Bacterial Wilt of Row Crops in Florida

Tom Kucharek, Professor, Department of Plant Pathology, University of Florida, Gainesville, Florida 32611. **September 1998**

Florida Cooperative Extension Service / Institute of Food and Agricultural Sciences / University of Florida / Christine Waddill, Dean

History and Host Range

Bacterial wilt was first identified in Mississippi in tomato and potato in the early 1890's and in tomato in Florida in 1897. However, this disorder was well known by growers around the world several hundred years prior to its formal identification. In Florida, bacterial wilt (BW) of solanaceous crops occurs commonly in tomato and potato and it has occurred occasionally in tobacco and eggplant. For example, only one major case of BW in tobacco has occurred in Florida in the past 28 years (Union County). Nearly 50 years ago a severe case of BW occurred in shade tobacco in Gadsden County. In other locations around the world, BW occurs commonly in tobacco. For example, BW is a major disease of flue-cured tobacco in North Carolina and South Carolina. Bacterial wilt became so severe in tobacco in Granville County, North Carolina from 1920 to l940 that hundreds of farm families sold their farms and moved elsewhere. Bacterial wilt is commonly called brown rot in potato and Granville wilt in tobacco. In recent years in Florida, BW of eggplant has been identified occasionally in Alachua County in gardens and once in a commercial field in Gadsden County. However, BW was reported in 1940 to be a severe problem in eggplant in northeast Florida.

For the past 30 to 40 years, BW has not been a problem at all in pepper in Florida. Pepper is generally considered to be less susceptible than the aforementioned crops in the plant family, solanaceae. However, BW can occur in pepper when artificially inoculated. Also, prior to 1940, BW was a severe problem in pepper that was planted following potato in northeast Florida. The only other row crop known in Florida to have sustained damage from BW is sunflower. Bacterial wilt was one of several problems with pests and production that prevented a fledgling sunflower industry from growing in north Florida in the mid to late 1970's.

It is not possible to provide an exact host range for the bacterium causing BW because of the extreme variation in pathogenicity within this bacterial species and the variation in susceptibility of numerous plant species and their respective commercial varieties to this bacterium. More than 200 plant species in at least 34 plant families in different locations around the world have been associated with BW from natural infection or from experimental inoculations. Some of the notable crop species, in addition to those mentioned previously, that sustain natural damage from BW in the world include: peanut, banana (moko disease), plantain, marigold, chrysanthemum, nasturtiums, dahlia, gerbera daisy, impatiens, lantana, pothos, brown indian hemp, ginger, and sesame.

Interestingly, BW is a severe problem in peanut in Africa, China, Indonesia, and Vietnam but it is not a problem in peanut in the United States. Several reports in the first half of the 20th century indicate that BW was a fairly common disease in peanut in some southeastern states in the U.S. If BW was a problem back then, one might hypothesize that it's contemporary absence is related to the different varieties planted in the two different eras. However, it is questionable that BW was even an uncommon problem in peanut back then because not one case of BW has been seen in peanut in Florida and some other peanut producing states for at least the past 40 years.

Some of the notable weeds that have been infected with this bacterium are: black nightshade, cutleaf ground cherry, common ragweed, Spanish needles, horseweed, cocklebur, and Jimson weed. In Florida, it has not been determined how important the aforementioned weeds or other possible weed hosts are in relation to sustaining populations of this bacterium. Another factor that adds to the possible sources of inocula for this bacterium is that many plant species, including some grass species, can maintain populations of *R. solanacearurn* in their root systems without causing symptoms.

The Pathogen

The bacterium causing BW is called *Ralstonia solanacearum*. Prior synonyms include *Burkholderia solanacearum*, *Pseudomonas solanacearum*, *Xanthomonas solanacearum*, *Phytomonas solanacearum*, *Bacterium solanacearum*, and *Bacillus solanacearum*. This bacterium is capable of producing billions of microscopic cells in one plant. Each bacterial cell is about 1/37,500" long and 1/12,250" wide. Multiplication occurs by each cell dividing to make two new cells. The interval between each cell division is about one hour. Thus, from one cell, about eight million cells may be formed in 24 hours. Each cell has one or more tails (flagella) that assist with movement within water. In mass, these cells form a whitish slime or colony.

Because of variation among the numerous strains of this bacterium, the optimum temperature for multiplication (growth) ranges between 81 and 98° F (27-37° C). Maximum temperature for growth ranges from 95 to 106° F (35-41° C) and minimum temperature for growth ranges from 47 to 65° F (8-18° C). BW is generally considered to be a warm to hot weather disease. In the United States, bacterial wilt rarely occurs in the field above a latitude equivalent to Virginia because *R. solanacearum* has a high temperature requirement for growth. Bacterial wilt typically occurs in the tropical and the warm temperate regions in the world. In the United States, BW is found commonly in the southeastern states where the climate and soil has extended moist and warm periods. The importance of warm soils for the development of BW is indicated by the reduction of BW from 93%, when tomatoes were planted in the Ft Pierce area in 1978 during the last week in September, to 17%, when the tomatoes were planted during the second week in November.

Even though *R. solanacearum* survives and multiples at warm temperatures, it can be reduced if the soil temperature gets too hot. In locations where many clear days occur, such as in Israel, BW and other diseases have been reduced by allowing clear plastic to remain on the soil and heating the soil to thermal death points for the pathogens involved. This practice is called soil solarization. It has been used in Florida experimentally and on a limited basis in commercial settings for suppression of BW in tomatoes in north Florida. Combining soil solarization with soil fumigation is more effective for suppressing BW. Remembering that *R. solanacearum* can exist deep in the soil, it is not surprising that soil solarization is only partially effective. Soil solarization is highly effective for suppressing pest population in the upper few inches of soil, but it becomes progressively less effective at greater depths in the soil. For example, in one situation in Florida, soil solarization with clear plastic heated the soil at the two- inch depth to 110° F for 69 hours but at a 10-inch depth the soil never exceeded 105° F. Similarly, at a common point in time, the temperature in solarized soil at a two- inch depth exceeded 120° F where immediately below at a 10-inch depth, the soil temperature was 104° F.

Bacterial wilt has been introduced via transplants to northern states, but typically it does not survive at high enough levels outdoors in the cold soils to cause disease. One known exception to that is when it overwintered and caused disease in tomatoes in New Jersey in 1940 after being introduced in tomato transplants imported from Georgia. Bacterial wilt has not been found west of New Mexico. It has been found on all the continents except Antarctica and many tropical islands including those in the Caribbean Basin. Occasionally, BW has been found in potato in colder climates such as in Sweden and the Netherlands and at higher altitudes in Costa Rica, Columbia, Peru, and Sri Lanka because a certain "potato strain" is adaptive to cooler climates. Conceivably, this bacterium could survive in northern climates within greenhouses, hotbeds or cold frames.

One of the most confusing aspects of this disease is its variability with respect to infection of different plant species in different locations. As mentioned above, bacterial wilt is a major problem in tobacco in the North and South Carolina but not in Florida in fields known to be infested with the bacterium. Similarly, peanuts do not sustain any damage from BW in Florida, but tomatoes grown in the same fields may be totally destroyed by BW. One possible explanation for such phenomena is the existence of groups, strains, races, biovars, pathovars, and divisions of *R. solanacearum*. While these classification schemes may be helpful in some instances, common agreement among scientists does not exist for their use in a dependable manner. The reader should remember that all aspects (e.g. soil survival, pathogenicity, host range, symptom expression, etc.) of BW are influenced differentially by the various strains of this bacterium

Sources of Inoculum and Soil Survival

The most common source of inoculum for BW in Florida is within the soil. Bacterial wilt has occurred in fields in Florida that had never been planted to a crop and contained only native vegetation. This bacterium can survive in association with old crop debris or live in plant tissues deep in the soil. In general, *R. solanacearum* survives best in the upper 12 inches of soil, but it has been found 30 inches deep. Because of the depth of survival of this bacterium and other factors, attempts to suppress BW with preplant soil fumigation or soil solarization have typically resulted in moderate and short term suppression of this disease.

While it is commonly indicated that the bacterium is capable of surviving in "the soil," for long periods of time (years, decades), it has been shown that over a 20 week period, the bacterium progressively declines in population in some soils unless the roots of host weeds or crops are present. When roots of susceptible or even some non-host plant species (e.g. corn, soybean, bean, green pea, & sorghum) are present, this bacterium can survive, multiply to low levels, and maintain enough of a population to cause disease in a known susceptible crop such as tomato. Similarly, because of the apparently high number of weeds that can maintain populations of *R. solanacearum*, less BW occurs sometimes following corn rather than weed fallow. Some have professed that maintaining a field free of plants of any kind for one season helps in minimizing BW. Although rotation with non-host crops maintains populations of this bacterium at low levels, such a rotation has an overall affect of reducing populations of this bacterium over time when compared to the continual cropping of susceptible crops such as tomato. Similarly, rotation with eggplant will maintain populations of the bacterium even though eggplant is typically not as susceptible as tomato. Resistant varieties of tomato may not express symptoms of BW but they too can act as carriers of the pathogen. Rice does not maintain populations of this bacterium and has been found to be a crop, which helps to significantly reduce, not eliminate, BW when used in crop rotation schemes. Granville wilt in tobacco has been reduced significantly with rotations including fescue when compared to continual growing of tobacco.

Soil factors influence survival of this bacterium. In Florida, BW occurs throughout the state with the exception of the soil with high pH (7.2 to 8.4) around Homestead in Dade County. Attempts to lime soils to higher pH's has led to slight suppression of BW possibly because the lime was not mixed in the deeper portions of the soil. In general, soils that are commonly warm, frequently wetted, and with moderate pH will support populations of *R. solanacearum.* To exemplify the degree of difficulty in attempts to suppress BW by adjusting soil pH, large volumes of sulfur (800-1200 lbs / acre) were added to the soil in June to drop the pH to near 4.0 at which point, this bacterium does not survive well. Because this pH is too low to grow eggplant, tomato, and potato, the pH was raised to the original level prior to planting by adding 2000 lb of lime per acre in January. This is not done in contemporary times because of the intense logistical problems and cost.

Some soils suppress this bacterium and are referred to as "suppressive soils." The nature of these suppressive soils is not clearly understood, but they are thought to possess bacterial and actinomycotic antagonists to this bacterium. It is not uncommon to see BW commonly at a site year after year but not at a nearby site even when the bacterium is introduced into the latter site. Soils that are commonly dry, such as in the southwestern United States are not conducive for the survival of *R. solanacearum.*

Another source of inoculum is transplants infected with the bacterium. The transplants may not be expressing symptoms at the time of being produced or during transport. Because of the common occurrence of BW in the southeastern U.S., seed is not generally considered to be a major source, if at all, of *R. solanacearum.* However, seed transmission of *R. solanacearum* has been reported for peanut and tomato in Asia and India. It is likely that infested soil adhering to seed could provide a mechanism for transmission. Seed pieces of potato or other clonally propagated material, such as ginger rhizomes, provide sites for the bacterium to exist while being transported. Field equipment (e.g. tractors, implements, hand tools, irrigation equipment, etc.) and pond water that are contaminated with soil from infested sites can be sources of inoculum.

This bacterium can be transported within a field or greenhouse or between sites with contaminated hands, tools and any other object that comes into contact with the bacterium. Such can happen during pruning and tying of tomatoes, suckering and topping of tobacco or root pruning from cultivation. Clipping and mowing plants such as tomato or tobacco is an effective method of transmitting pathogens including *R. solanacearum.*

Damage to roots from nematodes has increased the incidence of BW. Although wounding from nematodes and root damage can increase BW, the bacterium can infect roots without such damage. Roots are naturally damaged as they grow through the soil and as new emerging roots from older roots cause tears in the root tissue which provide avenues for bacterial ingress into the plant. Thus, the bacteria associated with one infected plant can spread to nearby plants and enter into a healthy root system that contains natural wounds. If running water is present such as after a flooding event or in a hydroponic system, the bacterium can move longer distances quickly and ingress into more distant plants.

Besides causing disease inside the plant, this bacterium has an "exterior" phase (epiphyte) where it can reside on the outside of the plant. Wounding infected plants is one way of allowing the bacterium to exude from the inside to the outside of the plant. The bacterium can occur at high populations on the soil near infected plants. From these sources, the bacterium may be splashed with rain or irrigation. This bacterium has survived for 15 days outside of the plant when the relative humidity was in excess of 95%. It does not survive for long periods of time outside of the plant when exposed to hot and dry conditions, especially when sunlight is intense. Conceivably, insects could be attracted to bacterial slime produced on plants or soil and then carry the bacterium to other locations. This has been shown to be an important means of dissemination in banana. Occasionally, *R. solanacearum* infects leaves; such infections occur when the bacteria enter into wounds or stomates (breathing pores in leaves and stems).

Symptoms and Growth of the Bacterium in the Plant

After entering into a susceptible plant, *R. solanacearum*, multiplies in soft, non-vascular tissues first. Usually infection occurs in the roots, but infections in stems or leaves are possible. Through enzymatic activity, the bacterium causes cells within the soft tissues of the plant to bulge and grow into nearby hard vascular cells (tube-like cells that transport water) causing plugs (tyloses) that serve to interfere with water transport from the roots to the upper potions of the plant. As the infection progresses, more vascular tissue is plugged by the tyloses, polysaccharides (complex sugars), and other products produced by limited enzymatic activity from the bacterium. The bacteria, themselves, become so numerous that they add to the plugging significantly and progressively more plant wilting occurs. Such vascular plugging becomes strongly evident in susceptible plants such as tomato and tobacco as the vascular tissue turns yellow to yellow brown and later reddish-brown. The discoloration appears as dark linear streaks when the stems are cut lengthwise. (Figures 1, 2, 3, and 4). The entire infection process from the time of bacterial ingress into the root until the bacteria multiply in the vascular tissue is progressively faster with increasing rates of soil moisture. For example, in one test it required 72 hours for the bacteria to abound in the vascular tissue of plants grown in dry soil compared to 20 hours when grown in wet soil.

In addition to vascular discoloration, soft tissues such as the pith in the center of stems will be discolored as the disease progresses (Figures 2, 3, and 4). Roots of infected plants appear dark and decayed. In potato, vascular tissue extends into the tuber and this tissue, which occurs as a ring near the outside of the tuber, can also be discolored from infection with *R. solanacearum* (Figure 5). Symptoms of BW can occur in tubers after harvest and has been more severe when tubers are harvested from infested fields when soils are warmer due to later harvests or during hotter seasons.

The mass of bacteria become so numerous in the vascular tissue that when a stem of an infected plant is cut and placed into water, the bacteria exude linear streams of slime (Figures 6 and 7). For potato, do not squeeze the stems when placing the stem into water because another bacterial disease called ring rot is more likely to exude the bacterial slime if the stem is squeezed. Ring rot has not been found in Florida for the past several decades, but it was present in Florida in the 1930's and 1940's. In some plant species, such as strawberry, normally considered as resistant to this bacterium, a small amount of infection and vascular plugging occur, but it is not enough to cause wilting. In pepper, true wilt does not occur in Florida (Figure 8), but streaks of vascular browning may be seen when the lower stem is cut lengthwise and leaves may drop.

In susceptible plants, initial wilt may be seen in the plant (Figure 9) between two to 14 days after infection. Longer intervals for symptom expression to occur may result if cooler weather prevails. Typically, soil temperatures need to be 70° F or above at a five- to six inch depth for active growth of *R. solanacearum.* At early stages, vascular discoloration may be slight. Commonly, the earliest wilt symptoms occur during the day but are absent during the nighttime or overcast days when it is cooler and moisture demand of the plant is reduced. Entire plants may remain green but exhibit strong wilt (Figure 10). As the vascular tissue becomes progressively more occluded (plugged), wilting becomes more severe, is less likely to disappear during cooler periods of time, and is more apt to be accompanied by yellow and brown leaves (Figures 11, 12, and 13). Stunting is likely to occur when young plants are infected. Diseased plants may be restricted to localized areas of fields (Figures 12 and 13) or throughout a field (Figure 11). In ebb and flow (hydroponic) production systems in greenhouses, the occurrence of one infected plant on one day can result in all plants being infected in a few days because of the movement of these bacteria through a common water and nutrient system.

Sometimes other pathogens, such as *Pseudomonas corrugata*, may be present by themselves or as a mixed infection with *R. solanacearum* and cause similar symptoms to BW (Figure 14). *Pseudomonas corrugata* causes a disease called pith necrosis (stem necrosis) in tomato where the central pith of the stem becomes hollowed out in pockets. This latter disease will sometimes result in a plant reverting back to a normal appearance, but with BW that will not occur except as described earlier.

Plants infected with either *R. solanacearum* or *P. corrugata* may form bumps at the base of the stem in tomato. These are root initials for secondary (adventitious) roots formed on the stem. Although this symptom is considered one of the diagnostic features for BW and pith necrosis, it should not be relied upon for that purpose. Other dysfunctions in tomato and other plants cause formation of adventitious roots.

Control

Bacterial wilt is among the most difficult diseases to control. The only way to totally control BW is to not plant in fields or greenhouses infested with the pathogen. Crop rotation may help somewhat but is typically not a reliable control for BW. Rotation with fescue has been beneficial for suppression of BW in tobacco in North Carolina, but fescue is not currently grown in Florida. One of the most promising tactics developed so far for suppression of BW in potatoes in the Hastings area is the use of sorghum or sorghum-Sudan hybrids as a summer crop followed by the incorporation of the dried stalk and leaf debris into the soil when the cover crop is mature. Care must be taken not to incorporate these cover crops as a green manure because, BW is likely to be enhanced. Disease incidence was reduced from over 80% to less than 5%. Because some fields are suppressive to *R. solanacearum*, try to use fields that do not buildup this bacterium.

Resistant varieties are available in tobacco to a limited extent but the resistance is incomplete; some plants will become wilted or mildly infected. Fortunately, BW is not a major problem in tobacco in Florida. Resistant varieties are also available in potato but like the resistance in tobacco, the resistance in potato is incomplete. Some of the old line potato varieties such as Sebago, Katahdin, Bel Rus, Ontario (not currently available), La Chipper, Russet Burbank, and Green Mountain are moderately resistant. Interestingly, Bel Rus was found to be a carrier of the bacterium even though it appeared resistant. In the late 1970's and early 1980's, BW recurred as a severe problem in northeast Florida when growers began growing susceptible varieties or those with just intermediate resistance such as Atlantic. From 1941 to 1978, Sebago and Katahdin were the dominant varieties in northeast Florida and during that time BW occurred but ceased to be a major problem when compared to earlier years.

Resistant varieties in tomato are available, but in some of the varieties the fruit size is small (e.g. Venus, Saturn). Some of the more recent varieties with resistance have larger fruit size (e.g. Capitan). These varieties might be acceptable for utilization in gardens, but, so far, they have not been acceptable to the commercial tomato industry. Available resistant varieties may not be resistant at multiple locations. Because of the multiple strains of the bacterium that exist, it would not be unexpected that a variety would be resistant at one location but not at another location. Warmer soil temperatures may offset the level of resistance in some tomato varieties because warmer soils support higher populations of this bacterium. Recently, considerable gains have been made to develop tomato genotypes that have resistance to BW and yet have marketable fruit.

Planting when the soil is cool can reduce the level of BW. In north Florida, planting early in the spring can reduce the exposure time of the plants to *R. solanacearum.* This tactic will not eliminate the problem but would be expected to help in some seasons. This technique is risky unless you have the ability to cover the plants during periods of time when frosts or freezes occur. For home gardeners, this technique is easy to do. Methods for protecting commercial plantings from cold damage are available, but they are expensive and labor intensive. Planting later in the fall in south Florida has been beneficial for suppression of BW. Again, home gardeners have an advantage. For commercial situations, later planting might eliminate favorable marketing periods.

Various sanitary techniques can be employed. Sanitation is used primarily to avoid contamination of an area not already infested with these bacteria. For example, washing soil off of field equipment after it is used in contaminated fields is helpful. This can be done with pressure water washing or use of steam cleaners. Similarly, movement of people or livestock from contaminated fields to non infested fields will allow for movement of these bacteria. Avoid planting in fields that receive water runoff from infested fields. Avoid irrigating with pond or ditch water. Another sanitary technique is the use of well water for irrigation or other purposes. Although well water can be contaminated with pathogens, it is less likely to be so compared to pond or ditch water.

In greenhouse production for fruit or transplants, sanitation is imperative. Plant and transplant production systems should be isolated from crop production fields. Wind-blown soil and insects may carry pathogens from the outside into the interior production areas. Soil from the outside should not be brought in plant production areas or transplant areas. Implements, shoes, gloves and other materials used for indoor production should not be taken outside for use. Soil mixes should be sterilized or pasturized and containers or materials used for production of transplants or fruit-bearing plants should be sanitized before use. Never allow these materials to come into contact with floors or soil when storing them or during planting operations. Keep them elevated from the floor and soil in a location where they will not be contaminated from floor washing or splashing rain. Transplants should be produced on raised benches.

Sumps for ebb and flow irrigation systems should be protected from contamination. Chlorine-containing materials (e.g. bleach) should be used for sanitizing plant production equipment between crops. Clean out all old crop debris from production systems such as PVC lines, sumps and trays before sanitizing them. Do not allow diseased plants or old debris to stay within crop production systems or nearby cull piles. Restrict the people who enter production areas to those who need to enter. Having a foot wash with a bleach solution at the point of entry is suggested. Inspect all plants for dysfunctions and determine as soon as possible what is causing the problem. If it is parasitic disease, such as BW, those plants or trays of transplants should be removed from the premises immediately. For BW in ebb and flow systems, it may be already too late. One system that should be fairly easy to keep from being contaminated is the bag system (one plant/bag) that is irrigated with a drip system from well water.

Use disease-free transplants. Similarly, use only disease-free seed piece stock for potatoes. You should purchase transplants and seed pieces that have been inspected and certified as disease-free within the limits of the inspection process.

Treating soil with chemicals has been attempted many times for suppression of BW. Amending soil with lime to raise the pH has been somewhat helpful. However, if only the upper few inches of soil are treated, it is not likely to provide satisfactory suppression because the roots will eventually grow into the untreated soil. Treatment with lime must include the liming of the deeper strata of soil also for best results. This is difficult to do with available tractor-drawn equipment.

Treating the soil with pesticides has been used also. Because the roots commonly grow out of treated zones of soil or the treated zone becomes recontaminated, such treatments provide partial suppression or delayed occurrence of BW. Soil fumigants with multi-spectrum products such as methyl bromide, chloropicrin or SMDC provide temporary suppression. Fumigant nematicides such as 1,3D provide suppression of nematodes which can enhance BW, but again, the level of suppression will be partial. Granular nematicides are not consistently effective. Combining the use of soil fumigants with resistant varieties has been effective for production of potatoes.

Amending the soil with various types of compost has not been consistently effective. Research on this subject is being conducted, but no soil amendment has excelled up to this point in time. One of the most promising tactics developed so far for suppression of BW in potatoes in the Hastings area is the use of sorghum or sorghum-Sudan hybrids as a summer crop followed by its incorporation into the soil as a green manure when the cover crop is mature. Disease incidence was reduced from over 80% to less than 5%.

Soil solarization has been somewhat effective in Florida in reducing BW as mentioned earlier. It is more effective when combined with the use of broad spectrum fumigants. Soil is solarized by maintaining a clear plastic cover over the soil for at least one month; longer periods of time are likely to be more effective. The key to success with solarization is to have sunny days. If cloudy days prevail, solarization will be considerably less effective.

Figure 1. Dark vascular bands in tomato stem with bacterial wilt.

Figure 2. Dark vascular bands and pith in tomato stem with bacterial wilt.

Figure 3. Dark vascular bands in tobacco stem with vascular wilt.

Figure 4. Dark vascular bands and pith in tobacco stem with bacterial wilt.

Figure 5. Dark vascular bands in stem and tuber in potato with bacterial wilt.

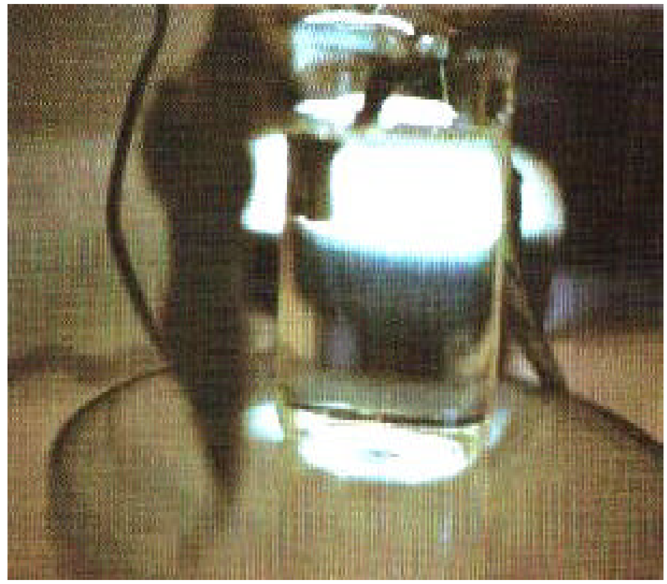

Figure 6. Bacterial flow from bacterial wilt-infected tomato stem immersed in water.

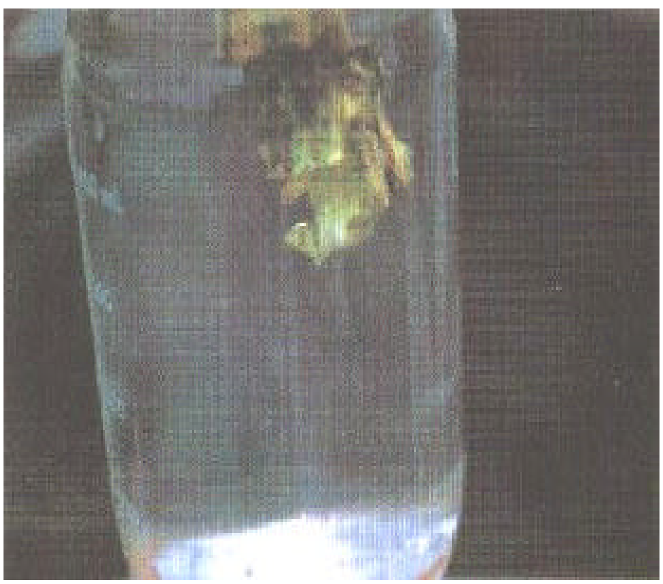

Figure 7. Bacterial flow from bacterial wilt-infected tobacco stem immersed in water.

Figure 8. Symptoms of bacterial wilt in tomato but absent in pepper.

Figure 9. Initial wilting of some leaves in potato with Bacterial wilt.

Figure 10. Bacterial wilt in tomato with green leaves.

Figure 11. Bacterial wilt in tomato with green and brown leaves.

Figure 12. Bacterial wilt (Granville wilt) in tobacco.

Figure 13. Bacterial wilt (Granville wilt) in tobacco.

Figure 14. Bacterial wilt and pith necrosis in tomato.