all around the margin is apparently healthy or only slightly diseased." The writer concurs fully with this statement.

Susceptibility to this rot is also correlated with the physical and physiological age of the plant, which is determined in part by soil temperature and the amount of available nutrients in the soil. For example, *Piialii* grown at sea level at the mouth of a valley matures in 16 months, on the average. If this variety is then allowed to remain in the soil before harvesting, due to the low market price of taro, rotting of the corm will start, or if already present it will be rapidly amplified. If grown at the head of the valley, 200 to 400 feet above sea level, where water and soil temperatures are sometimes as much as 5 degrees (F.) cooler than at sea level, this variety will mature in approximately the same time. It is possible, however, to hold plants in the soil for 2 to 3 months, until market prices are more favorable, with no appreciable development of rot.

Control

Exclusionary methods are not applicable to this disease, with one possible exception. *Huli* should never be used if basal rot can be detected, nor should they be taken from diseased corms, for the subsequently developed plants are slow to form roots, are easily attacked by diseases, and yield poorly. Some growers prefer to plant small *huli* (1 to 1½ inches basal diameter), which they believe contain more reserve food than *huli* from larger corms. In several instances, the growth of small and large *huli*, planted side by side, has been observed; in no case could a difference be detected in top growth. No data on subsequent yields or susceptibility to corm and root rot were gathered.

Diseased corm and root material should be removed from a taro patch at harvesting. Discarded corms and leaves commonly seen floating in the water of a patch or partly submerged in the soil furnish a food supply for maintenance of the fungus.

Elimination of the fungus by drying and plowing the soil between crops has been recommended by various investigators. However, according to Sedgwick (*8*), "The high rental values of the lands, and the present methods of cultivation of taro work against the adoption of rational methods of combating the rot. With a crop which requires from 12 to 14 months for its complete maturity, the cultivator feels that he must have something growing on the soil during the entire term of the lease, and a crop of taro is no more than harvested before another is planted, sometimes not more than 3 or

4 days intervening between the harvesting of the crop and the replanting of the hules." These statements apply just as perfectly today as they did in 1902. According to Akana,[1] F. A. Clowes recommended that not more than two crops of taro be taken from the land without planting it to some other crop, such as bananas or forage crops, that fields be plowed as deeply as possible after the removal of each crop, that the time of exposure be at least 1 month, and that the ground be harrowed and soaked with water before being replanted. When taro soil is allowed to dry, the soil cracks but does not resolve itself into small particles. If thoroughly plowed and cultivated at frequent intervals for 3 to 4 months, this soil can be used to grow peanuts, squash, tomatoes, potatoes, or other crops. There is no reason why such crops cannot be irrigated from the taro ditches without disturbing the physical aspects of the agricultural system. Truck crops are grown on abandoned taro land on a small scale in the territory, but it has occurred to no one to utilize these cash crops *in rotation with taro.* Not only is the taro root- and cormrot problem alleviated by the drying of the soil, but a serious root pest of truck crops in Hawaii, the nematode *Heterodera marioni,* is rarely present in wetland taro patches.

As previously mentioned, liming of poor taro soils was recommended by Sedgwick (*8*) and by Carpenter (*4*). The former believed that 1½ to 2 tons per acre of slaked lime should be applied to the soil after every second or third crop. Carpenter experimented with slaked lime at 2 tons per acre, and beach or coral sand at 4 tons per acre, but could draw no definite conclusions as to the value of these materials in the control of pythium rot. However, he states, "Other experiments made by growers of taro in Halawa [Molokai] gave strong indications that taro rot could be practically controlled by drying and plowing the patches and by applying either lime or coral sand some time before they are replantd to taro." Lime is not believed to have any direct action on the fungus but may be beneficial in improving the physical condition of the soil and neutralizing toxic substances.

Larsen (*6*) in 1915 attempted to control taro rot chemically by adding a 1:10,000 solution of copper sulfate to the soil. Bluestone was placed in the irrigation water on one side of a large patch, while

[1]AKANA, DAVID A. THE PRODUCTION OF WET LAND TARO. Hawaii Univ. Agr. Ext. Serv. Agr. Notes 16, 3 pp. 1932. [Mimeo.]

the other side, separated by a dike, was untreated. The solution was allowed to stand over the soil for 6 days and then flushed out of the patch with fresh water. At harvesting, the treated plot showed 25-percent rot while a 75-percent loss was registered in the check. Larsen recommended that a weaker solution of copper sulfate be used, several applications made, and the length of time of treatment increased. Carpenter (*4*), in a limited series of experiments on the island of Molokai, placed copper sulfate in the irrigation water until a 1 :30,000 concentration was reached within the taro patch; then the inlet was plugged and the water was allowed to stand on the soil for 1 week. The mud and water were stirred with a hoe, the water was drained off, fresh water was run in, and *huli* were planted. The latter were given a preplanting dip in 1 :10,000 copper sulfate. Two months later a concentration of 1 :60,000 copper sulfate was allowed to circulate around the young growing plants. At harvest only 5-percent rot was present in the patch whereas no marketable taro had been obtained from two previous crops.

In field trials by the writer, copper sulfate was effective in reducing disease in only 3 out of 10 plots. Moreover, it was shown that taro may be injured by this chemical unless an interval of 3 or more weeks elapses between application of the copper sulfate and planting. The injury appears as a yellowing of the foliage and transient stunting of the plant. If copper sulfate is used, it should be applied to the dry soil and plowed in.

A number of other chemicals were added to taro soil where pythium rot had been consistently severe, to determine their possible beneficial effect in reducing losses. In only a single plot was lime of benefit. Sulfur added to the soil usually caused an increase in rot, or was of no benefit. The same was true of chloropicrin. Other treatments gave variable results; no treatment consistently gave a reduction in disease.

The effects of soil treatments on yield were likewise variable. Lime at 4 tons per acre or copper sulfate at 200 to 400 pounds per acre increased yields. Tetrachloroethane and chloropicrin decreased yields; these organic materials stimulated and prolonged vegetative growth, and corms on treated plants were low in starch. (See *Loliloli* Taro, p. 21.)

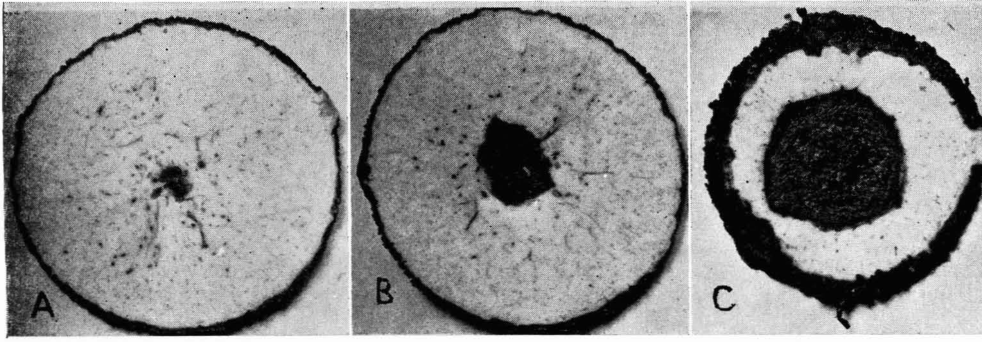


Figure 2.—Hard rot of the taro corm: Cross-sections showing (A), initial lesions; (B), a more advanced stage of the disease; and (C), a severe infection with over 50 percent of the cross-section destroyed (note in C the much thickened bark-like skin of the corm, usually associated with the presence of hard rot in a corm)

Of the wetland varieties commonly grown in Hawaii, *Piialii* is more susceptible to pythium rot than *Piko Uliuli (Hachae),* while the varieties *Kai Kea* and *Kai Uliuli* are quite resistant. According to Sedgwick (*8*) the Chinese taro, *Bun-long,* is highly susceptible. It may be possible to cross some of the more resistant varieties of the *Kai* group with the susceptible but higher yielding *Piialii, Piko Uliuli,* and *Piko Kea.*[1]

Hard Rot

A second disease of the taro corm, hard rot, may also cause appreciable losses. In contrast to pythium rot, hard rot transforms the tissues into a hard woody mass, useless for human consumption. The variety *Piko Uliuli* is more susceptible to hard rot than *Piialii,* a fact which has been noted in numerous instances where these two commercial varieties were planted side by side. It has also been noted that, when pythium rot is abundant in a locality, hard rot is relatively insignificant or absent; the reverse also seems to hold. This might be expected where taro plantings are fairly pure as to variety, with pythium rot more severe on *Piialii* than on *Piko Uliuli* and the latter more susceptible to hard rot, but these observations are also true of mixed plantings.

This disease is known locally as "guava seed," due to the resemblance of symptoms in the corm to the seed of the guava. Hawaiians call the disease *kalakoa,* meaning "black and white," referring to the color differences of diseased and healthy cells.

Rotted tissues are generally located in the lower third or in the center of the taro corm, in a single woody core (fig. *2*) or in a number of localized, hardened regions distributed throughout the corm (fig. *3, left*). These diseased portions are removed at harvesting, and

[1]That it is possible to produce viable taro seeds by artificial fertilization of the flowers has been demonstrated by K. Kikuta, assistant in plant pathology in this station.

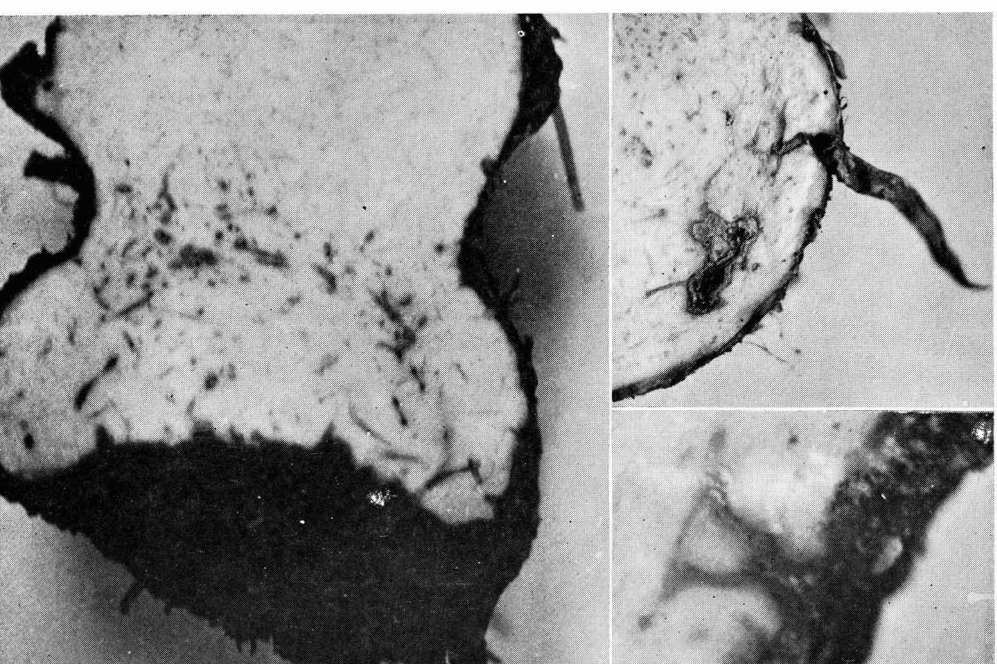
the grower is obliged to cut away and discard appreciable amounts of surrounding healthy tissues.

Losses may vary from less than 5 percent to almost 100 percent, and a 30-percent average is fairly common through the territory. Again assuming taro yields to be 200 to 300 bags per acre and the harvested corms to be worth 1 dollar per 100-pound bag, this means a loss of 60 to 80 dollars per acre.

Symptoms

The disease destroys the vascular system of the corm, starting with the root traces at the periphery (fig. *3, right*) and working progressively inward. A diseased corm can be distinguished from a healthy corm in most instances by examination of the skin. The skin of a healthy corm or a corm diseased with pythium rot is smooth, paper-like in consistency and thickness, and easily scraped away with a knife. The color of the skin varies with the variety: for white taros the color is yellowish-brown, while for pink or red taros the skin is light pink. Leaf scars can easily be identified, and the buds from which secondary corms *(oha)* arise are large, firm, and stand

Figure 3.—Hard rot of the taro corm: Longitudinal sections showing left, complete destruction of the base and irregularly distributed affected areas in the median part of the corm; upper right, initial lesions starting at the periphery and associated with a dead rot; and lower right, a hardened, discolored root trace and much thickened epidermis (magnification in C about 5×)



away prominently from the surface of the corm. The color of the buds may be creamy white or pinkish, depending upon the variety. A few shallow furrows may be present on the corm, located parallel to the long axis.

The skin of the diseased corm is bark-like, 1/8 to 1/4 inch thick, deeply furrowed, crumbly, and coarse. In color it is dirty white or purplish. Buds are retracted and often deeply sunken. The outer coarse covering can be removed with the finger nail to expose a second layer, somewhat harder to remove, which approximates the skin of a healthy corm in color and consistency. All or only a part of the corm surface may show this thickened epidermis. Hard rot may be expected within the corm wherever the skin is thickened on the outside.

Affected tissues are disintegrated, woody, and light yellow or dirty brown in color. The disease may range in extent from a discolored root trace, through lesions the size of a pea, to almost complete destruction of the cross section of the corm (fig. *2*). Small lesions can be extracted after the manner of a chiropodic corn, leaving a clean-cut, smooth, round hole. This feature led to the name "guava seed." In advanced stages of hard rot a hardened, browned or blackened skeletal framework is all that remains of the corm.

The base of a *huli* taken from a diseased corm often shows a slightly darker than normal peripheral ring of tissue. This symptom is used by many growers to segregate healthy and diseased *huli;* they believe that dark-ringed *huli* reproduce the disease in the next crop. This has been demonstrated to be correct in a high percentage of cases.

Oha may show the disease when the mother corm is affected. Large *oha* are occasionally used as planting material; when diseased *oha* are planted, the later-developing corms show hard rot in a destructive form.

Cause

The cause of hard rot of taro is unknown. Though hundreds of isolations have been made from diseased tissues, no organism has ever been obtained, and microscopic examinations of dead areas have shown that no organism is present. It is possible that the disease may be due to toxic materials absorbed from unthrifty submerged soil; that the disease is due to a specific organism might also be postulated, for *huli* from healthy corms planted in soil infested with diseased corm material become diseased more often than they remain healthy. Also, *huli* taken from diseased corms and planted in steam-sterilized soil reproduce the diseased condition in a large number of cases.

On the assumption that the condition of the base of the *huli* plays no small part in the subsequent development of hard rot, be the condition due to some physiological unbalance or to a specific organism, the value of a preplanting *huli* dip in 1 :1 :3 bordeaux paste was studied. *Huli,* variety *Piko Uliuli,* were selected from healthy corms and from hard-rotted corms, and the lower ends of half of the total number of *huli* in each group were dipped in the bordeaux paste. The remainder were left untreated. Some *huli* of each type were planted in: (a) steam-sterilized soil, (b) steam-sterilized soil infested with finely chopped pieces of diseased corms, and (c) untreated soil. The soil was gathered from a taro patch where the previous crop had been a complete failure due to hard rot. At harvest about 70 percent of the *huli* from diseased corms and 40 percent of the *huli* from healthy corms produced diseased plants. A greater number of plants were diseased with hard rot when *huli* from healthy corms were planted in sterilized infested soil than when they were grown in nonsterilized field soil. The bordeaux paste dip was of definite benefit in reducing hard rot, and the material and method merit field trial.

Little is known about the effect of environment on the development of hard rot. The disease has been serious in several localities where the water table was low, along the sea coast, and where seepage of salt water occurred. Inadequate irrigation after the plants are 8 to 9 months old may be another cause of hard rot. On land previously in *Panicum purpurascens* for 5 or more years, hard rot has been encountered in severe form. Such soils invariably exhibit a scum of iron oxide on the surface of the irrigation water or on the taro *huli*. No correlation has been found between the pH of the soil and the incidence of this disease.

In a limited series of fertilizer tests, no difference was established in the susceptibility of taro to hard rot in the absence of nitrogen, phosphorus, or potassium.

Control

There are few recommendations for the control of hard rot. No *huli* or *oha* should be taken from diseased corms. The preplanting dip of bordeaux paste, mentioned previously, might well be tested by growers.

A number of soil treatments with chemicals have been tried; lime at 2 tons per acre caused appreciable reductions in hard rot in two localities but cannot be recommended unqualifiedly. No other treatment gave any control.

Taros of the *Kai* group seem to possess resistance to both hard rot and to pythium rot; it may be possible to develop a variety resistant to both diseases by breeding.

LOLILOLI TARO

Wetland as well as upland taro may be affected by this disease, which attacks the base of the corm and the *oha*. The term *loliloli* is local, derived from the Hawaiian, and means "water-soaked." It may also be called "punky" taro. The disease has been found in most taro regions in the territory.

Affected taro is of little value in the manufacture of poi or taro flour, and diseased parts must be discarded before the corm is processed. It is difficult to estimate the losses caused by the disease for its presence is often masked by other corm diseases. While the disease should not be completely ignored, losses are probably not over 5 percent.

Symptoms

A normal corm is firm, crisp, and resilient to the touch. *Loliloli* taro is soft, and when affected parts are squeezed between the fingers, water exudes. The cells of a normal taro corm are crammed with starch, while in *loliloli* taro starch is deficient or lacking. The application of iodine to the cut surface of a normal corm gives the blue-black test for starch; applied to a *loliloli* corm, iodine produces only a faint color or no reaction.

Cause

Loliloli taro is believed to be due to a natural withdrawal of starch from the corm by the leaves of the plant. The starch is converted into sugars, which are transported away to be used in the formation and development of new parts. Corm formation and maturity in taro is generally accompanied by a diminution in stature. Any process, natural or man-made, which encourages rejuvenation of the plant, causes loss of starch from the corms. Some growers think that they can delay the normal maturation process by fertilizing almost mature plants with nitrate of soda. This practice, followed when the market price of taro is low, almost invariably results in loss through *loliloli* corms.

Muddy water passing through a patch of almost mature or mature plants may also cause *loliloli* taro, through the introduction of plant food.

The disease may be caused in still another way. Following destruction of the mother corm by pythium rot, the previously attached, partially mature *oha* are often freed. With the controlling influence of the *kalo* removed, these *oha* put forth new leaves and develop individual root systems. When harvested, such *oha* often are *loliloli.*

Control

To reduce losses from this disease, nitrogenous fertilizers should be applied judiciously. Their use is not recommended after the corm has formed or the natural growth-decadence of the plant has started.

Sclerotium Rot

Upland taro may be attacked by this disease; wetland taro, seldom, if ever. Other plants affected are potato, pepper, tomato, peanut, and numerous ornamentals. All varieties of taro are probably susceptible. The disease is of little economic significance and is generally seen on overmature plants or plants suffering from inadequate irrigation.

Symptoms

Affected plants are usually stunted. On uprooting, the lower portion of the corm will be seen to be partially rotted away. Corms are often covered with numerous, small, almost spherical, lemon-yellow to dark brown bodies, called sclerotia, about the size and color of cabbage seed. The rotted tissue is ocherous to brown in color, soft but not watery, with a tendency to stringiness. A sharp line of demarcation separates diseased from healthy tissues.

Cause

The cause of this disease is a fungus, *Sclerotium rolfsii,* which persists in the soil as mycelium, but more commonly as sclerotia. The latter germinate in the presence of moisture to produce mycelium which infects young and old roots and overmature corms. It does not seem to be able to live in the saturated gumbo soil of the wetland taro patch.

Control

When well established in the soil, this is a very difficult organism to control, due to the resistance of the abundantly produced sclerotia and the wide range of susceptible host plants. Plowing infested soil to a depth of 4 to 8 inches should reduce losses. Infected plants and the surrounding soil should be removed and burned. The taro should be harvested before it becomes overmature.

Nematodes

The root-knot nematode, *Heterodera marioni,* has been found attacking upland taro in Hawaii and producing characteristic enlargements or galls on the roots. The plant has previously been recorded as a host of this nematode in Florida by Byars (*1*), where the disease occasionally becomes serious. Corms as well as roots may be attacked, the swellings on the corms serving as avenues of entrance for secondary fungi and bacteria which produce corm decay. When the roots are badly affected, the aerial parts of the plant are reduced in stature and may be yellowed.

The nematode can be eradicated by soil fumigation with carbon bisulfide or chloropicrin, but these materials are expensive and the effect is not lasting. The plants should be kept growing rapidly by providing adequate irrigation.

DISEASES OF THE TARO LEAF

Several leaf-spotting fungi occur in Hawaii, two of which may cause appreciable defoliation—phytophthora spot, always present on wetland taro but seldom found on upland taro, and phyllosticta spot, found exclusively on upland taro.

Phytophthora Spot

This disease, ordinarily severe at all times on wetland taro, has been found occasionally on upland taro in areas of high rainfall during

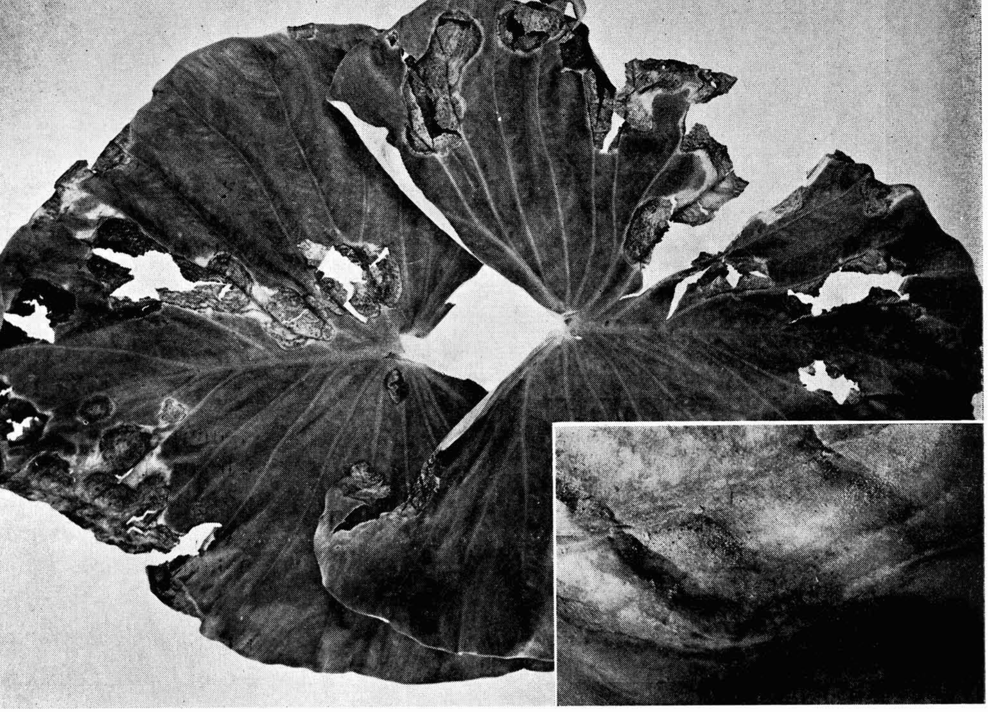


Figure 4.—Phytophthora spot, caused by Phytophthora colocasiae (insert shows portion of a spot on whose surface can be seen the distinguishing mildew or fuzz which consists of the sporangia or fruiting bodies of the fungus; magnified about 10×)

the winter months. The writer tested the susceptibility of 32 varieties and found none to be resistant. Destruction of the foliage is the most devastating effect of this disease on the plant; occasionally the petioles are also rotted. In other parts of the world a corm rotting has been noted and ascribed to the organism causing phytophthora spot. A 25-percent loss in yield in Hawaii due to the disease is a conservative average figure.

Symptoms

In the early stages the disease is characterized by the appearance of small, dark, roundish specks which rapidly increase in size until the spots are from 1 to 2 centimeters in diameter (fig. *4*). The shape of spot may vary considerably with increase in diameter. As the spots enlarge, drops of a clear, yellowish or amber-colored liquid ooze from the center of the lesions. This liquid, when dry, turns bright yellow or dark purple. Lesions may occur on any part of the leaf but are most common at the tip, the base, and the sides. The margins of spots are yellowed. One or more rings of a whitish fuzz (fig. *4, insert*) can be observed with the naked eye on both surfaces of the spots, particularly before the sun has dried the air.

Cause

The cause of this disease is *Phytophthora colocasiae,* one of the downy mildews, closely allied to late blight of potato. The fungus produces its spores on the spots, the above-mentioned fuzz consisting of many thousands of conidia or sporangia, as the spores are termed. The sporangia are blown by the wind or splashed by rain from diseased to healthy leaves, where they germinate in the presence of moisture to reproduce the disease in 3 to 5 days.

There is a close connection between the severity of phytophthora spot and abnormal atmospheric conditions, particularly rainy weather accompanied by high winds which whip the leaves about and scatter the sporangia. Temperature seems to play little part in the severity of the disease in Hawaii. The practice of close interplant-spacing is conducive to the development of leaf spot, due to poor air drainage and maintenance of a high humidity around the leaves of the taro plant, which permit the sporangia to germinate easily and abundantly.

Control

The disease can be controlled by spraying with 4-4-50 bordeaux at 10- to 17-day intervals. A spreader must be added to the bordeaux for the waxy surface of the taro leaf is not easily wetted. Spray trials installed in several localities on Oahu gave increased yields of 10 to 30 percent; all operations have been limited to plants adjacent to the banks of taro patches, and special machinery will have to be devised if the entire patch is to be sprayed. No data were collected on the cost of spraying. Dusting is not adaptable to taro.

The fungus may also be eliminated to a marked degree by increasing the interplant-spacing distance. From tests conducted by the writer and his associates, the following results were obtained: There was no difference between yields at 16 inches and 24 inches, nor between yields at 24 inches and 30 inches; however, yields at 30 inches were better than yields at 16 inches. One may therefore conclude that it is better to plant 30 inches apart; interestingly enough, this is the approximate distance which the Hawaiians often used. Plants so spaced have very large corms with luxuriant root systems, and harvesting is more laborious and time consuming than when plants are set 16 to 18 inches apart. With labor inclined to be scarce and speed of harvesting an asset, the existing interplant-spacing distance of 16 to 18 inches seems best suited to present-day conditions.

Phyllosticta Spot

This leaf spot occurs exclusively on upland taro, occasionally becoming serious. Twenty-seven varieties of taro were tested by the writer and only one, *Manini Uliuli,* is resistant. If the epidermis of the leaf of this variety is broken, resistance is lost.

Losses are due to destruction of parts of the leaves. Stevens (*9, pp. 129-131*) held that the disease was of great significance in the islands and wrote, "Its ravages cause such havoc that the leaves are largely or quite destroyed." Severe cases of this type have never been observed by the writer.

Symptoms

The spots on the leaves vary from a quarter of an inch to one inch or more, and are oval or irregular in shape (fig. *5, A*). The young spots are buff-colored; older spots are dark brown and about them are pale marginal zones. The diseased areas become rotted, and frequently the centers of the spots drop out. Spots are visible on both surfaces of the leaf. In general, spots resemble those caused by *Phytophthora colocasiae,* but the previously described whitish fuzz of sporangia is absent on *Phyllosticta*-produced spots.

Figure 5.—Two leaf spots of upland taro: A, Phyllosticta spot, caused by Phyllosticta colocasiophila; B, cladosporium spot, caused by Cladosporium sp. (photo B taken by O. N. Allen)

A B

Cause

The disease is caused by one of the Fungi Imperfecti, *Phyllosticta colocasiophila,* which produces its spores in specialized fruiting bodies, called pycnidia. The pycnidia on the spots can often be seen with the naked eye, appearing as small, rounded, black or brown dots. Spores ooze from the pycnidia in wet weather and are splashed from plant to plant, where they germinate to reproduce the disease. The mycelium of the parasite probably also lives in the soil on decaying taro material.

The disease is influenced by temperature but more particularly by rainfall. Cloudy, rainy weather for any protracted time, accompanied by cool winds, is conducive to infection. With a change in weather to dry, hot days and dry, cool nights, the disease will decrease in importance. Taro plants probably lose only three to five leaves per season from this disease.

Control

This disease, like phytophthora spot, can be controlled by covering the leaves with a fungicide, which will prevent germination of spores landing on the foliage. Bordeaux mixture is an effective spray, but whether or not spraying is worth the cost of labor and materials is not known. Unless phyllosticta spot is continuously present and causing appreciable defoliation, spraying is not recommended. The collection and burning of diseased leaves seem to be of practical value.

Cladosporium Spot

This is a relatively innocuous disease which is common on upland taro, particularly the *Tsurunoko* variety, also termed Japanese taro. It has not been observed on the variety *Apu.* Spots are dark brown, inclined to be diffuse in general appearance, some 5 to 10 millimeters in diameter (fig. *5, B*). No visible injury occurs to the affected leaf. The cause of the disease is a fungus, *Cladosporium* sp., one of the Fungi Imperfecti.

Control is not deemed to be necessary.

SUMMARY

In Hawaii taro is subject to diseases which attack the corm, the roots, and the leaves. Diseases of the corm and roots are found chiefly on wetland taro; they can best be controlled by thoroughly plowing and drying the soil and not replanting to taro for 6 months to 1 year. During this resting period the land can be adapted to the cultivation and production of truck crops such as peanuts, cucurbits, tomatoes, et cetera. No chemical treatment of the soil has been found to reduce losses consistently or produce a beneficial action equivalent to that obtained by resting or rotation. Lime at the rate of 2 to 4 tons per acre is being used by some growers with beneficial results; the lime probably serves to ameliorate unfavorable soil conditions rather than to act directly on the soil organisms responsible for corm and root diseases.

Diseases of the leaf can be controlled by spraying the plant with a copper fungicide at 10- to 20-day intervals from the time the disease first appears. Sprayed wetland plants have yielded 10 to 30 percent more than unsprayed plants; all spraying operations have been limited to plants adjacent to the banks of taro patches, and special machinery must be devised if spraying is to be practiced on wetland *lo'i*. No quantitative data have been obtained on the benefits derived from spraying upland taro, and unless the leaf spot is causing appreciable destruction of the foliage, spraying is not recommended.

Leaf diseases of wetland taro may also be controlled in an indirect method, by increasing the interplant-spacing distance from the present 16 or 18 inches to 30 inches. However, plants so spaced are large, possess extensive root systems, and are difficult to harvest. If labor is cheap and abundant, it might pay growers to utilize the greater spacing distance, which produces greater yields and, incidentally, approximates that used by the old Hawaiians.

The taro plant is very susceptible to unfavorable growing conditions, and a knowledge of its proper culture is very important if a high-grade product is to be obtained. Brief notes on handling of the land and the irrigation water are presented; methods of planting, selection of planting material, and fertilization are also discussed herein.

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