The Case for Sanitation as an Insect Pest Management Strategy in Greenhouse Production Systems[1]

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Abstract Protection of greenhouse-grown horticultural crops, including ornamentals and vegetables, from damage caused by insect pests involves implementing strategies such as insecticidal and/or biological control. However, cultural control may also mitigate plant damage caused by insect pests, as well as plant diseases including fungi and bacteria. An important cultural control is sanitation. Herein, we review the use and potential impact of sanitation practices as a part of an integrated pest management program for greenhouse production. These include removing weeds from inside and around the greenhouse perimeter, disposing of plant and growing medium debris from inside the greenhouse, and managing algae within the greenhouse. Weeds serve as alternate hosts for insects, such as aphids (Aphididae), whiteflies (Aleyrodidae), and thrips (Thripidae), that can spread plant viruses among greenhouse-grown horticultural crops. Sanitation practices that may reduce problems with weeds include installing geotextile fabric barriers underneath benches and on walkways, hand removal, mowing around greenhouse perimeters, and/or applying herbicides. Plant and growing medium debris serve as sources of insect pests, such as whiteflies, thrips, and fungus gnats (Sciaridae). Therefore, removal of plant and growing medium debris from within greenhouses and/or placement into refuse containers with tight-sealing lids before disposal may reduce problems with insect pests. Algae provides a habitat for fungus gnats and shore flies (Ephydridae) to breed. Overwatering and overfertilizing plants contributes to algae growth. Applying disinfectants or algaecides may mitigate problems with algae accumulating in greenhouses. In addition to reducing insect pest problems, sanitation practices may help reduce inputs from insecticide applications.

Key Words algae, debris, pest management, weeds, protection

Protection of greenhouse-grown horticultural crops, including ornamentals and vegetables, from damage caused by insect pests is primarily associated with applying insecticides and/or biological control agents (Fransen 1992, Pilkington et al. 2010). However, the success of either strategy may be improved by implementing proper cultural control. Cultural control may substantially alleviate problems with insect pests and subsequent plant damage to greenhouse-grown crops (Ferguson and Shipp 1994). Furthermore, cultural control may reduce environmental contamination and the development of insecticide resistance (National Academy of Sciences 1969) by decreasing inputs from insecticide applications.

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An important cultural control affiliated with horticultural crop production systems is sanitation. Sanitation involves maintaining a clean work environment by removing weeds and disposing of plant and growing medium debris. Sanitation is widely discussed in trade journal articles and extension publications (Cloyd 2009, 2015, Hogendorp and Cloyd 2006a, Kleczewski and Egel 2011, Marble and Pickens 2018). Sanitation is an important component of plant protection programs designed to mitigate problems with insect pest populations and prevent plant damage (Hogendorp and Cloyd 2006b, Leach et al. 2018, Morse and Hoddle 2006, Naegele and Jefferson 1964, Shipp et al. 1991). However, there is no quantitative information indicating that implementing sanitation practices results in a reduction of insect pest populations in greenhouse production systems. Therefore, research studies are needed to quantify the effectiveness and promote the value of sanitation practices in alleviating problems with insect pests to greenhouse producers.

Regardless, sanitation may be used with other plant protection strategies such as scouting/monitoring and/or applying insecticides or biological control agents (e.g., parasitoids or predators) to improve the management of insect pest populations and prevent damage to greenhouse-grown horticultural crops (Perdikis et al. 2008). This review discusses three major sanitation practices that may reduce problems with insect pests including: weed management, disposal of plant and growing medium debris, and algae management (Cloyd 2003).

Weed Management

Weeds can serve as hosts for many insect pests (Capinera 2005, Duffus 1971, Norris and Kogan 2005) including aphids (Aphididae) (Duffus 1971, Toscano et al. 1979), thrips (Thripidae) (Yudin et al. 1988), leafhoppers (Cicadellidae) (Cranshaw et al. 2019, Oloumi-Sadeghi et al. 1987), mealybugs (Pseudococcidae) (Pandey and Johnson 2006), and whiteflies (Aleyrodidae) (Godfrey et al. 1994, Naveed et al. 2007). It is interesting that there are no scientific studies indicating a relationship between mites and weeds, which may be because mites cannot fly. However, Solaneous or night-shade weeds adjacent to a cut flower delphinium, *Delphinium* × *cultorum* Voss., crop in a greenhouse resulted in twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), populations moving from the weeds onto the delphinium crop, which led to a 100% economic loss because of twospotted spider mite feeding (R. A. Cloyd. Kansas State Univ.; pers. obs.).

Weed seeds may enter greenhouses through vents, doors, and sidewalls by means of wind currents. Weed seeds may also enter greenhouses via plant material, tools, equipment, and personnel (Marble and Pickens 2018). The presence of weeds in the greenhouse, either underneath benches or in containers, may lead to increases in insect pest populations. Insects can then migrate onto the main crop(s) and cause damage (Norris and Kogan 2005). The weed species, growth stage (vegetative versus flowering), and density of weeds in the greenhouse may influence the types and numbers of insects present (Pandey and Johnson 2006).

Weeds also can harbor diseases such as viruses, which may be transmitted by insects that initially feed on weeds and then feed on the main greenhouse-grown horticultural crops (Chellemi et al. 1994). Insects that can transmit viruses from

Table 1. Common name and scientific name of weeds that serve as sources of *Impatiens necrotic spot* virus.

Common Name	Scientific Name
Annual sow thistle	*Sonchus oleraceus*
Bittercress	*Barbarea vulgaris*
Burning nettle	*Urtica urens*
Chickweed	*Stellaria media*
Field bindweed	*Convolvulus arvensis*
Galinsoga	*Tridax trilobata*
Gill-over-the-ground	*Glechoma hederacea*
Jewelweed	*Impatiens capensis*
Common lambsquarters	*Chenopodium album*
Little mallow	*Malva parviflora*
Nettleleaf goosefoot	*Chenopodium murale*
Oxalis	*Oxalis* spp.
Common purslane	*Portulaca oleracea*
Shephard's purse	*Capsella bursa-pastoris*
Shortpod mustard	*Hirschfeldia incana*

Tabular data obtained from Wick et al. (1997).

weeds include aphids (Ali et al. 2012, Duffus 1971), leafhoppers (Nault and Ammar 1989), thrips (Chatzivassiliou et al. 2001, Groves et al. 2001, 2002, Johnson et al. 1995, Kahn et al. 2005, Srinivasan et al. 2014), and whiteflies (Bezerra et al. 2004, Papayiannis et al. 2011). For example, weeds located under benches, or in planting beds or containers, may harbor the tospoviruses, *Impatiens necrotic spot* virus and *Tomato spotted wilt* virus, that are transmitted by adult western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) (Daughtrey et al. 1997). Weeds that serve as sources of *Impatiens necrotic spot* virus are presented in Table 1.

The removal of weeds from within and around the greenhouse may alleviate problems with insects that vector viruses, such as aphids, thrips, and whiteflies. Removing weeds eliminates hosts for insect pests and reservoirs of viruses and reduces the potential for insect pests to migrate into a greenhouse, attack the main crop(s), and transmit plant viruses (Cloyd 2018, Coppel and Mertins 1977, Duffus 1971, Gholami and Sadeghi 2016, Helle and van de Vrie 1974, Jacobson 1997, Parrella and Jones 1987, Pizzol et al. 2014, Reitz and Funderburk 2012, Shipp et al. 1991). For example, western flower thrips overwinter on weeds and may migrate into greenhouses in spring and summer (Bielza 2008, Bielza et al. 2008).

Consequently, eliminating weeds may impact the overwintering life stages of the western flower thrips, resulting in an overall reduction in populations.

Sanitation practices that may minimize problems with weeds in and around greenhouses include the installation of geotextile fabric barriers, hand removal, mowing, and applying herbicides (Cloyd 2004, Marble and Pickens 2018). Geotextile fabric barriers are woven materials (Marble et al. 2015), which may alleviate problems with weeds in greenhouses when installed over flooring and underneath benches. Hand removal is quick but can be a labor-intensive and time-consuming method of weed control in large greenhouse operations with soil or gravel floors (Case et al. 2005). Weeds should be removed from inside the greenhouse before they flower and set seeds. In addition, gravel placed around the greenhouse perimeter may prevent weeds from establishing.

Mowing before weeds flower will reduce the potential for any seeds to enter and germinate in greenhouses (Cloyd 2012). Pandey and Johnson (2006) recommended using herbicides to control Rhodes grass, *Chloris gayana* Kunth, and other weed hosts of the pink pineapple mealybug, *Dysmicoccus brevipes* (Cockerell) (Hemiptera: Pseudococcidae), to reduce mealybug populations. However, few pre-emergent herbicides (i.e., applied before weed seeds germinate) are registered for use inside greenhouses and those that are labeled should only be applied when greenhouses are empty because of the potential for plant damage (Marble and Pickens 2018). In addition, postemergent herbicides (i.e., applied after weeds germinate) should only be applied inside greenhouses when crops are not present (Cloyd 2004). However, postemergent herbicides containing glyphosate (e.g., Roundup Pro) may be applied to eliminate weeds around the perimeter of the greenhouse.

Although there may be a substantial installation cost, concrete floors reduce weed growth inside the greenhouse during the growing season more so than soil or gravel floors, resulting in fewer weed hosts for insect pests (Cloyd 2012). There is no quantitative information on the extent of a weed-free zone required around greenhouse perimeters to keep insect pests from migrating into greenhouses. Therefore, research needs to be conducted so that recommendations can be made to greenhouse producers regarding the distance a weed-free zone should be established and maintained around greenhouse perimeters.

Disposal of Plant and Growing Medium Debris

Plant debris may harbor certain insect pests such as aphids, thrips, and whiteflies. Consequently, immediate removal of plant debris from the greenhouse should decrease insect pest populations and prevent reinfestation of the main crop(s) (Parrella and Jones 1987, Shipp et al. 1991). In addition, removing growing medium debris from the greenhouse (Gholami and Sadeghi 2016) may alleviate problems with certain insects such as fungus gnats, *Bradysia* spp., and western flower thrips that may pupate in growing medium debris.

Hogendorp and Cloyd (2006b) reported that plant material and growing medium debris placed into uncovered refuse containers serve as a source of insect pests, including fungus gnats, western flower thrips, and whiteflies. The winged adult stages of these insect pests may migrate out of uncovered refuse containers and subsequently infest the main crops grown in greenhouses (Hogendorp and Cloyd

2006b). The study demonstrated the importance of sanitation associated with routinely removing plant and growing medium debris from greenhouses or placing into refuse containers with tight sealing lids (Hogendorp and Cloyd 2006b).

Algae Management

Algae may be a problem during the production of greenhouse-grown horticultural crops by accumulating on containers, growing media, benches, floors, walkways, cellulose pads, and underneath benches (Chase and Osborne 1984, McCain and Sciaroni 1984). Algae are usually affiliated with water accumulation, and the presence of algae in greenhouses may lead to problems with shore fly, *Scatella* spp., and fungus gnat populations (Cloyd 2012, Keates et al. 1989). For instance, excessive populations of fungus gnats can result in damage to young plant material such as seedlings or transplants (Keates et al. 1989).

Algae management involves not overwatering and overfertilizing plants, as well as using well-drained growing media (Marble and Pickens 2018). In addition, applying commercially available disinfectants containing hydrogen peroxide or quaternary ammonium chloride salts, and copper-based algaecides may reduce problems with algal accumulation (Chase and Conover 1993, Nameth and Powell 2004). Geotextile fabric barriers used for weed management may also help reduce algae growth. Greenhouses with concrete flooring have less algae growth because they are easier to clean, resulting in fewer problems with shore flies and fungus gnats than greenhouses with soil or gravel floors (Cloyd 2016, Keates et al. 1989).

Conclusion

Sanitation is a practice that may lead to a reduction in insect pest populations in greenhouse production systems. Consequently, the three major sanitation practices discussed in this review, removing weeds from within and around the greenhouse, disposing of plant and growing medium debris from inside the greenhouse, and managing algae within the greenhouse will help greenhouse producers manage insect pests.

However, quantitative research is warranted to determine how sanitation practices function in reducing insect pest populations in greenhouse production systems. Therefore, studies are needed to (a) quantify the economic value of sanitation practices as a component of plant protection programs, (b) determine the distance a weed-free zone needs to be around greenhouse perimeters to prevent insect pests from entering greenhouses, (c) identify the common weeds of greenhouses and the insect pests associated with these weeds, and (d) assess the importance of managing algae to reduce problems with shore flies and fungus gnats. The results from such research will demonstrate to greenhouse producers the importance of implementing appropriate sanitation practices during the growing season.

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