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Best Management Practices in Citrus Production

Farhat Abbas • Ali Fares*

Department of Natural Resources and Environmental Management, University of Hawaii, USA

Corresponding author: * AFares@Hawaii.edu

ABSTRACT

There are growing concerns about the environmental impact of intensive agricultural production including citrus cultivation on our natural resources, i.e., water resources. In addition to enhancing citrus tree growth, fruit yield, and quality of citrus orchards, the properly adopted citrus best management practices (BMPs) should help protecting our environment. Thus, the goals of citrus BMPs are to integrate different approaches to optimize irrigation water and minimize surface- and sub-surface transport of nutrients and pesticides, and control citrus related pests, weeds, and disease attack. This article reviews the major citrus BMPs including: i) citrus irrigation management, ii) citrus nutrient management, and iii) citrus pests, weeds, and disease control. Environmental impact of citrus cultivation on our water resources, if the recommended BMPs are not properly adopted, are also discussed. The information presented in this article should help scientists, professionals, and citrus growers adopt the recommended BMPs for sustainable citrus cultivation.

Keywords: citrus best management practices, disease control, environmental impacts, irrigation management, nutrient management, pest management, weed control

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INTRODUCTION

Citrus is native to eastern Asia, having been known in China more than 4,000 years ago (Sauls 2008) and is now produced worldwide. The top five citrus producing countries include Brazil, US, China, Mexico, and India, which produce 20, 14, 12, 6, and 5%, respectively, of the world citrus that was estimated at over 105 million tons in the period from 2000 to 2004 (UNCTAD-FAO 2005). Florida (67%), California (29%), and Texas (3%) are the three top citrus producing states in the US (USDA-NASS 2006). Smajstrla and Haman (1996) reported that over 37% of the total irrigated acreage of Florida (i.e., 930,777 ha) is under citrus production. California, the second largest citrus producer in the USA, produces navel orange fruit on 50,336 ha (Carol and Faber 2008). Texas ranks third in the US citrus production, with annual production ranging from 350,000 to 400,000 tons from 12,950 ha, the 83% of which is based in the Rio Grande Valley's Hidalgo followed by Cameron and Willacy counties (Holloway and Smith, n.d).

Citrus produced in arid, semi-arid, and even humid regions need supplemental irrigation to enhance their fruit yield. Surface, sprinkler, and drip irrigation systems are generally used to irrigate citrus groves in Florida (Smajstrla and Haman 1996), California (Carol and Faber 2008), and Texas (Sauls 2008). In addition, large amounts of chemicals are employed in the management of insect pests, weeds, and citrus related diseases. Many citrus orchards are located on sandy loam or loamy sand soils in Florida (Alva *et al.* 2003), California (Zhang *et al.* 2003), and Texas (Sauls 2008). A portion of input water (irrigation or rainfall) is retained in the soil for plant use and the excess water drains through the soil profile into the groundwater. The leached water may contain agricultural chemicals and soluble nutrients (Fares and Alva 2000). In the early 1990s, The Florida Department of Environmental Protection (FDEP) revealed that the level of nitrate-nitrogen (NO_3-N) in groundwater of surficial aquifer in the citrus production areas of central Florida, was above the US-EPA maximum contaminant level of 10 mg L^{-1} (Alva *et al.* 1998). Groundwater contamination

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with NO_3-N and with other contaminants is the result of leaching of excessively applied nutrients, followed by rainfall and irrigation events (Balogh and Walker 1992; Starrett *et al.* 1995).

Environmentally-protective, science-based, economically-viable, and problem-focused best management practices (BMPs) should be adopted to counter the adverse environmental impacts of citrus cultivation practices (Parsons and Boman 2006). The target of citrus BMPs is to optimize irrigation water, minimize nutrient leaching below tree rootzone, enhance plant nutrient uptake, and maintain optimal fruit yield (Alva *et al.* 2006). Proper implementation of citrus BMPs is a challenging task as they are not regulatory or enforcement-based, but strictly voluntary (Zekri 2007). Citrus cultivation without the adoption of BMPs, could result in soil degradation and surface- and sub-surface water contamination (Lipecki and Berbec 1997; Castillo *et al.* 2003; Durán Zuazo *et al.* 2004). This paper discusses major citrus BMPs, i.e., citrus irrigation BMPs, citrus nutrient BMPs, and citrus pests, weeds, and disease control practices. The paper also presents the environmental impact of citrus cultivation if the recommended BMPs are not followed properly. The environmental impacts are discussed based on soil and surface-, and sub-surface water contamination.

CITRUS IRRIGATION BMPs

Citrus irrigation BMPs are adopted to primarily optimize irrigation water and eventually minimize nutrient leaching. The right amount and right time of irrigation application (i.e., irrigation scheduling) are crucial for achieving the optimum benefits from irrigation practices (Fares *et al.* 1997). Best irrigation management can be achieved by using efficient irrigation systems that assure uniform application/ distribution of irrigation water and prevent irrigation water losses.

Citrus irrigation systems and management

Microsprinklers, drip or trickle, and surface/flood irrigation are among the common citrus irrigation systems (Kusakabe *et al.* 2006). Feasibility of these systems is based on the scale of farming, topography, soil texture, irrigation water availability, and grower's affordability. One system may be more efficient under one set of conditions, but may not be better than the others under different sets of conditions, due to the irrigation system's water use efficiency that varies with soil properties and crop characteristics and not with with the application system itself (Tennakoon and Milroy 2003). Soil properties, such as soil texture, structure, organic matter content, permeability, water holding capacity, and infiltration rate, influence irrigation water use efficiency (Viets 1962). Crop characteristics that influence irrigation water use efficiency, include plant root structure, root distribution, and rooting depth or stage (Tennakoon and Milroy 2003). Irrigation water use efficiency generally refers to a) the volume of water beneficially used relative to the volume delivered from an irrigation system or b) the increase in crop yield over non-irrigated yield relative to the volume of water applied by an irrigation system (Smajstrla *et al.* 1991). Irrigation system's water use efficiency follows the first definition. The pressurized irrigation systems (i.e., sprinkler and drip systems) have substantially higher irrigation efficiency as compared to the traditional, surface irrigation methods (Sanchez and Peralta 2003).

Contrary to the conventional sprinkler irrigation systems that operate with high pressure pumps, the microsprinkler irrigation systems are low volume systems operated at a comparatively lower pressure. The high pressure systems are used for agricultural crops, whereas microsprinklers are preferred for nurseries and fruit orchards that are especially planted in rows, e.g., citrus groves (Hla and Scherer 2003). Several types of microsprayers, microjets, and spitters are usually grouped as microsprinklers (Phocaides 2000) that are used to irrigate citrus orchards and for freeze protection. Microsprinklers evenly distribute irrigation water over citrus floors with higher application efficiency (i.e., 60–70%) as compared to that of flood irrigation (50–60%) (Smajstrla *et al.* 1991). Burt *et al.* (1997) present various definitions of irrigation system efficiency and distribution uniformity. Under-tree microsprinklers are recommended as a practical and efficient system for citrus irrigation as compared with conventional sprinklers that operate between the tree rows (Grieve 1989).

Drip or trickle irrigation is a technique of point application of irrigation water to the soil where plant roots grow extensively (Goldberg *et al.* 1976; Nir 1982). Water is frequently applied to maintain favorable soil moisture conditions, avoid moisture stress, and assure optimum plant growth (Burt and Stuart 1994; Yildirim and Korukcu 2000). The primary advantage of this system is its high application efficiency (80–90%), as compared to those of sprinklers or surface irrigation systems (Smajstrla *et al.* 1991). The high irrigation application efficiency of drip irrigation systems is a result of minimal evaporation (Baars 1976; Fares *et al.* 1997; Nakayama and Bucks 1986) and negligible deep percolation of water (Baars 1976; Nakayama and Bucks 1986). Since the drip irrigation system applies a controlled and precise amount of water to the field, the negative impact, i.e., surface runoff, soil erosion, deep percolation, or nutrient leaching are avoided (Nir 1982; Phocaides 2000; Yildirim and Korukcu 2000). Drip irrigation systems are ideal for irrigating young citrus trees and facilitate the establishment of mature orchards (Sauls *et al.* 1997).

Flood irrigation or ponding delivers large scale irrigation to agricultural fields or orchards and is further categorized to basin, border, and furrow irrigation systems. During basin irrigation, a bowl-like basin, approximately equivalent to the size of the plants canopy diameter, is constructed around the tree trunk. The basins in an orchard are interconnected through open channels or by plastic pipes to divert water from one basin to the other. For border or furrow irrigation, the fields with a gentle slope are divided into long strips separated by earth bunds. The advantage of flood irrigation is that the water percolates deep into the soil and thoroughly moistens a vadose zone below the tree, and thus reduces the need for frequent irrigations. Other advantages of flood irrigation include the prevention of salt accumulation around the plant roots and the development of strong/ deep rooting systems.

Regulated deficit irrigation of citrus trees

Regulated deficit irrigation (RDI) is supplying less irrigation water to the plants than their total water requirements for an optimum fruit yield (Fereres *et al.* 2003), improved fruit quality (Uriu and Magness 1967; Goldhamer and Salinas 2000), enhanced fruit total soluble salts (Erickson and Richards 1955; Castel and Buj 1990) and high water use efficiency (Naor *et al.* 2001; Ruiz-Sánchez *et al.* 2000). RDI is a common practice in many areas of the world, especially in arid countries (English and Raja 1996). González-Altozano and Castel (2000) conducted a 2-year experiment on RDI in a drip-irrigated Clementina de Nules/Carrizo Citrange orchard in Moncada (Valencia, Spain). They reported water savings between 6 to 22% without affecting citrus yield and fruit quality. Velez *et al.* (2007) evaluated the feasibility of RDI during two consecutive seasons in a citrus orchard planted with mature 'Clementina de Nules' trees, in Valencia, Spain. They reported no significant reduction in yield and fruit weight in the deficit irrigated treatment compared with control treatment, allowing seasonal water savings between 12 and 18%. Kirda *et al.* (2007) studied the fruit yield response of a mandarin (*Citrus reticulata* cv. 'Marisol') orchard to RDI and reported only a marginal yield reduction (i.e., 10 to 14%) under the RDI (irrigation equivalent to 60% Class-A pan evaporation), but more than a 2-fold increase in irrigation water use efficiency compared with the traditional practice of full irrigation.

Environmental impacts if irrigation BMPs are not adopted

Before discussing the environmental impacts of citrus irrigation, it is essentially important to understand different soil water conditions and the phenomena that govern soil water dynamics. Movement of the applied water and fate of the soil nutrients are influenced by soil physical and hydrological properties (Kar and Oswal 2002). Soil water movement is simultaneously governed by capillary and gravitational forces (Jury and Horton 2004). Capillary forces are based on adhesion (i.e., attraction of water molecules to the soil solids) and cohesion (i.e., attraction between the water molecules). Soil water held by capillary forces is called adsorbed water. Capillary forces control the soil water movement, mostly under unsaturated conditions and especially in soils with dominant micropores and/or capillaries (e.g., fine-textured loamy and clayey soils). The water, that is not adsorbed on the soil solids, moves vertically downward due to the gravitational forces that dominate mostly under saturated conditions and in soils occupied by macropores (e.g., sandy soils).

In agricultural fields or orchards, when clayey or fine-textured soils are irrigated, a larger portion of the water is held within the soil pores as compared to the case of sandy or coarse-textured soils, where most of the water drains downward very quickly. At a stage when most of the gravitational water drains, the soil is then at field capacity (FC). At a point when no more water is available for plant uptake and the plants may die if supplemental water is not applied before reaching this point, the soil is at permanent wilting point (PWP). Available soil water for plant uptake is the water content between FC and PWP. The energy required to move a unit mass of water in the system is termed as water potential, which comprises gravitational, matric, osmotic, and pressure potentials (Kar and Oswal 2002). These four types of water potential depend on the position of the water in a gravitational field, the adsorptive forces that bind the water to the soil matrix, the concentration of dissolved substance in the water, and the hydrostatic or pneumatic pressure on the water, respectively (Jury and Horton 2004).

Poorly managed irrigation may result in water loss in addition to causing environmental problems by transporting nutrients, pesticides, and sediments to the surface and ground water bodies. For example, the major disadvantage of the sprinkler irrigation system is the loss of large amounts of irrigation water in the form of evaporation, especially during hot and windy conditions. Studies have shown that 1.5 to 7.6% of irrigation water can be lost due to wind drift and evaporation during irrigation with sprinkler systems (Frost and Schwalen 1960; Kohl *et al.* 1987). Since the water is sprinkled over a wide soil surface, even in the no plant areas, this results in the wastage of water resources. Though the water is sufficiently applied to meet plant water demand, the applied water is not sufficient to leach the salts that accumulate within the plant root zone over a period of time. Moreover, the raindrop impact of sprinkled water results in soil erosion (Walker *et al.* 2007) and seal formation (Levy *et al.* 1992) that increase surface runoff, and in turn erosion, especially under slopping and saturated conditions. The nutrients or pesticides adsorbed over the eroded particles (i.e., phosphorous) end up being transported, which ultimately cause the water quality problems of the neighboring surface water bodies.

Salt accumulation in the near-surface perimeter of wetted soil volume has been a concern of drip irrigation performance. Such accumulated salt can be leached by more than 300 mm of total rainfall or with the equivalent amount of water applied with a portable sprinkler system (Yildirim and Korukcu 2000). Frequent and excessive application of irrigation with drip systems may result in the leaching of applied or accumulated nutrients below the root zone. Inherent to drip irrigation is the water content distribution pattern around the emitter, which results in a build up of salts at the fringes of the wetted soil volume. Citrus roots growing in the vicinity of the point source can intercept and take up the applied water and salts. Movement of nutrients with the applied water is also a function of temporal and spatial variations in the movement of the applied water. Mmolawa and Or (2000) conducted field and greenhouse experiments to investigate and elucidate temporal and spatial solute dynamics under drip irrigation systems. The monitoring of spatial and temporal variation in soil water content and soil water solution bulk electrical conductivity was conducted with plants actively growing in the rootzone, as well as after the removal of the plants. They reported that soil water content dynamics were mainly at the top 0.3 m of the soil profile and that there was a net movement of water downwards. The quantity and the patterns of temporal and spatial movement of soil water influence nutrients movement in the plant vadose zone. Time of application of irrigation water, even in case of drip irrigation systems, is crucial with regards to movement or accumulation of the applied nutrients in the plant rooting system. The influence of the amount of irrigation water applied on the solute distribution under drip irrigation was studied by Nightingale *et al*. (1986). They reported that a pre-plant irrigation of 190 mm led to a substantial reduction in the soil salinity in the plant rooting system as compared with the zero pre-plant irrigation.

Surface irrigation has adverse environmental impacts in terms of soil salinity in countries that commonly use this irrigation system. Present estimates of soil salinization in India range from 27 to 60% of the total irrigated land, Iraq 50%, Egypt 30%, Australia 20%, China 15%, Pakistan 14%, and Israel 13% (Droogers 2001). Grieve (1989) compared conventional sprinklers and under-tree microsprinklers for their effect on patterns of plant water and nutrient uptake, soil salinity, and water use efficiency in a 20-year old 'Valencia' orange orchard in Sunraysia on the Murray River. The conventional sprinkler was a full ground cover system with the sprinklers in the middle of the rows operated at 14 day intervals to fulfill plants' peak water demand. The microsprinkler was a partial (60-65%) ground cover system operated under the trees at 7-day intervals. The author concluded that during this 4-year experiment, 1) 10% less water was applied using microsprinklers, 2) the plant roots extracted 5 and 17% of their water use below 1.0 m in conventional and under-tree microsprinkler irrigated areas, respectively, 3) fertilizer injection with the microsprinkler system significantly increased the efficiency of nitrogen (N) and phosphorous (P) uptake compared with surface broadcasting of fertilizers, 4) fruit yield averaged 12% higher from micro-irrigated trees, and 5) the micro-irrigation increased water use efficiency by 22%. Quiñones *et al*. (2003) compared drip and flood irrigation systems in a study on the water use efficiency and N uptake efficiency in citrus trees [*Citrus sinensis* (L.) Osb.] on Carrizo citrange rootstock (*C. sinensis* × *Poncirus trifoliata Raf.*). Their results showed that the drip irrigation system was more efficient in improving water use efficiency and plant N uptake from the applied fertilizer, thus potentially enhancing plant growth and reducing N leaching losses.

CITRUS NUTRIENT BMPs

Citrus cultivation requires substantial quantities of agrochemicals including fertilizers, pesticides, and herbicides. Field application of such agrochemical amendments contributes to soil salinity and groundwater degradation (Vanclooster *et al.* 1994). A wide range of agrochemicals has been identified in groundwater in many parts of the globe. In order to estimate and predict the magnitude of environmental degradation caused by agrochemicals, it is important to understand the processes that control nutrient transport through the soil medium (Bresler 1973).

Processes of nutrient transport

Solutes move through soil by convection and/or by diffusion processes (Rose 1973; Jury *et al.* 1991). In field soils, the solute transport can vary in magnitude as well as in direction from point to point due the soil matrix complex pore geometry. A combined diffusive and convective solute flow results in an erratic solute flow that disperses solutes between the displacing (rainfall and/or applied irrigation water) and the displaced (the existing soil water) fluids. The term "mechanical dispersion" is used to differentiate this spreading mechanism from those due to convection and diffusion. Therefore, the spreading of a solute across the initially sharp boundary between the displacing and the displaced fluids can be either due to dispersion or due to diffusion or by both (Knox *et al.* 1993).

The negative net charge of the soil surfaces interacts with the dissolved substances (nutrients and pollutants) in the liquid phase of soils through the adsorption/desorption processes. Adsorption is a surface phenomenon due to the attraction of cations (i.e., the positively charged ions, e.g., P^+, K^+, etc.) over the surface of a negatively charged clay particle (Koorevaar *et al.* 1983). The anions (i.e., the negatively charged ions, e.g., NO_3^-, Cl^-) are repelled from the negatively charged clay particles due to the phenomenon called anion exclusion (James and Rubin 1986; Melamed *et al.* 1994). Some solutes react with the soil particle surfaces as they travel through the soil matrix, resulting in dissolution and precipitation in or out of soil water solution. For example, nitrates are transported mainly by convection with streams of water, while the less mobile phosphates are transported by diffusion or convection. A portion of the excess N and P enters water from agricultural fertilizers and manures. Nitrogen dissolves in water and is carried in runoff or is leached to the groundwater. Phosphorus remains immobile (Feigen *et al.* 1990) as it is held tightly by soil clay particles and is transported mainly by convection upon soil erosion.

Nutrient requirements of citrus plants

For a healthy citrus cultivation, macro- [i.e., N, P, potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)] and micro-nutrients [i.e., iron (Fe), zinc (Zn), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni)] are essential. The plants obtain the other mineral nutrients, carbon (C), hydrogen (H), and oxygen (O) from soil, the atmosphere, and from water. The following is a brief description of the effect of some of these nutrients on plant growth and on fruit yield (Sauls *et al.* 1997; Zekri and Obreza 2003).

Nitrogen: Nitrogen is the pre-requisite and most important nutrient for citrus cultivation (Embleton and Jones 1978; Dasberg *et al.* 1984; Alva and Tucker 1999; Boman and Obreza 2002; Alva *et al.* 2003). It is essential to enhance plants biological processes (i.e., normal cell division, growth, and respiration) and enables plants to use the energy of sunlight to form sugars from carbon dioxide and water. Citrus trees use N to produce leaves, flowers, and fruits. Although there is no apparent symptom of initial N deficiency in citrus plants, trees grown on N deficient soils are mostly undersized and the N deficiency symptoms appear on older leaves first before the effect proceeds toward the younger leaves (Zekri and Obreza 2003).

Phosphorus: Phosphorus is necessary for photosynthesis, synthesis and breakdown of carbohydrates, and for the transfer of energy from one part of the plant to the other. It helps the plants to store and use energy from photosynthesis to form seeds, develop roots, speed up maturity, and resist different kind of stresses. Phosphorus is involved in nutrient uptake and their translocation within the tree. It is a major part of the cytoplasm and the cells nucleus, where it is involved in the organization of cells and the transfer of heredity characteristics. High level of soil P availability results in colonization of plants by VAM (vesicular-arbuscular mycorrhizal) fungi and depresses plant growth (Cooper 1975; Crush 1976; Buwalda and Goh 1982; Hall *et al.* 1984; Son and Smith 1988). Citrus roots with VAM contain significantly more phosphorlipid and triglycerides than those not affected by VAM (Nagy and Nordby 1980). Mycorrhizal fungi can contribute up to 17% of the dry root weight (Hepper 1977).

Potassium: Potassium is necessary for several basic physiological functions, i.e., the formation of sugars and starch, synthesis of proteins, normal cell division and growth, and neutralization of organic acids. Potassium is important in fruit formation as it enhances fruit size, flavor, and color. It helps to reduce the influence of adverse weather conditions like drought, cold, and flooding. Potassium helps regulate the CO_2 supply to the citrus plants by controlling stomata opening and closing. Potassium improves plant health and their resistance to disease and tolerance to nematodes and insects attack. Potassium deficiency causes citrus old trees to transform yellow to yellow-bronze chlorotic patterns on older leaves. Before deciding for K fertilizer application, visual diagnosis should be confirmed by leaf analysis. McColloch *et al.* (1957) conducted soil and leaf analyses of orange trees in a series of six field experiments in California orchards fertilized with K and/or Mg and reported that K fertilization accentuated Mg deficiency (i.e., leaf magnesium concentrations of 0.20% or less).

Calcium: Calcium is an important element for the development and functioning of plant roots and cell walls. It is required for chromosome stability and cell division. Calcium activates several enzyme systems and neutralizes organic acids in plants. The deficiency of calcium that usually occurs on acidic soils results in small and thickened leaves and causes loss of vigor, thinning of foliage and reduction in fruit yield (Zekri and Obreza 2003).

Magnesium: Magnesium is involved in photosynthesis process and performs as catalyst for several enzymes. It is also involved in carbohydrate metabolism and synthesis of nucleic acids as it influences the movement of carbohydrates from the leaves to other parts of the tree and also stimulates plant P uptake and its transport with in the plant. McColloch *et al.* (1957) reported that application of Mg fertilizer results in a marked increase in leaf Mg content and a disappearance of Mg deficiency symptoms in citrus leaves.

Sulfur: Sulfur is important for the production of amino acids, proteins, and chlorophyll and is a constituent of vitamins and some of the plant hormones. It improves root growth, promotes vigor and hardiness, and affects carbohydrate metabolism. Sulfur deficiency is characterized by stunted growth, delayed maturity, and general yellowing of plants. Unlike N deficiency which begins in the older leaves first, S deficiency symptoms begin in the young and upper leaves first (Tucker 1999).

Iron: Iron catalyzes the production of chlorophyll and is involved in some respiratory and photosynthetic enzyme systems. Approximately 20 to 50% of fruit trees grown in the Mediterranean basin suffer from Fe deficiency (Jaegger *et al.* 2000), which results in considerable loss of fruit yield (Pestana *et al.* 2003), delayed fruit ripening, and impaired fruit quality (Pestana *et al.* 2001).

Zinc: Zinc is involved in plant carbon metabolism and is a necessary component of several enzyme systems that regulate various metabolic activities within the plants. It helps in the functions of chlorophyll and photosynthesis and improves plant water uptake. Zinc deficiency is common in citrus trees and is termed as "mottle leaf" or 'little leaf' derived from its symptom of developing distinctive leaf patterns. Zinc deficiency results in reduced vigor, lower production, smaller fruit size, and poor fruit quality (Tucker 1999).

Manganese: Manganese is involved in the production of amino acids and activates several plant enzymes. It plays an essential role in plant respiration, reduces nitrates and helps make them usable by plants. It plays a role in photosynthesis and in the formation of chlorophyll. Deficiency of Mn in citrus trees may be overlooked as it commonly occurs along with Zn and Fe deficiencies. Even a mild Mn deficiency may result in reduction of tree vigor and fruit yield (Zekri and Obreza 2003).

Boron: Boron plays a key role in flowering, pollen-tube growth, fruiting processes, N metabolism, and hormone activities. It maintains Ca in a soluble form that insures its (Ca) proper utilization. Citrus fruits turn hard due to B deficiency commonly know as "hard fruit". Zekri and Obreza (2003) describe the B deficiency symptoms in citrus trees as 1) premature shedding of young fruits with brownish discolorations in the white portion of the rind (albedo), described as gum pockets or impregnations of the tissue with gum and unusually thick albedo, 2) older fruit are undersized, lumpy, and de-shaped with an unusually thick albedo containing gum deposits, and 3) seeds fail to develop and gum deposits are common around the axis of the fruit.

Copper: Copper plays a role in photosynthesis and chlorophyll formation. Copper appears to be concentrated more in the rootlets of plants than in leaves or other tissues. It regulates several biochemical processes affecting plant growth, which has been related to physiological changes in plants due to oxidative stress (Lombardi and Sebastiani 2005). These changes could lead to biotic and abiotic stress resulting in an enhanced production of harmful reactive oxygen species that damage the plant macromolecules (Scandalios 1990). Copper deficiencies (i.e., dieback, ammoniation, and exanthema) in citrus trees results in the dying back of the twigs and are caused by frequent excessive applications of N fertilizers (Zekri and Obreza 2003).

Molybdenum: Molybdenum helps in the formation of starch, amino acid, and different vitamins in fruits. It works as a catalyst that aids the conversion of gaseous to the usable forms of N by nitrogen-fixing microorganisms. It constitutes a plant enzyme (e.g., *Desulfovibrio desulfuricans*) that converts nitrate to ammonia (Bursakov *et al*. 1995). Molybdenum deficiency in citrus trees (i.e., yellow spot) was first spotted in Florida a century ago (Floyd 1908). Yellow spot occurs when Molybdenum in citrus is between 0.01 and 0.02 ppm (Vanselow and Narayan 1949). In extreme cases yellow spot may cause complete defoliation of the trees (Stewart and Leonard, n.d)

Chlorine: Chlorine is associated with turgor in the guard cells through the osmotic pressure exerted by imported K ions. It is involved with oxygen production during photosynthesis (Zekri and Obreza 2003).

Nickel: No Ni deficiency has been reported in soil-grown plants. Its importance to the plants is unknown but most of the plants act as Ni fixing. Disorder in citrus leaves, i.e., "mouse-ear" or "little-leaf" is caused by Ni deficiency that is easily cured by on-time foliar application of Ni at the rate of 100 mg L^{-1} (Wood *et al*. 2008).

Nutrient application to citrus orchards

Nutrients are applied to citrus orchards either via surface broadcast or through fertigation, which is the application of liquid fertilizers through irrigation systems (Papadopoulos 1985; Ogg 1986). Fertigaiton is the mechanized form of nutrient application that facilitates timely applications and uniform distribution of fertilizers as compared with the conventional fertilizer broadcasting method (Boman and Obreza 2002). Since the uniformity of the fertilizer application depends on irrigation system application uniformity, the pressurized systems offer the potential for higher water- and fertilizer use efficiency than flood irrigation (Kusakabe *et al.* 2006). Fertigation through low volume pressurized irrigation systems has been reported in a number of studies (Gerstl and Albasel 1984; Gerstl and Yaron 1993). The major advantages of fertigation over conventional surface broadcasting include high flexibility in selecting the timing and the amount of nutrient application (Koo 1980), lower and precise application of fertilizer to prevent leaching of water-soluble nutrients in case of either excessive rainfall or over-irrigation (Boman and Obreza 2002), 29-78% saving in nutrient application costs (Csinos *et al.* 1986) due to the high efficiency of fertilizer application (Miller *et al.* 1981), and due to less fertilizer leaching (Klein *et al.* 1989).

In organic farming, a vast scale nutrients application to the soils involves surface broadcasting or slurry spreading of livestock manures (e.g., chicken, dairy or swine manures). As the applied manures decompose, the resultant nutrients leach through vadose zone via water flux movement as result of over irrigation or excessive rainfall events (Khan *et al.* 1977). The movement of these nutrients from the decomposed manure varies with the manure application rate (Woodard *et al.* 2002), existing soil moisture, irrigation and precipitation, and time (season) of manure application (van Es *et al.* 2006). Citrus fertigation through low volume pressurized irrigation systems have been reported in a number of studies (Gerstl and Albasel 1984; Gerstl and Yaron 1993).

Environmental impacts if nutrient BMPs are not adopted

Optimum application of N fertilizers to citrus groves requires information regarding N dynamics in soil, existing soil N residues, and crop N requirements (Hartz 1993). Soil nutrient accumulation determines nutrient availability for plants (Obreza 2003). An increase in nutrient concentration in soil does not necessarily mean that they are available for plant uptake. Under given climatic conditions and irrigation systems, the nutrient accumulation in soil also depends on the nature and the amount of the applied nutrients in addition to the major soil physical and hydrological properties as discussed earlier. The tendency of nutrient accumulation or leaching is closely related to their negative (anions) or positive (cations) charges which determine the type of the reaction (adsorption or exclusion) with the soil minerals. Calcitic or dolomitic limestone applications or inorganic fertilizers result in Ca and Mg accumulation in the tree root zone. The accumulation of S applied as a component of many fertilizers increases with an increase in the amount of organic matter or clay in the soil. Sandy soils poorly hold N, K, and B resulting in the leaching of these nutrients by rainfall or excessive irrigation.

Boswell *et al.* (1985) reported that NO_3-N moves through diffusion and convection in a soil water system because a) nitrate is readily soluble in water and b) it is not usually adsorbed on the negatively charged soil particles. Since NO_3-N is highly soluble and non-adsorbing, it is more likely to be lost through deep percolation of water. Leaching of N is probably the dominant way of its loss from a soil–plant system, especially if the soil already contains substantial amounts of N compounds. Miscalculations of the residual N levels in the soil, from the previous growing season as well as incorrect N fertilizer application, result in N leaching. Soluble N compounds cause undesirable growth of algae and aquatic plants, which deplete oxygen and kill fish and other aquatic life in freshwater bodies (Fruh 1967; Elrashidi *et al.* 2005). High level of NO_3-N in drinking water (> 10 ppm) may cause Blue Baby Syndrome in infants (Pool *et al.* 2004). Paramasivam *et al*. (2000) evaluated NO_3-N distribution in soil solution at various depths within and N leaching below the root zone under the canopy of mature 'Hamlin' orange [*Citrus sinensis* (L.) *Osbeck*] trees on Cleopatra mandarin (*Citrus reticulata Blanco*) rootstock, grown on an entisol of central Florida. Their treatments included 112, 168, 224, and 280 kg N ha^{-1} yr^{-1} as either dry granular fertilizer (DGF; broadcast, in 4 equal doses) or fertigation (FRT; 15 applications yr^{-1}), and 56, 112, and 168 N kg ha^{-1} yr^{-1} as controlled-release fertilizer (CRF; single application yr^{-1}). They found that at the 60 or 120 cm depths, the NO_3-N concentrations occasionally peaked at 12 to 100 mg L^{-1}, though at 240 cm depth the NO_3-N concentrations mostly remained below 10 mg L^{-1}.

Zhang *et al*. (2004) investigated the seasonal and spatial patterns in the concentrations of ammonia-nitrogen (NH_4-N), NO_3-N, P, and heavy metals at six drainage ditches distributed in flatwood soils in commercial vegetable farms and citrus groves in St. Lucie County, Florida. They reported that the concentrations of NH_4-N, NO_3-N, and total P ranged from non-detectable levels to 9.13, 283 and 4.86 mg L^{-1}, respectively. Concentrations of Cu and Zn ranged from non-detectable levels to 63.7 and 121.7 mg L^{-1}, respectively. The concentrations of N, P, K, Cu, and Zn in ditch water were higher during the wet season than during dry season, indicating higher nutrient input through surface runoff from the adjacent fields during the wet season.

In the case of fertigation, the internal area of the irrigation system remains in contact with acidic fertilizers and may corrode the inner surfaces of fertigation device. If P fertilizers are applied with Ca and Mg rich irrigation water, precipitate formation results in irrigation system clogging (Haynes 1985; Mikkelsen 1989). If the fertigation system components, i.e., supply tank, injection devices, and irrigation system are not securely connected, there is a high risk of contamination. A faulty operating system could cause a backflow of water into the chemical supply tank, the overflow from which may contaminate the neighboring areas. Handling of acidic fertilizers can also pose many health hazards especially to the skin and eyes of those handling the fertigation equipment.

Backflow in a fertigation system

Environmental problems could occur in the absence of a proper backflow prevention mechanism in a fertigation system. The potential risks of an improperly managed fertigation system include backflow of fertilizers to the water source causing contamination of irrigation fresh water, and water backflow into the fertilizer storage tank causing contaminated outflow. Backflow prevention equipment is a safety device used to prevent any of the above situations. Some states in the US have made it legal to equip the fertigations system with an anti-siphon backflow equipment. For example, the Florida state law (Florida Statutes Section 487.055) requires that backflow prevention equipment be properly installed and periodically maintained. Backflow prevention is an extremely important practice in the prevention of both ground and surface water degradation.

CITRUS PEST, WEED, AND DISEASE CONTROL

Citrus pest management and its environmental impacts

Citrus orchards are known for harboring a range of common insects and pests that include the Angular-winged katydid (*Microcentum retinerve*), Brown garden snail (*Helix aspersa*), Brown soft scale (*Coccus hesperidum*), California orangedog (*Papilio zelicaon*), Citrus leafminer (*Phyllocnistis citrella*), Citrus looper (*Anacamptodes fragilaria*), Fuller rose beetle (*Pantomorus cervinus*), Melon aphid (*Ahis gossypii*), Navel Orangeworm (*Amyelois transitella*), Potato leafhopper (*Empoasca fabae*), Spirea aphid (*Aphis citricola*), and common housefly (*Musca demestica*) (UC IPM 2008a). An insect becomes a pest when it starts residing on and harming the plants. Asian Citrus Psyllid (Diaphorina citri Kuwayama) and African Citrus Psyllid (Trioza erytreae, *del Guercio*) are the most common citrus pests (Halbert and Voeg 2006).

Integrated Pest Management (IPM) is a holistic approach for the prevention of pest problems and the reduction in the use of pesticides that may adversely affect the environment and the materials being protected against pests. The guidelines of IPM for citrus have been reported in literature (e.g., Flint 1991). The practice of IPM starts with pest identification, a crucial step in any IPM program followed by monitoring pests in an orchard at regular intervals and ends with pesticide application to the concept of economic injury level (i.e., the pest population that causes crop damage greater than the cost of pest control measures). Therefore, a successful IPM for any insects or pests requires determining whether the presence of the pests and/or their population densities within the grove are high enough to cause economic loss (Dufour 2001).

Different types of pesticides are used to control citrus insect pests. However, pesticide exposure to the human skin is the most common way by which pesticide illness occurs. Since most of the pesticides break down once exposed to oxygen and water, the pesticides are usually applied one hour after dusk and well before (at least 2 hours) dawn (Johnson 1998). Some pesticides break down by directly absorbing sunlight. Pesticide breakdown is a process of mineralization by which the pesticides, depending upon their compounds, break down into CO_2, H_2O, minerals containing elements, i.e., N, P, S, and the halogens including chlorine, fluorine, and bromine. Similar to the nutrients, the pesticides can be harmful to the environment if leached and/or transported away from their intended zone in citrus orchards. Pesticides move, though short distances in a soil profile, by diffusion and convection processes. Systemic application of insecticides to the tree trunks would minimize environmental degradation (Davis *et al.* 2005). Common citrus insect pests and pesticides used to manage pest populations along with a description and use are given in **Table 1**.

Citrus weed control techniques and their environmental impacts

Depending upon the climatic conditions and the consequence of management decisions, weeds of various kinds invade citrus orchards and compete for nutrients, water, and light (Sullivan 2003). Weeds also multiply and harbor insects and rodents. Wilson (1988) recovered 140 weed seeds per pound of surface soil, which is equivalent to over 80 million seeds ha^{-1}. Major citrus weeds include bermudagrass (*Cynodon dactylon*), purple nutsedge (*Cyperus rotundus*), and other broadleaf weeds including common purslane (*Portulaca oleracea*), London rocket (*Sisymbrium irio*), sowthistle (*Sonchus oleraceus*) and Guineagrass (*Panicum maximum*), Narrowleaf Guineagrass (*Panicum maximum*), Torpedograss (*Panicum repens*), Broadleaf Signalgrass *(Brachiaria platyphylla)*, Smallflowered Alexandergrass (*Brachiaria subquadripara*), Southern Sandbur (*Cenchrus echinatus*), Crowfootgrass (*Dactyloctenium aegyptium*), Natalgrass (*Rhynchelytrum repens*), Johnsongrass (*Sorghum halepense*), Vaseygrass (*Paspalum urvillei*), and Goosegrass (*Eleusine indica*) (Futch and Hall 2003, 2004).

The invasion of weeds is more harmful to young citrus plants as weeds slow tree growth and increase the risk of insect and disease attack. Mature citrus trees offer less favorable conditions for weed expansion due to the shading of a large part of the orchard floor by the dense tree canopy. Once established, the weeds may restrict irrigation (ARS 2004) and other operations in the orchard. Microsprinkler and drip irrigation provide suitable conditions for weed growth, as under these low-volume irrigation systems, the permanently wet zone around emitters and sprinkler heads favors the growth of weeds (UC IPM 2008b). Additionally, the availability of nutrients near tree trunks also favors weed growth. In an orchard under furrow irrigation, the weeds grow vigorously in furrow bottoms and at furrow ends due to the presence of fertilizers and the availability of moisture.

Weed management practices include cultural, biological, chemical, and mechanical control (Sauls *et al.* 1997; Boman *et al.* 2002). Organic mulching is a cultural weed control that includes solarization, i.e., raising the soil temperature by covering it with plastic sheets. The heat kills most of the

Table 1 Common citrus insect pests, the pesticides used to control them, and the description and use of the pesticides.

Citrus insect pests	Pesticides	Description and use
Citrus Thrips *Scirtothrips citri*	Abamectin (AGRI-MEK)	It is relatively nontoxic and is applied in combination with oil. Three applications per year are advised.
	Cyfluthrin (BAYTHROID)	It is an occasionally used toxic pyrethroid insecticide. Only one application per crop per season is permitted.
	Dimethoate	It is an organophosphate that is widely used in citrus orchards. Dimethoate is so toxic that its day time use is prohibited to avoid its possible entry to open bloom.
	Fenpropathrin (DANITOL)	It is a broad spectrum pyrethroid insecticide that has recently been registered for use in citrus and is applied once per season.
	Formetanate Hydrochloride (CARZOL)	It is a broad spectrum toxic insecticide that is persistent unless washed off by rain. No more than one application can be made per season.
	Kaolin (SURROUND)	It is a highly refined clay mineral product that disrupts citrus thrips feeding and behavior.
	Spinosad (SUCCESS)	It is a macrocyclic lactone isolated from the soil microorganism *Saccharopolyspsora spinosa*. It may not be applied more than twice per year, and may not be used in nurseries.
Citrus flat mite *Brevipalpus lewisi*	Wettable Sulfur	Wettable sulfur is applied to thoroughly cover foliage as soon as mites are detected or as additive when treating for citrus thrips.
	Dicofol	It is an organochlorine that is applied at label rates to all varieties of citrus. Though it has a narrow range of activity, it is very efficacious towards mites. It is however, toxic to predaceous mites because of its persistence.
	Abamectin	Same as described above (Abamectin).
Citrus Mealybug *Planococcus citri*	Chlorpyrifos (LORSBAN)	It is an organophosphate that is used to suppress citrus mealybug. Chlorpyrifos is applied at an average rate of 4 to 6 lb per acre. Although a thorough coverage is needed for effectiveness, but mere application will still provide suppression of citrus mealybug. Inclusion of narrow range oil will aid in efficacy. Chlorpyrifos is toxic and should not be applied during daylight hours during bloom. The restricted entry interval for chlorpyrifos is 0 days.
Citrus Peelminer *Marmara salictella*	Chlorpyrifos (LORSBAN)	It is an organophosphate that is applied with oil to aid in efficacy. Since chlorpyrifos is toxic, it is not recommended to be applied during daylight hours during bloom.
	Spinosad (SUCCESS)	Same as described above (Spinosad)
California Red Scale *Aonidiella aurantii*	Chlorpyrifos (LORSBAN)	It is toxic to bees and should not be applied during daylight hours during bloom. In case applied during daylight, the pesticide could breakdown and contaminate environment.
	Pyriproxyfen (ESTEEM)	It is an insect growth regulator used to control whiteflies. Because its effect is slow, it takes several months for full efficacy.
Cottony Cushion Scale *Icerya purchasi*	Chlorpyrifos (LORSBAN)	Chlorpyrifos is toxic and not be applied during daylight hours during bloom for the reasons discussed above.
	Pyriproxyfen (ESTEEM)	It is a slow insect growth regulator for whiteflies. As it does not easily breakdown, it is at risk of transport.
Omnivorous Leafroller *Platynota stultana*	Chlorpyrifos (LORSBAN)	Same as described above (Chlorpyrifos)
	Methomyl (LANNATE)	This is a toxic pesticide and applied from 1 hour after sunset until 2 hours before sunrise. If applied during daylight, this pesticide is at risk of breakdown and could cause environmental contamination.
Texas Citrus Mite *Eutetranychus banksi* Twospotted Spider Mite *Tetranychus urticae* Yuma Spider Mite *Eotetranychus yumensis*	Wettable Sulfur Dicofol Abamectin	Same as described above (Wettable Sulfur, Dicofol, Abmectin)
Woolly Whiteflies *Aleurothrixus floccosus*	Pyriproxyfen (ESTEEM)	Pyriproxyfen has potential risk of transport with water to the neighboring areas because of its slow breakdown.

weed seeds and insects as well. Solarization can also be effective during growing periods other than the summer season. Organic mulching has proven to be effective in early weed suppression (Putnam *et al.* 1983; Weston 1990; Schonbeck *et al.* 1991), IPM, water conservation (Porter 2007), and the addition of nutrients to soil on decay (McIntyre *et al.* 2000). Mulched trees have been reported to experience lower soil moisture tensions and higher rates of stomatal conductance, either through reduced evaporative loss or less competition with weeds (Downer *et al*. 1993).

There are three common forms of mulches; living, organic and inorganic. Living mulches may include rhodes grass, klein grass, and buffelgrass (Evensen and El-Swaify 1997). Organic mulches include manures, bark chips, ground corncobs, sawdust, grass clippings, leaves, newspapers (shredded or in layers), and straw. Black plastic is the most frequently used inorganic mulch. Properly applied mulches could serve as herbicides (Singh *et al.* 1985) and in some cases, combined mulch-herbicide applications give excellent results in the managegement of weeds (Robinson 1988). Several durable weed fabrics that are very effective in weed suppression are also used as inorganic mulches. Organic mulches are effective against annual weeds, but have little effect against established perennial weeds, which can emerge through deep layers of applied organic mulches (Robinson 1988).

Since organic mulches slowly and steadily release nutrients for the plants, these are considered as slow-release fertilizer sources (Jackson and Davies 1984) that were reported to enhance the growth of young citrus trees in Texas (Fucik 1974) and in Florida (Khalaf 1980), probably due to a continuous rather than a fluctuating supply of nutrients. Slow-release nitrogen sources are also effective in reducing the amount of nitrogen lost through leaching (Khalaf 1980). Casale *et al.* (1995) analyzed urban and agricultural waste products generally available to avocado and citrus growers in southern California for their suitability for their potential use as bioenhanced mulches. They reported that the yard waste (consisting of wood chips, grass and leaves), rice hulls and rice hulls-and-paper materials were not harmful to any of the studied growth parameter of citrus including roots length and shoot weight. However, the mulches including almond and peanut hulls, several manures, and alfalfa hay, reduced shoot and/or root growth and released large amounts of ammonia upon degradation. Faber *et al*. (2000) related the effect of different thicknesses of a mixed-source urban yard-waste mulches on weed growth in a citrus orchard and reported that in the mulched plots, scarlet pimpernel (Anagallis arvensis), purslane (*Portulaca oleracea*), spurge (*Euphorbia maculata*), horseweed (*Conyza canadensis*), yellow clover (*Melilotus indica*), tall fescue (*Festuca arundinacea*), and common groundsel (*Seneclo vulgaris*) either did not occur at all or were at extremely low levels and they were common in the unmulched plots. They also found that in the plots of 2.5 cm mulching depth, the weeds covered between 2 and 5 times the area as compared with the plots of 7.5 and 15 cm mulching depths. However, there was no statistical difference in the weed cover of the plots with 7.5 and 15 cm mulching depths. Based on their findings, they concluded that the weed diversity decreased with the increase in mulching depth.

Biological weed control includes the practice of intercropping so that the spaces between the citrus trees are occupied by a cash crop that not only suppresses weeds but also uses the excessive tree nutrients and soil moisture. Chemical practice of weed control involves applying herbicides to the citrus groves. Common citrus herbicides applied to young or mature citrus orchards include bromacil (Hyvar), norflurazon (Solicam), thiazopyr (Mandate), trifluralin (Treflan), oryzalin (Surflan), diuron (Diuron, Karmex, Direx), oxyfluorfen (Goal), sethoxydim (Poast), fluazifop-p-butyl (Fusilade), Glyphosate (Roundup), bromacil (Hyvar X and Krovar I), diuron (Karmex, Krovar I), and simazine (Princep, Simazine), and napropamide (Devrinol) (Futch 2001). Some of the above pesticides are categorized as pre-emergence and the rest as post-emergence; the former are soil-applied and the latter are foliar-applied.

Chemical weed control practices have some potential environmental impacts. For example, leaching of herbicides not only favors weed growth but can also contaminate soil and groundwater. Flood irrigation of citrus orchards grown on sandy soils, can leach some herbicides into the tree root zone causing injury to the tree subsurface portion of the trunk and roots. In the citrus orchards with steep slope, the eradication of weeds could result in favorable conditions for erosion as a result of no land cover. Repeated application of a single herbicide may result in a herbicide-resistant variety of weed species that may not be evident initially; however, over time, their populations may build up until they infest the entire grove and become the dominant weed species (Jordan *et al.* 1992). It is a common practice to provide a pre-emergence application of herbicides to kill and/or control weed seedlings. A given dosage of pre-emergent herbicide may be more toxic to trees in sandy soils or soils that are low in organic matter (UC IPM 2008b). During herbicide application, citrus foliage or trunks may be injured with herbicides.

Disking is a mechanical weed control method which effectively works on the orchard floors except underneath the tree canopies where most of the weeds survive. A disadvantage of this method is that, if not applied carefully, it can damage tree branches, bury plant debris into the surface soil and damage shallow tree roots. Disking or other surface disturbances cause additional spread of noxious weeds. The disking operation is reported to increase purslane in the summer, and London rocket and sowthistle in the winter (Wright *et al.* 2000). Disking or other surface disturbance cause additional spread of noxious weeds. Soil disturbance due to disking can result in loose top soil that is susceptible to soil loss due to erosion upon surface runoff resulting from the extreme rainfall events or over irrigation. Instead of surface disking, deep tillage has been used as an effective method of decreasing annual weeds. Likewise, deep tillage increases the chances of soil erosion and can potentially damage the shallow fibrous citrus roots (Futch and Singh 2008). More than 80% of citrus tree roots are located within the top 30 cm of the soil profile (Paramasivam *et al.* 2000) and thus are at risk to being damaged by deep tillage. Weed control with hand hoeing presents another mechanical weed control method in citrus cultivation. However; despite its positive environmental impact, this method presents the growers' biggest pre-harvest investment. In the case of sloppy orchard floors, the eradication of weeds could result in favorable conditions for erosion resulting from no cover on citrus floors.

Citrus diseases control measures and their environmental impacts

Citrus diseases cause various plant disorders that lead to

Table 2 Common citrus diseases, chemicals used to control these diseases, and the description and use of these chemicals.

Citrus diseases	Chemicals	Description and use
Phytophthora Root Rot and Gummosis *Phytophthora citrophthora*	Chloropicrin	For this pre-plant fumigation chemical, the site is trapped immediately after treatment. The treated site is not planted for at least three months. Lower rates are applied on sandy loam and higher rates are used on heavier soils with high clay content.
Phytophthora parasitica	Metam Sodium	The site is trapped immediately after treatment. The site is not planted for at least 45 days after application.
	Fosetyl-aluminum (ALIETTE)	This chemical is for nonbearing trees. The trees are treated at the time of planting and are sprayed to wet.
	Mefenoxam (RIDOMIL GOLD)	It is applied as a soil drench or as a surface spray with sufficient water for soil penetration. It is applied at planting and at three-month intervals to coincide with root growth during the growing season.
	Fosetyl-aluminum (ALIETTE)	It can be applied to bearing trees as it is a foliar treatment. It is sprayed to wet.
	Mefenoxam (RIDOMIL GOLD)	It is applied in the spring followed by 1 to 2 applications at three-month intervals to coincide with root flushes. Its application also depends on the tree size.
Brown Rot *Phytophthora*	Zinc Sulfate - Copper Sulfate - Hydrated Lime.	This treatment is applied from October through December, or just after the first rain. There is a severe danger of copper injury during the used of this chemical.
	Copper sulfate (BORDEAUX MIXTURE)	Tree skirts are sprayed about four feet above ground.
	Fosetyl-alluminum (ALIETTE)	It is applied when conditions favor disease development but not within 30 days of harvest. Tree skirts are sprayed about four feet above ground.
Citrus Nematode *Tylenchulus semipenetrans*	Metam Sodium	This is a pre-plant fumigation chemical. Pre-application steps must be taken because this chemical does not penetrate plant roots very well and is very difficult to get 4-5 feet below the soil surface. The area is thoroughly cultivated before this treatment. This chemical is easily applied if the clods have been broken to achieve a deeply loosen soil.
	Oxamyl	It is a post-plant chemical that is applied in flood irrigation water or through drip irrigation systems.
	Fenamiphos (NEMACUR)	It is applied by injections into the irrigation system with sufficient irrigation to wet the root zone. There is a risk of leaching of this chemical as excessive irrigation is applied.

poor tree health and low fruit productivity (Pydipati 2006). Most of the citrus diseases are caused by plant pathogens present in citrus orchards. Details on citrus diseases can be found in literature elsewhere (e.g., Flint 1991). Citrus greening, also known as Huanglongbing, is considered one of the most serious citrus disease worldwide (USDA 2006). Common citrus diseases include Sooty canker, Alternaria fruit rot, Brown wood rot, Stubborn Disease (*Spiroplasma citri*), Tristeza virus, Dry root rot (*Fusarium* spp.), Exocortis (*Exocortis viroid*), Psorosis Greasy Spot (*Mycosphaerella citri*), Greasy Spot Rind Blotch (*Mycosphaerella citri*), Scab (*Elsinoe fawcettii*), Melanose on Fruit (Diaporthe citri), Melanose on Leaves (*Diaporthe citri*), Star Melanose, Alternaria Brown Spot (Alternaria alternata), Postbloom Fruit Drop (PFD) (*Colletotrichum acutatum*), Foot Rot (Phytophthora nicotianae), Brown Rot of Fruit (*Phytophthora* species), and Citrus Canker (*Xanthomonas axonopodis*) (Futch and Timmer 2001). Physical control includes eradicating the infected plant/trees and transplanting disease-free seedlings from the areas where a disease proof nursery is established. Chemical control includes spraying various safe disease control chemicals that have no harmful environmental impacts. **Table 2** presents common citrus diseases, chemicals used to control these diseases, and the description and use of these chemicals.

CONCLUSIONS

Citrus cultivation will enhance based on its increased consumption and demand due to ever-increasing world population. Trends in increasing energy costs and reduction in agricultural water supplies would make agricultural inputs including nutrients unaffordable for small farmers. Most recent available information on citrus BMPs summarized in this article reveal that without adopting the recommended BMPs, citrus cultivation does not only result in resources loss but also causes adverse environmental impacts. Environmentally accepted citrus BMPs must be adopted for economically viable citrus cultivation to ensure high fruit yield and quality from optimal inputs of irrigation water and nutrients. Unfortunately, there are gaps between the requirements of BMP related technology transfer and implementation guidance or assistance to the citrus growers. Additionally, lacking are the studies that have evaluated cost-effective assessment of citrus BMPs. Since the voluntary adoption of BMPs has not proved a reasonable success, implementation of citrus BMPs should legally be enforced by imposing water restrictions, water quality compliance, and permit requirements/restrictions to buy fertilizers. Various aspects of citrus BMPs should be included in future research endeavors.

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