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Citrus Root Growth and Soil Pest Management Practices[1]

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The root system of the citrus tree is composed of an integrated network of woody lateral roots from which arise bunches of fibrous roots. A prominent taproot may not always be present in mature citrus trees. Major pioneer roots radiate out in all directions from the tree trunk, forming the framework of laterals roots, are primarily responsible for root system expansion. Fibrous roots, emanating in bunches from woody lateral roots, are the primary sites where water and nutrient uptake from soil occurs. The most important functions served by the citrus root system include anchorage and support as well as a means of collection and transport of water and nutrients essential for tree growth.

Soilborne pests which feed and proliferate on the citrus root system can seriously affect root system function, directly affecting tree growth and yield. Conversely, citrus root growth, distribution, and availability as a food resource can have a profound influence on pest population dynamics. Understanding the interaction between citrus roots and pest population growth is critical to the development and implementation of sound, biologically based, pest control practices. The objective of this report is to summarize relevant information regarding citrus root and pest population growth and distribution, and to relate this information to citrus integrated pest management (IPM).

CITRUS ROOT GROWTH

Citrus root growth is greatly affected by environmental factors, particularly soil temperature and moisture. Three distinct cycles of root growth have been observed in mature trees growing in Arizona, California, and Florida. The first root flush in Florida usually occurs between late February and early April, the timing of which is regulated by prevailing environmental conditions. The timing of the two remaining flushes are inconsistent, varying considerably between years and trees. However, distinct bursts of root growth frequently occur during the periods of May-June and again during August through October. It should be recognized that during the warm months, active periods of root growth can occur at any time in a series of smaller, reduced flushes or as major peaks of root growth activity. There is also some indication of biennial patterns of root growth in Florida citrus. The magnitude of root growth during one year may inversely influence root growth during the following year.

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In general, root growth is periodic during the months of February to early December with periods of inactivity occurring only during periods of shoot flush. During spring, summer, and fall, alternation of root and shoot growth has been repeatedly observed. For example, root growth activity declines with the initiation of each new shoot growth flush and then increases immediately after the cessation of shoot elongation (Figure 1). This alternation of growth is thought to occur as a result of competition between roots and shoots for photosynthetic carbohydrates.

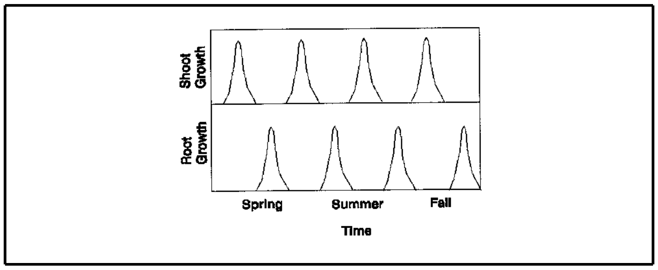


Figure 1.

In addition to carbohydrates availability, temperature and soil water content appear to be other important factors governing citrus root growth. The minimum temperature at which citrus roots will grow is approximately 54 F while in controlled experiments, maximum citrus root growth occurs between 78 and 90 F. In Florida studies conducted in buried observation chambers, root growth increased as the mean monthly soil temperature increased during spring and summer and decreased as soil temperatures declined during the fall and winter (Figure 2.). The most active period of root growth occurred during the summer when soil temperature was above 80 F. Seasonal differences in soil temperatures within and between years can greatly affect the timing and magnitude of root growth processes.

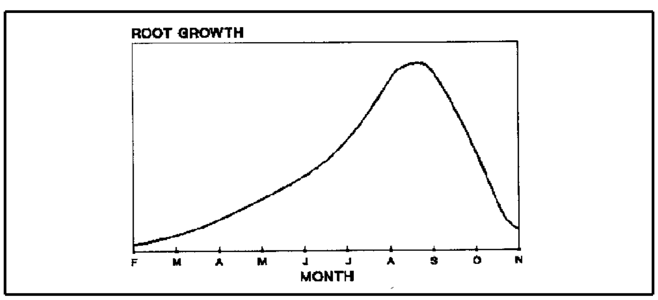


Figure 2.

Much of the new growth which occurs during the year serves to expand the citrus root system and to replace roots which have died or are no longer functional. Shedding of fibrous roots may occur at all times of the year, but highest turnover apparently occurs during the winter months and is probably related to lack of available carbohydrates. Fibrous root loss is also enhanced by severe pruning and freeze injury or as a result of unfavorable soil conditions and disease. Due to the significant loss of fibrous roots which occurs after a severe freeze, nematicide and fungicide treatments (and probably water and other agrochemicals) should be delayed until new fibrous roots develop and the balance between roots and shoots is restored. Significant fibrous root losses can also occur in water saturated soils due to poor aeration and anaerobic conditions. In the flatwoods, the cause is generally related to poor drainage, fluctuating water tables, or significant bed erosion. In these cases, improvements in drainage and irrigation systems and bed reconstruction should be conducted prior to consideration of soil applied pesticide treatments.

PEST POPULATION GROWTH

Similar to the seasonal bursts and temperature regulation of fibrous root growth, two population peaks of the citrus nematode, *Tylenchulus semipenetrans*, and of *Phytopthora parasitica*, causal agent of fibrous root rot, are known to seasonally occur in mature citrus (see Nematology Plant Protection Pointer NPPP-27). Nematode and fungal population cycling is closely associated with and commonly follows major spring and fall periods of root flushing. Root flushing and pest population cycling are closely interrelated because susceptible root tissues are produced prior to or during periods of soil temperatures conducive for nematode and fungal population development. The first population peak for both organisms usually occurs in April-May following the spring root flush when soil temperatures become favorable for development and again in October-November, following a fall root flush. Populations of Phytopthora and citrus nematode, like fibrous root growth, are usually at low levels during winter, from late December through February. Even though soil temperatures are conducive for development, lowest nematode population levels occur during summer. In contrast to citrus nematode, fungal activity and population abundance of Phytopthora often remain high during summer, corresponding with periods of active fibrous root growth and periods of high soil moisture and temperature. During active periods of root growth, available carbohydrates or some other chemical fraction within fibrous roots may represent the regulating factor which allows for an increase in pest population growth.

The close correspondence between citrus nematode and Phytopthora population growth with root flushing also strongly suggests the importance of timing of pesticide applications to maximize fungal or nematode control. Treatments are likely to be most effective if made in the early spring or fall prior to root flushing as soil temperature becomes optimum for nematode or fungal development. Most studies indicate the first cycle of root growth to follow the spring shoot flush. For purposes of timing spring pesticide treatments, monitoring of shoot flush activity in the spring may provide a reasonable approximation of initial root flush activity. It is important to recognize that root growth patterns between trees within a grove may not be synchronous, suggesting that the grove in general should be evaluated with regard to maximum shoot flush in making pest management timing-based decisions.

CITRUS ROOT DISTRIBUTION

Most studies of citrus root distribution in Florida have shown the potential for citrus to root very deeply and extensively under favorable environmental conditions. These studies showed that the depth of rooting was influenced by tree age, rootstock, soil type, and drainage characteristics. For example, citrus grown in the deep sandy soil of the central ridge area of Florida may root as deeply as 18 feet with over 50% of their fibrous roots located below 30 inches. More recent studies involving a range of rootstocks indicated a rooting depth from 7 to 12 feet. With the exception of some of the more vigorous rootstocks such as rough lemon grown on deep sandy soils in Florida, most of the fibrous roots are usually located within the top 24 to 30 inches of soil with significantly fewer roots occurring at greater depths (Figure 3.). In contrast, root growth in poorly drained flatwood soils, where trees are grown on raised beds and confined at depth by water or a hardpan layer, rooting depth is often limited to 28 to 40 inches and 75 percent of the roots are found in the surface foot of soil (Figure 3.).

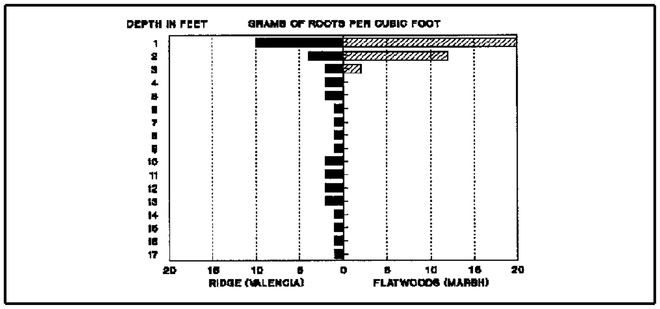


Figure 3.

The principal soil characteristics which limit vertical development of the citrus root system include poor drainage and a compacted or poorly aerated soil layer. Root growth studies in the poorly drained flatwood regions have shown rooting depth to be severely limited by high water tables. A close correspondence between the average depth of the water table and the depth to include 75 % of the root system was observed. In contrast, enhanced fibrous root growth above the water table in fine sandy soils has been observed where the height of the water table was stabilized by tile drains. Subsoil clay layers, limestone or marl horizons, soil pH below 5.0, and high levels of metals(copper, zinc, manganese) have been shown to restrict rooting depth.

Studies of the lateral distribution of citrus fibrous roots have shown that the highest density of roots in the surface 2 feet of soil grow directly under the tree canopy and decreases markedly with distance from the trunk towards the row middle. This is not to say that lateral roots of the citrus tree do not often extend well beyond the tree canopy. In fact, citrus roots have been detected up to 46 feet from the tree trunk in a rain fed 44 year old planting of rough lemon. In general, however, the most recent studies of root distribution in irrigated citrus indicate that fibrous root density is highest near the surface and decreases with depth and distance from the trunk.

Fibrous root distribution can also be strongly influenced by tree spacing. In high density plantings, lateral spread and overlap of roots between adjacent trees in a row can occur quite rapidly. Lateral spread of surface roots to a distance of 6 ft from the tree trunk has been observed as soon as 18 months postplanting in both bedded and nonbedded planting systems. With time, the overlap becomes most dramatic in surface soil horizons where fibrous root density is significantly higher than trees planted on wider spacings. Trees on closer spacings often develop a deeper root system with over significantly more of the fibrous roots below the surface 12 inches of soil. At present it is not clear whether closer tree spacings will ultimately limit root development for all rootstock-scion combinations or increase root competition for water and nutrients which will then limit individual tree growth and per acre yield.

The affect of tree spacing on root spread and overlap between adjacent trees can also influence nematode population development. Two factors may influence the rates of nematode increase under newly planted, closely spaced, young trees. In widely spaced young trees, nematode population growth is generally slow until the canopy develops and shades the soil providing for more favorable soil temperature for nematode infection and development. Closer tree spacings may also accelerate nematode population growth due to the rapid closure and overlap of the citrus root system thereby providing an earlier, larger food supply for population increase.

With regard to nematicide placement, the distribution of citrus fibrous roots with distance and depth from the tree trunk is of practical importance. Nematicides are often placed in bands centered for the most part on the tree canopy dripline . The proportion of fibrous roots likely to come in direct contact with the nematicide is directly related to the downward movement of the toxicant. Nematicide treatment bands shifted in towards the trunk and expanded in width will generally contact a significantly higher proportion of the undercanopy root system. For example, on trees with driplines of 8.5 ft from the tree trunk, nematicide treatment bands moved 2 feet toward the trunk and increased in width from 3 to 4 feet, directly contacted 46 to 87 percent more of the undercanopy root system on the row middle tree side than treatments centered on the tree dripline.

tree canopy dripline.

Potential benefits derived from more undercanopy placement include improved tree and yield response, presumably due to enhanced uptake and improved efficacy with regard to overall undercanopy nematode populations. In most documented cases, nematode control occurs primarily within the zone of application and to a lesser degree, due to systemic activity, within and around roots outside the zone of application. A number of field trials have indicated that nematicide placement under more of the tree canopy significantly improved overall nematode control by targeting applications to areas of highest fibrous root and nematode density.

In practice, however, treatment of roots at the dripline and under the tree canopy may not always be possible. Some granule applicators are not sufficiently offset to apply and incorporate nematicides beneath the canopy of the tree. In other cases where machinery is available, concerted efforts are not made to extend and maintain applicator booms undercanopy. This may occur because of obstructions within the grove or for the sake of speed and reduced labor costs. Growers have the responsibility to guarantee that proper placement occurs by demanding that applicators achieve proper placement.

Growers must also recognize and evaluate other potential negative side effects associated with tillage-type incorporation equipment. For example, damage to and pruning of surface fibrous roots must be considered, particularly in groves with shallow root systems or during periods of environmental stress. Potential for significant fruit loss or limb damage in groves with low canopy skirts must also be considered. On rootstocks which sprout in response to injury, undercanopy incorporation of granules may also increase sprout incidence.

EXCLUDING ROOT GROWTH INTO NEMATODE BARRIERS

Spreading decline (Plate 4, Plate 5), caused by the burrowing nematode, *Radopholus citrophilus*, is a citrus disease confined principally to the deep, sandy soils of the central ridge of Florida. Prior to the widespread adoption of irrigation, yield reductions of 40-70 % were commonly observed, resulting from the near complete destruction of citrus fibrous roots below 30 inches. Burrowing nematode damage now can be mitigated in large degree, simply by maintaining an adequate water supply (usually requiring supplemental irrigation) within the surface soil profile above 30 inches. The use of herbicides, rather than disking for weed control, can also help maintain shallow root density in the row middles. Disking in row middles for weed control can significantly reduce shallow fibrous root abundance beyond the dripline while promotion of root growth in the row middles has been observed following prolonged use of herbicides.

Plate 4.

Plate 5.

With containment programs, burrowing nematode buffers are used to restrict the spread of the burrowing nematode from infested to noninfested areas of a grove. To construct a buffer, rows of trees are removed well in advance of the known infestation and maintained as a weed free, bare soil, buffer zone. In the past, buffer zones were chemically treated twice annually to prune deep roots to prevent movement of the nematode into noninfested areas. With the loss of chemical treatments (EDB) in 1984, mechanical pruning of deep roots along the edges of the buffers was recommended for burrowing nematode containment. The practice has been only partially successful. When trenches are dug outside of the canopy dripline to a maximum depth of about 5 ft, many of the deep lateral roots which extend into the row middles, below the level of the trench, are not severed. Vertical hedging of trees to allow trenching closer to the tree trunk will significantly increase the number of major lateral roots which are cut and reduce the potential for intergrove spread.

mechanical pruning.

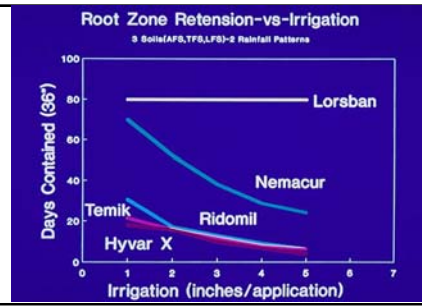
Other cultural practices which should be employed to reduce the rate of root growth into buffers include complete elimination of irrigation and fertilization of bare soil zones between the tree rows along the edges of the buffer. Rows of trees bordering the buffer should be irrigated and fertilized only on the side interior to the buffer. Maintaining strict policies regulating between grove vehicular traffic should also be enforced. Grove implements utilized within infested groves should be committed exclusively for use within infested groves or cleaned and sterilized prior to use noninfested areas. This will reduce the risk of cross contamination within or between groves.

IRRIGATION

Irrigation practices also affect citrus root system development and distribution. For example, the highest concentration of fibrous roots develops under drip-irrigated systems within the volume of wetted soil around the emitters. When a new irrigation method is introduced into a grove, high fibrous root densities develop within the irrigated areas while remaining unchanged in the nonirrigated areas. Thus, transition from one form of irrigation to another can result in a redistribution of the root system. In California, changing from tillage and furrow irrigation to non-tillage and sprinkler irrigation increased the quantity of roots in the top 60 inches as well as the proportion of roots in the surface foot of soil. The transition in fibrous root abundance and redistribution was not immediate and required a period of six years.

The relationship between root distribution and water extraction from soil has not been studied in any great detail. Research conducted in Florida shows that soil water depletion is directly related to water availability and fibrous root abundance. The general pattern of water absorption by citrus trees suggests that water is depleted first in surface roots experiencing high soil water content. As the available water supply decreases in the surface soil there is an increase in absorption from roots at successively greater depths in advance of the drying front. This would suggest that if nutrients or pesticides are readily leached by rainfall or irrigation water, an irrigation delay following application may be beneficial to minimize rapid leaching and to maximize absorption first within areas of highest fibrous root abundance.

It should also be recognized that many pesticides will leach, in some cases to groundwater, if attempts are not made to restrict or manage their residence in soil. The apparent failure to control nematodes in soil for an extended period is probably the result of excessive irrigation in many instances which results in poor chemical retention time in the primary root zone of the tree. In the sandy, low organic matter soils of Florida, nematicide efficacy is likely related to depth of movement and distribution of pesticide within the wetted zone. In soils with rapid rates of water infiltration, serious dilution effects may occur if the pesticide advances downward too rapidly with each water front. Optimal timing and amounts of irrigation water following nematicide application may therefore be critical for adequate nematode control. In Phytopthora infested groves, avoiding excessive amounts of irrigation is also of equal importance because disease severity increases significantly when soils remain moist for prolonged periods, particularly during hot weather.



excessive irrigation.

CONCLUSION

Citrus tree growth and productivity is closely linked with root system health and both can be seriously affected by different soil borne pests and diseases. Very little information has been summarized for growers use which connects host-parasite relationships to soil pest control strategies. This has occurred primarily because of the hidden, below ground, nature of the problem, and because of the difficulties in generalizing environmental and production factors which impact pest and root growth processes. It is now becoming increasingly clear however, that some basic understanding of host parasite relationships is fundamental to the development of site specific, biologically based, citrus integrated pest management. For example, the close correspondence between pest and root system growth has emphasized the importance of pesticide timing and placement, particularly with respect to root system distribution and abundance. Production costs and environmental concerns are also enforcing recognition that the integration of chemical and cultural control practices with sound principals of water management are vital concerns for today's citrus grower.