Fusarium wilt of tomato, caused by *Fusarium oxysporum* f. sp. *lycopersici* race 3 – a soil-borne killer

Kelley Paugh and Cassandra Swett, Vegetable Crop Pathology, Department of Plant Pathology, UC Davis

DISEASE PROFILE

Fusarium oxysporum f. sp. *lycopersici* (Fol) race 3 causes Fusarium wilt, a disease currently affecting most tomato-producing counties in California. Fol is divided into groups called races, based on the ability to overcome genetic host resistance. Fol race 3 is the most recent race, which overcame genetic resistance to race 2. Fol race 3 was long restricted to the Sutter Basin but began spreading in the early 2000s and is now present in every county with large-scale tomato production – making this one of the greatest economic threats to the industry.

Growers are seeking solutions for this damaging soil-borne disease. In this article, we provide an issue overview as well as the latest information on Fusarium wilt race 3 spread, control, and prevention. The focus is on current research that is shining a light on new prospects for management of Fusarium wilt in tomato. This research is ongoing, and updates may be available from your local farm advisor.

Key characteristics of disease. Bright yellow foliage on one or several shoots on an otherwise normal plant are the earliest symptoms, typically starting at about 60 days after planting. The one-sided yellowing of a branch or whole plant can help distinguish this disease from other wilt pathogens (e.g. Verticillium wilt) and other causes of chlorotic conditions (e.g. nutrient disorders) (Figure 1A). From time of initial symptoms to harvest, disease symptoms progress from shoot yellowing to branch death. Disease progression may include decline of multiple branches, leading to partial or entire canopy collapse (Figure 1B). Fruits in this exposed canopy typically develop sunburn and may rot. Another important diagnostic feature of Fusarium wilt of tomato is the presence of chocolate-brown vascular discoloration in the plant stem (Figure 1C). Vascular discoloration is also a symptom of Verticillium wilt, which can lead to misdiagnosis, though usually tan in color instead. At advanced stages of Fusarium wilt, the general canopy collapse is similar to other tomato diseases, such as southern blight, bacterial canker, and Fusarium crown rots. Because of the potential for misdiagnosis of Fusarium wilt even by experienced scouters, it is prudent to submit plant samples to a diagnostics laboratory prior to making management decisions.

Survival and spread. Fusarium wilt race 3 occurs across Central Valley counties from the Sacramento Valley region (Colusa, Sutter, Yolo, Sacramento, and Solano) to the central San Joaquin Valley (San Joaquin, Stanislaus, Merced, Fresno, and Kings) and, most recently, to the southern end of the San Joaquin Valley (Kern) (Figure 2). The pathogen is thought to move within a field and locally from field to field by hitching a ride on farm equipment that is contaminated with plant debris and soil. Hence, the increased movement of farm equipment across processing tomato regions may have facilitated spread of this disease. There is also speculation that the pathogen could move between fields or within a field in pathogen-laden irrigation water. For example, furrow irrigation may disperse the pathogen down planting rows with the flow of water. At present, there are no studies to substantiate this means of spread.

Once present in the field, this pathogen can persist for several years in soil. Although Fol can only cause *disease* in tomatoes, it can infect many different non-tomato crops, including melons, pepper, and sunflower and without causing any symptoms, and persist in both tomato and non-tomato crop residue in soil. Thus, Fol can feasibly be introduced into a field that has never had tomato, propagate on these silently-infected crops, and cause severe losses in the first year the field is planted to tomato. These "silent" hosts may be the reason that Fusarium wilt has historically been considered extremely long-lived in the field, especially in cases where rotation out of tomato was ineffective. Of note, there are also many Fusarium wilt diseases of rotation crops (e.g., Fusarium wilt of cotton, garbanzo, melon, lettuce), but these Fusarium wilts are all caused by completely different pathogens. Therefore, the pathogen causing Fusarium wilt in these other crops will not cause Fusarium wilt in tomato.

MANAGEMENT

Overview of IPM for Fusarium wilt. The most effective tool for Fusarium wilt management is preventing pathogen introduction. If introduced into a field, then the disease can usually be successfully managed with resistant cultivars (F3 cultivars), although there are some caveats in F3 efficacy. If F3 cultivars are not available for management, pathogen-tolerant cultivars and early season chemical management options are also available. Crop rotation can help reduce pathogen pressure and reduce the risk that an F3 resistance-breaking race will emerge (race 4). At present, Fol race 4 has not been detected anywhere in the world, but UC Cooperative Extension advisors and specialists continue to monitor for its emergence annually. If you see Fusarium wilt symptoms in your F3 field, contact your local farm advisor to submit samples for testing.

Effective management of Fusarium wilt requires accurate diagnosis. As noted above, there are many diseases that look like Fusarium wilt, and at present, it is challenging to differentiate these diseases in the field. Before developing a Fusarium wilt management plan, it is critical to submit samples for analysis by a diagnostic lab. Soil testing tools for Fol race 3 are also under development at UC Davis (contact C. Swett for more information).

Management with host (genetic) resistance. Fol race 3 resistant cultivars, called F3 cultivars, typically develop no disease and are an excellent management tool. The tomato industry has worked hard to overcome challenges in F3 cultivar quality, yield, and seed availability. In addition, certain F2 cultivars are "tolerant" of Fusarium wilt race 3 – in that their yield does not appear to be significantly impacted in mildly infested fields. Fusarium wilt tolerance is not a listed trait for existing commercial cultivars, but this information is often available through seed dealers.

In some cases, F3 cultivars develop Fusarium wilt due to Fol race 3. This is typically attributed to either the presence of off-type plants which did not get the resistance gene (when incidence is below 2%) or environmental stresses (when incidence is higher). Abiotic and biotic stresses appear to play a role in influencing stability of resistance. Recent studies have demonstrated that salt stress can compromise F3 resistance and lead to Fusarium wilt development in up to 30% of F3 plants in a field. Likewise, root knot nematode and herbicide damage have both been associated with higher incidence of Fusarium wilt in F3 plants; previous studies have shown that root knot nematode could compromise genetic resistance to Fol race 1. While the role of various stresses in mediating Fol race 3 resistance is not well characterized, research in this area is ongoing. Management of these stresses may help maintain the efficacy of host resistance against Fol race 3.

Chemical control pre- and post-planting. Fol race 3 is notoriously difficult to control once established in soil. Although host resistance is the gold standard for management, F3 cultivars are not always an option. Chemical management may function as a short-term alternative. Recent studies have shown promising results for pre-plant fumigation as chemigation via buried drip irrigation with K-Pam HL (AMVAC Corporation) at 30 gal/A or higher (maximum rate of 60 gal/A) for optimal efficacy (Figure 3). Further work is needed to understand the cost-benefit aspects of using K-Pam HL to increase yield in infested fields.

Crop rotation. Rotation with non-host crops can reduce pathogen build up and survival in soils. However, the efficacy of this method relies on the inability of the pathogen to infect rotation crops. In multi-year studies we have found that several rotation crops are poor hosts and/or suppressive to pathogen build up in soils; these include cotton, bean crops (i.e., garbanzo, fava, lima, and green bean), grass crops, including wheat and potentially corn and rice (poor hosts, not field tested), as well as onion (Figure 4). These appear to be good crops to grow either right after tomato or the year before planting to tomato. Some crops, such as pepper, melons, pumpkins, and sunflower, are extensively colonized by Fol race 3 – even though these crops do not develop symptoms. Rotation with these heavily colonized crops can result in Fusarium wilt losses similar to what occurs with a repeat planting of tomato. Therefore, rotation with these crops should be avoided when possible, especially within a year before or after planting to tomato. Ongoing studies will further clarify the minimum duration that is needed for crop rotation to suppress disease.

No free rides for pathogens. The most effective tool for Fusarium wilt management is preventing pathogen introduction. This is best achieved through sanitation of equipment between fields. There is limited information on which equipment is the most important to target for sanitation, but *Fusarium* has been found at high levels on harvesters which retain large amounts of plant debris (Figure 5). Only using equipment that remains within the farm and avoiding use of shared equipment can help reduce the chances of pathogen infection and spread. However, this option is not available for many producers and is ineffective for preventing pathogen spread within a grower-controlled farm. There may be potential to minimize spread using an effective sanitation regime – perhaps including chemical disinfection or steam sterilization and using scrapers for physical removal of the bulk of plant debris and soil. There is a strong need for further study of the relative efficacy and logistics involved in implementing effective disinfestation practices.

Further management options under study. Compost amendments are commonly used for soil fertility management, and our recent studies suggest that composts may also suppress pathogen survival in soil. Pathogen-infested tomato residue decomposes more rapidly in soil with long-term inputs of poultry manure compost. Similarly, cover crops such as hairy vetch and broccoli are reported to suppress other Fusarium wilts, and these are being examined for Fusarium wilt of tomato in ongoing work.

WHERE TO GO NEXT

There are no documented cases of Fol race 4 in California – but, given the history of this pathogen, it is almost inevitable that a new race (race 4) will emerge that overcomes the genetic resistance that is effective against Fol race 3. As a result, race 4 monitoring continues to be a top priority across the state. Another concern is that Fol race 3 has been documented as causing disease in multiple F3 tomato fields, with indication that F3 resistance is compromised by stress. Understanding how biotic and abiotic plant stresses affects host resistance can help growers prioritize management strategies. In addition, long term studies of pathogen survival in soil are important for establishing both the optimal duration for rotating out of tomato and best choices for rotation crop. There are still several common rotation crops with unknown risk status, including corn, rice, safflower, alfalfa, and potato. To improve decision support, more accurate and rapid diagnosis and detection tools are needed for Fol race 3; the UC Davis Vegetable Pathology program is working to improve molecular tools for both soil detection and diagnosis in plants. Industry innovations in effective sanitation of farm equipment could also provide a breakthrough in slowing spread of Fusarium wilt and other soil-borne pathogens. Developing comprehensive strategies that minimize damage wrought by this disease will be critical for achieving healthy tomato production in California.

For more information, please contact: Cassandra Swett, clswett@ucdavis.edu

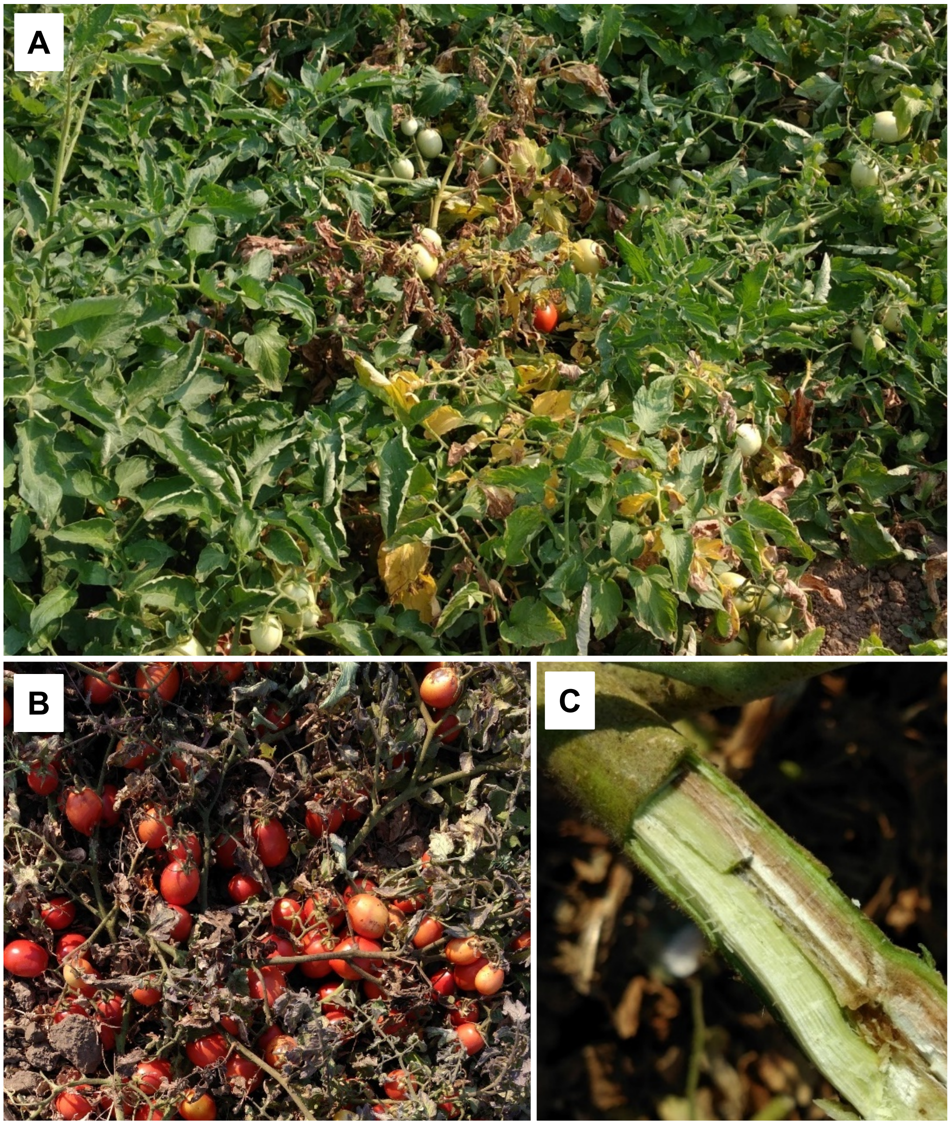

Figure 1. Symptoms of Fusarium wilt in tomato plants, shown here as a shoot with bright yellow and dying foliage (also known as “yellow flagging”) on an otherwise healthy plant (A), collapse of the vine (B), and chocolate-brown discoloration inside a stem (C). Photos taken by Kelley Paugh.

Figure 2. California counties with documented cases of Fusarium wilt race 3, as highlighted in red.

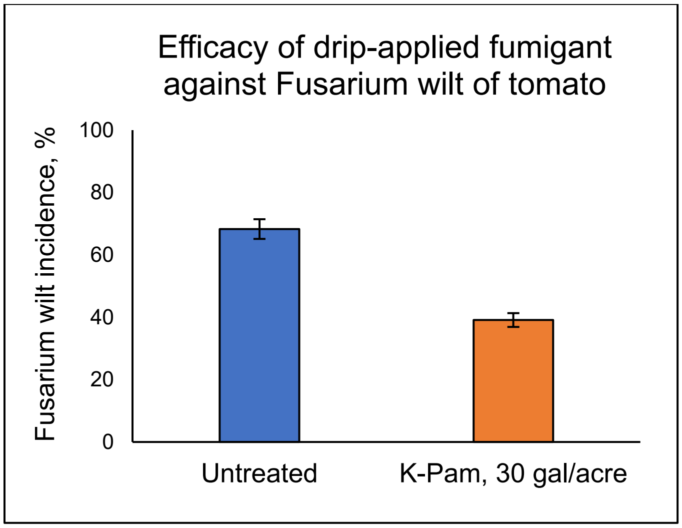

Figure 3. Results for a 2019 small plot trial at the UC Davis Plant Pathology research farm on the efficacy of the drip-applied fumigant, K-Pam HL, against Fusarium wilt of tomato. The experimental plot was too highly infested with the pathogen to observe a significant effect on yield; accordingly, K-Pam HL may be unsuitable for use in fields with high disease pressure.

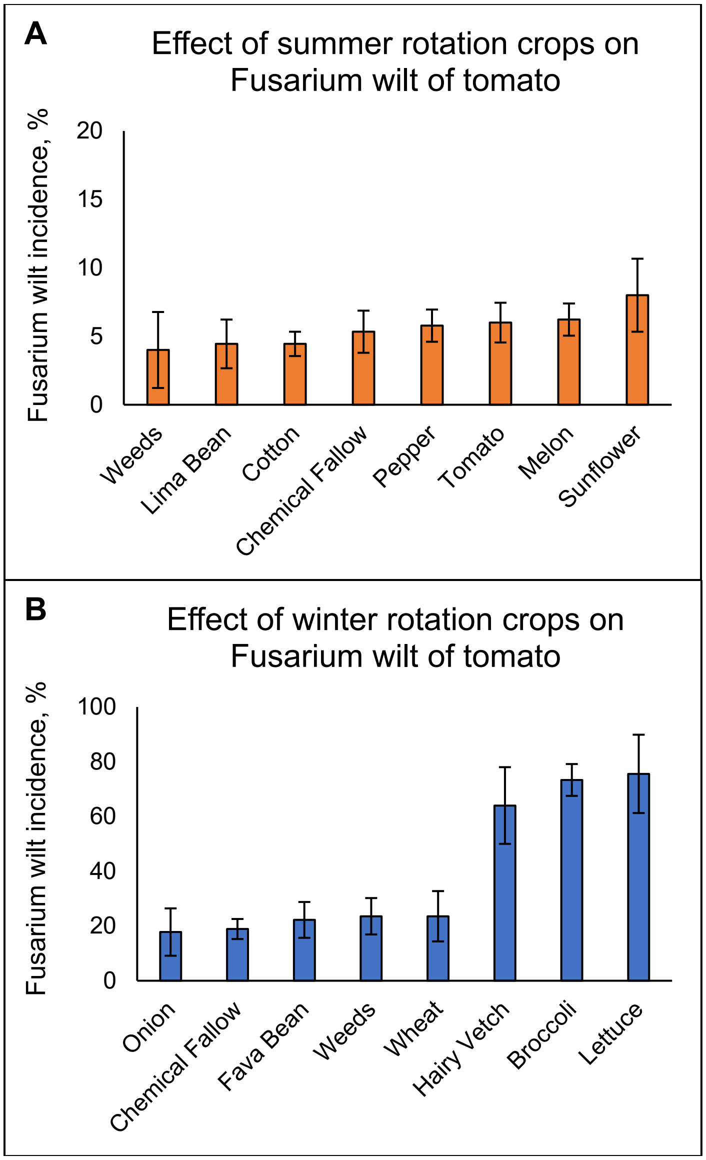

Figure 4. Results for small plot trials on the effect of rotation crop on development of Fusarium wilt in tomato. Plots at the UC Davis Plant Pathology research farm were previously planted to either a summer or winter rotation crop or tomato or left in chemical fallow (i.e. maintained vegetation-free through herbicide applications) or unmanaged fallow (="weeds"; weed species were not catalogued) in summer 2019 (A) or winter 2019-2020 (B), respectively. Plots were artificially infested with pathogen propagules during summer and winter rotation crop plantings. Yield impacts were not assessed in these experiments.

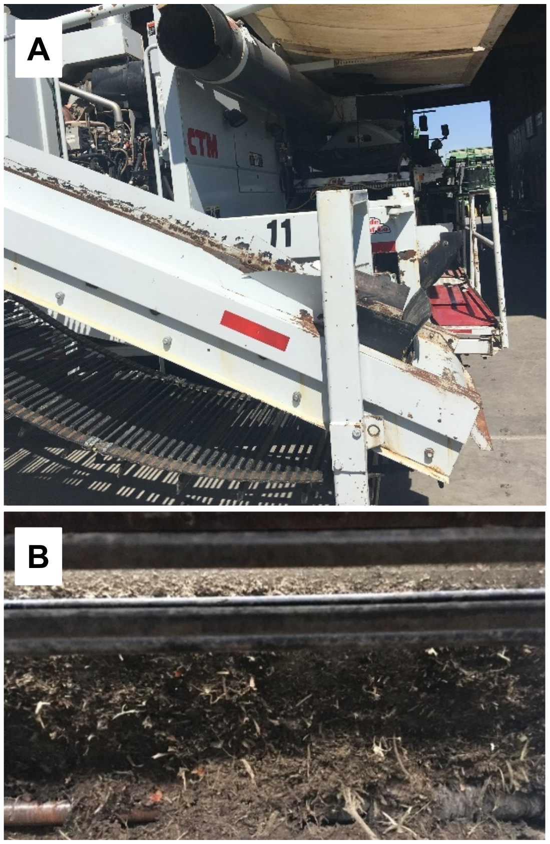

Figure 5. A tomato harvester (A) and soil and plant debris buildup on parts (B). Photos taken by Cassandra Swett.