# Topics in Subtropics Newsletter

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# Natural enemies have significantly suppressed Asian citrus psyllid populations in southern California

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## *Is California facing a citrus apocalypse?*

Asian citrus psyllid (ACP) (*Diaphorina citri*) (**Fig. 1**) is an invasive pest of citrus first discovered in urban citrus in San Diego County California (CA) in 2008 (Grafton-Cardwell 2010). ACP presents a significant economic threat to CA's citrus industry because it vectors a bacterium, *C*Las, which causes a citrus-killing disease, huanglongbing (HLB) (Grafton-Cardwell et al. 2013). There is currently no cure for HLB which kills susceptible commercial citrus varieties in as little as 5 to 8 years. Since HLB was first discovered in Florida (FL) in 2005 (ACP was discovered in FL in 1998), citrus production in that state has fallen by 80% (USDA NASS 2022a). In CA, the first case of HLB was detected in 2012 in Los Angeles County and infestations of ACP-*C*Las are largely restricted to urban-grown citrus in southern CA (Kumagi et al. 2013; CDFA 2022). Should HLB spread north into the San Joaquin Valley, where 75% of CA's citrus fruit is grown, it would jeopardize ~262,000 fruit-bearing acres, which generates over $3 billion annually and provides over 26,000 jobs (USDA NASS 2022b). Because ACP-HLB poses such a significant threat to CA's citrus industry, ACP population suppression is key to slowing the spread of *C*Las into CA's commercial citrus groves (Bassanezi et al. 2013).


**Figure 1.** ACP adult (a) and nymphs (b) infesting citrus. (c) The waxy white tubules hanging from nymphs are threads of solid honeydew which are harvested by Argentine ant (*Linepithema humile*). (Photos by Mike Lewis, UC Riverside).

## *Biocontrol suppresses ACP populations*

In CA, ACP has been the target of a classical or introduction biological control program with two tiny parasitic wasps or parasitoids, *Tamarixia radiata* and *Diaphorencyrtus aligarhensis* (**Fig. 2**), sourced from Pakistan, a part of the ACP's presumptive native range (Hoddle 2012; Milosavljević et al. 2017). CA's biocontrol program against ACP began with the release of *T. radiata* in December 2011, and in December 2014, *D. aligarhensis* was added to the release program with the intent of establishing a complementary set of parasitoids that specifically attack ACP nymphs (Milosavljević et al. 2017). To date, >24 million parasitoids (*T. radiata* and *D. aligarhensis* combined) have been mass-produced and released at >19,500 sites in southern CA by the Applied Biocontrol Lab at UC Riverside and the California Department of Food and Agriculture (CDFA 2022). Of these two parasitoids, *T. radiata* established readily and rapidly spread into sites in CA where it was not released (Hoddle et al. 2016, Milosavljević et al. 2021). Conversely, *D. aligarhensis* failed to establish following release in CA and mass production and release of this parasitoid was subsequently discontinued in 2019 (Milosavljević et al. 2022).


**Figure 2.** Female (a) *Tamarixia radiata* and (b) *Diaphorencyrtus aligarhensis* parasitizing (i.e., laying eggs) ACP nymphs. (c) *Tamarixia radiata* adults emerge from the anterior region of parasitized ACP nymphs (left), while *D. aligarhensis* adults emerge from the posterior region (right). Emergence hole position is used in the field to determine parasitoid species identity. (Photos by Mike Lewis, UC Riverside).

### *The ongoing biocontrol effort: So far, so good, but there is room for improvement*

Since the inception of the ACP biocontrol program in CA in 2010 and the first release of *T. radiata* in 2011, densities of ACP infesting urban citrus have declined by ~70%. Two different multi-year and multi-site studies in urban citrus in southern California has clearly demonstrated that the proximate causes of these widespread population declines are due to natural enemies, specifically parasitism of ACP nymphs by *T. radiata* (**Fig. 2**) and predation by generalist predators, of which syrphid fly larvae are key predators of ACP nymphs (**Fig. 3**) (Hoddle et al. 2022; Kistner et al. 2016, 2017; Milosavljević et al. 2021, 2022). Consequently, reduced ACP densities may have slowed the spread of *C*Las in CA and subsequent development of HLB in infected citrus trees. However, the efficacy of natural enemies attacking ACP eggs and nymphs has been reduced by the presence of another invasive pest, the Argentine ant (AA) (*Linepithema humile*) (**Fig. 4**). Field work on ACP biocontrol in CA identified AA as a significant impediment to natural enemies (Kistner et al. 2016, 2017; Schall & Hoddle 2017; Milosavljević et al. 2021). When present on trees, AA reduced the abundance of natural enemies interacting with ACP and suppressed the efficacy of *T. radiata* and syrphids by over 50 percent. When AA is excluded from ACP colonies, natural enemy abundance and attack rates increase significantly, particularly impacts by *T. radiata* and syrphid fly larvae.

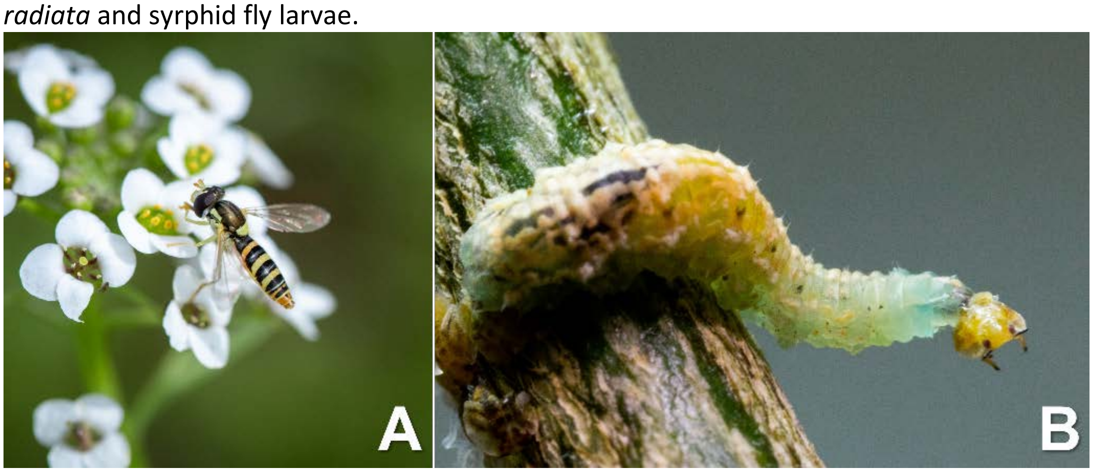


**Figure 3.** (a) An adult syrphid fly foraging on alyssum flowers in a citrus orchard (b) a syrphid fly larva feeding on an ACP nymph. (Photos by Mike Lewis, UC Riverside).

### *Why are Argentine ants problematic, and what can we do about them?*

AA aggressively protect >55% of ACP from natural enemies. In return for this protection, AA is rewarded with food, honeydew (**Fig. 1c**), which is a sugary waste product excreted by ACP nymphs (Tena et al. 2013). Consequently, AA protection exacerbates infestations of ACP and other honeydew producing pests in citrus (e.g., brown soft scale and mealybugs). This results in a positive feedback loop – more pests survive due to AA protection and their populations increase which in turn produces more food for AA which results in increasing ant populations. An undesirable outcome of these population increases is greater applications of insecticides to control sap sucking pests and AA (Schall et al. 2018). Ironically, sprays of contact insecticides targeting AA (and ACP) kill natural enemies needed for "free" pest control and this disrupts IPM programs which aim to reduce insecticide use.

To ameliorate this problem of increased insecticide use, biocontrol ACP (and other sap sucking pests) can be enhanced through three management practices: (1) monitoring AA activity with infra-red sensors to determine when ants have reached densities that need controlling, (2) controlling AA with highly targeted applications of ultra-low concentrations (i.e., 0.0001%) of insecticide delivered to foraging inside of biodegradable hydrogel beads that are infused with 25% sucrose water and insecticide (McCalla et al. 2020), and (3) floral resources that provide food and shelter to natural enemies, especially hover flies, that attack ACP nymphs. This three-pronged management approach for controlling AA and the pests ants protect (e.g., ACP) is undergoing field evaluation in commercial citrus orchards in southern California. The outcomes of these large, replicated field trials will be discussed in an upcoming article in Topics in Subtropics: "*Maximizing IPM of Argentine ant and sap sucking pests with biodegradable hydrogels, infra-red sensors, and cover crops in commercial citrus orchards*."


**Figure 4.** (A) Argentine ants harvesting honeydew from ACP nymphs infesting backyard citrus (B) an Argentine ant attacking a female *Tamarixia radiata* foraging on a patch of ACP nymphs. (Photos by Mike Lewis, UC Riverside).

## References

Bassanezi, R.B., L.H. Montesino, N. Gimenes-Fernandes, P.T. Yamamoto, T.R. Gottwald, L. Amorim, A.B. Filho. 2013. Efficacy of area-wide inoculum reduction and vector control on temporal progress of huanglongbing in young sweet orange plantings. Plant Disease 97: 789–796.

[CDFA] California Department of Food and Agriculture. 2022. CDFA ACP/HLB regulation and quarantine boundaries. https://www.cdfa.ca.gov/plant/acp/regulation.html

Grafton-Cardwell, E. 2010. How serious is the threat of Asian citrus psyllid and Huanglongbing? Citrograph 1 (1): 8–10.

Grafton-Cardwell, E.E., L.L. Stelinski, P.A. Stansly. 2013. Biology and management of Asian citrus psyllid, vector of the huanglongbing pathogens. Annual Review of Entomology 58: 413–432.

Hoddle, M.S. 2012. Foreign exploration for natural enemies of Asian citrus psyllid, *Diaphorina citri* (Hemiptera: Psyllidae), in the Punjab of Pakistan for use in a classical biological control program in California USA. Pakistan Entomologist 34: 1–5

Hoddle, M.S., R. Amrich, C.D. Hoddle, E.J. Kistner. 2016. Where's *Tamarixia*? Citrograph 7: 64–66.

Hoddle, M.S., Hoddle, C.D., Morgan, D.J.W., Milosavljević, I. 2022. Successful Biological Control of Asian Citrus Psyllid, *Diaphorina citri*, in California. USDA-FHTET, Morgantown WV.

Kistner, E.J., N. Melhem, E. Carpenter, M. Castillo, M.S. Hoddle. 2016. Abiotic and biotic mortality factors affecting Asian citrus psyllid (Hemiptera: Liviidae) demographics in southern California. Annals of the Entomological Society of America 109: 860–871.

Kistner, E.J., M. Lewis, E. Carpenter, N. Melhem, C.D. Hoddle, V. Strode, J. Oliva, M. Castillo, M.S. Hoddle. 2017. Digital video surveillance of natural enemy activity on *Diaphorina citri* (Hemiptera: Liviidae) colonies infesting citrus in the southern California urban landscape. Biological Control 115: 141–151.

Kumagi, L.B., C.S. LeVesque, C.L. Blomquist, K. Madishetty, Y. Guo, P.W. Woods, S. Rooney-Latham, J. Rascoe, T. Gallindo, D. Schnabel, M. Polek. 2013. First report of *Candidatus* Liberibacter asiaticus associated with citrus huanglongbing in California. Plant Disease 97: 283.

McCalla, K.A., Tay, J.W., Mulchandani, A., Choe, D.H., Hoddle, M.S. 2020. Biodegradable alginate hydrogel bait delivery system effectively controls high-density populations of Argentine ant in commercial citrus. Journal of Pest Science 93: 1031-1042.

Milosavljević, I., Schall, K.A., Hoddle, C.D., Morgan, D.J.W., Hoddle, M.S. 2017. Biocontrol program targets Asian citrus psyllid in California's urban areas. California Agriculture 71: 169-177.

Milosavljević, I., D.J.W. Morgan, R.E. Massie, M.S. Hoddle. 2021. Density dependent mortality, climate, and Argentine ants affect population dynamics of an invasive citrus pest, *Diaphorina citri*, and its specialist parasitoid, *Tamarixia radiata*, in southern California, USA. Biological Control 159: 104627.

Milosavljević, I., M.A. Vankosky, D.J.W. Morgan, C.D. Hoddle, R.E. Massie, M.S. Hoddle. 2022. Post-release evaluation of *Diaphorencyrtus aligarhensis* (Hymenoptera: Encyrtidae) and *Tamarixia radiata* (Hymenoptera: Eulophidae) for biological control of *Diaphorina citri* (Hemiptera: Liviidae) in urban California, USA. Agronomy 12: 583.

Schall, K.A., M.S. Hoddle. 2017. Disrupting the ultimate invasive pest partnership. Citrograph 8: 38-43.

Schall, K.A., Tay, J.W., Mulchandani, A., Choe, D.H. Hoddle, M.S. 2018. Harnessing hydrogels in the battle against invasive ants. Citrograph 9: 30-35.

Tena, A., Hoddle, C.D., Hoddle, M.S. 2013. Competition between honeydew producers in an ant-hemipteran interaction may enhance biological control of an invasive pest. Bulletin of Entomological Research. 103, 714-723.

[USDA NASS] United States Department of Agriculture National Agricultural Statistics Services. 2022a. Citrus Production Forecast. www.nass.usda.gov/Statistics_by_State/Florida/index.php

[USDA NASS] United States Department of Agriculture National Agricultural Statistics Services. 2022b. Citrus Production Forecast. https://www.nass.usda.gov/Statistics_by_State/California/index.php

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## Synergizing IPM of Argentine ant and biocontrol of sap sucking pests with biodegradable hydrogels, infra-red sensors, and cover crops in commercial citrus orchards

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### *Argentine Ant control critical for IPM in citrus groves*

The invasive Argentine ant (AA) (*Linepithema humile*) (**Fig. 1A**) is a serious impediment to the biological control of sap sucking pests (SSPs) in citrus orchards (Hoddle et al. 2022). SSPs include mealybugs, scales, aphids, and Asian citrus psyllid (ACP), the vector of a bacterium that causes HLB, a lethal citrus disease (Schall & Hoddle 2017). AA protect >85% of SSPs and >55% of ACP colonies (**Fig. 1B**) from their natural enemies which exacerbates pest infestations. In return for protection from natural enemies, ants are rewarded for this service by SSP's through the provision of a sugary waste product, honeydew, which ants harvest and return to nests to feed brood and queens (**Fig. 1C**) (Tena et al. 2013). AA (Milosavljević et al. 2017, 2021). Contact sprays for AA and SSP control applied to soil, trunks, and foliage kill natural enemies, cause secondary pest outbreaks, and increase the likelihood of insecticide resistance developing. IPM of AA and SSPs requires an accurate method of assessing pest densities so that appropriate treatment decisions can be made, precision delivery of insecticides to kill foraging AA is necessary if natural enemies are to be preserved, and enhancement of natural enemies through conservation biocontrol can increase the efficacy of free pest control services provided by natural enemies in citrus orchards.

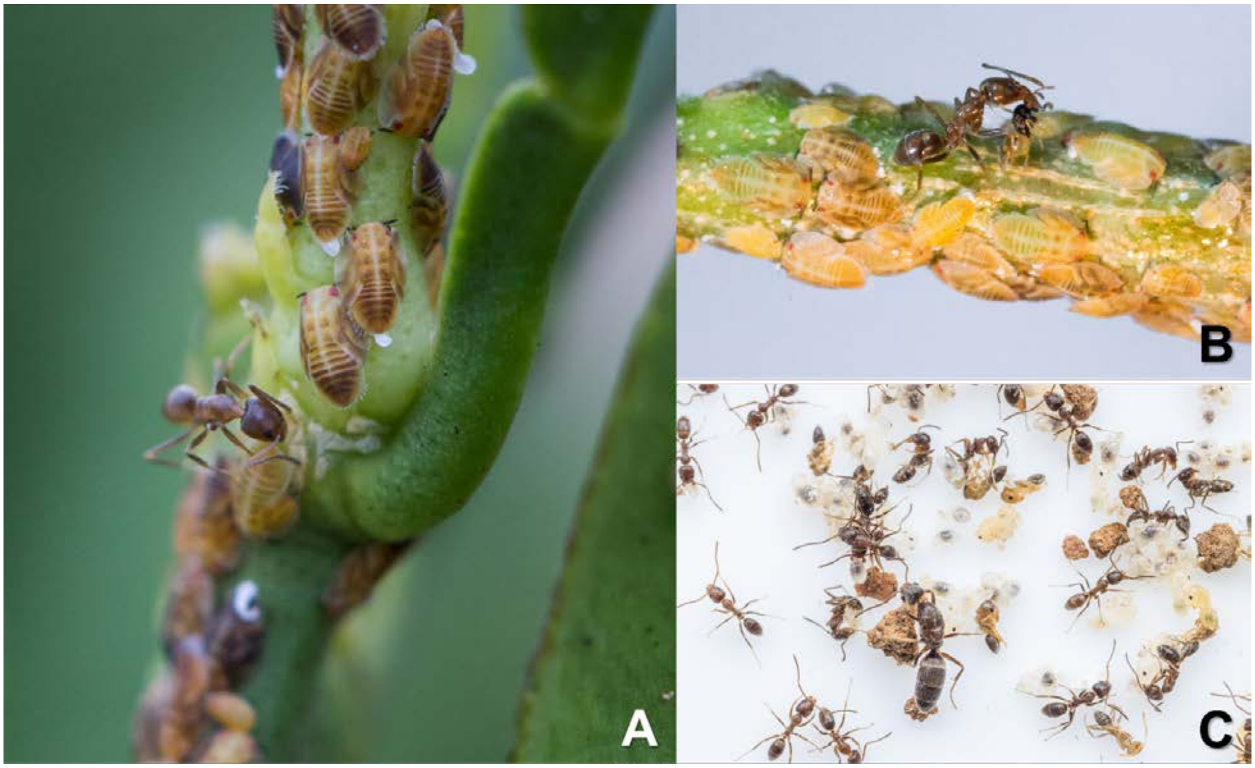


**Figure 1.** (A) Argentine ants tend an Asian citrus psyllid colony to collect sugary honeydew. The waxy white tubules hanging from nymphs are honeydew threads which are harvested by Argentine ant. (B) Argentine ant attacking *Tamarixia radiata*, a key natural enemy of Asian citrus psyllid; (C) Argentine ant colony. Alongside the large queen are workers, pupae, and grub-like larvae. Worker ants feed these life stages honeydew collected from SSPs (Photos by Mike Lewis, UC Riverside).

***Enhancing and automating Argentine ant monitoring using infra-red sensors and the internet of things***

Efficient and accurate pest monitoring is a key component of IPM programs. There are currently no standardized monitoring programs for assessing AA infestation levels. Visual ant counts are time consuming, tedious, and become inaccurate when counting fatigue sets in. To remedy this problem, we developed and field-tested infrared sensors (IRS) that clamp to irrigation lines to automate ant counts (**Fig. 2**). AA use irrigation lines as super-highways to rapidly move across the orchard floor to reach pest infested citrus trees (**Fig. 2B**). Statistical analyses indicated that it is possible to predict with about 85% accuracy the average number of ants ascending tree trunks based on the average number of ants running on irrigation lines. Thus, ant counts made by IRS on lines can be used to accurately predict the average number of ants ascending tree trunks in citrus orchards. Ant counts made by IRS are relayed wirelessly to the cloud where average AA densities are reviewed on an App that is loaded onto a smart device. IRS's eliminate the need for humans to monitor ant densities, they provide block specific estimates of AA activity, and they can potentially operate 24/7/365! We are currently determining the minimum number of IRS needed per acre to estimate ant densities with fixed levels of precision (e.g., 85, 90, 95% accuracy).

Based on accurate ant density estimates treatment decisions can be made, and importantly, just the areas of the orchard exceeding acceptable ant densities can be identified and treated (Schall et al. 2018). Focused applications reduces insecticide use, saves money, and minimizes adverse effects of insecticide use on beneficial non-target species, like natural enemies (McCalla et al. 2020). As part of an AA IPM programs, treatment decisions require action thresholds and when AA densities exceed the action threshold, treatments can be initiated. At this time, there are currently no established action thresholds for AA in citrus. This is an important problem we are currently working on.

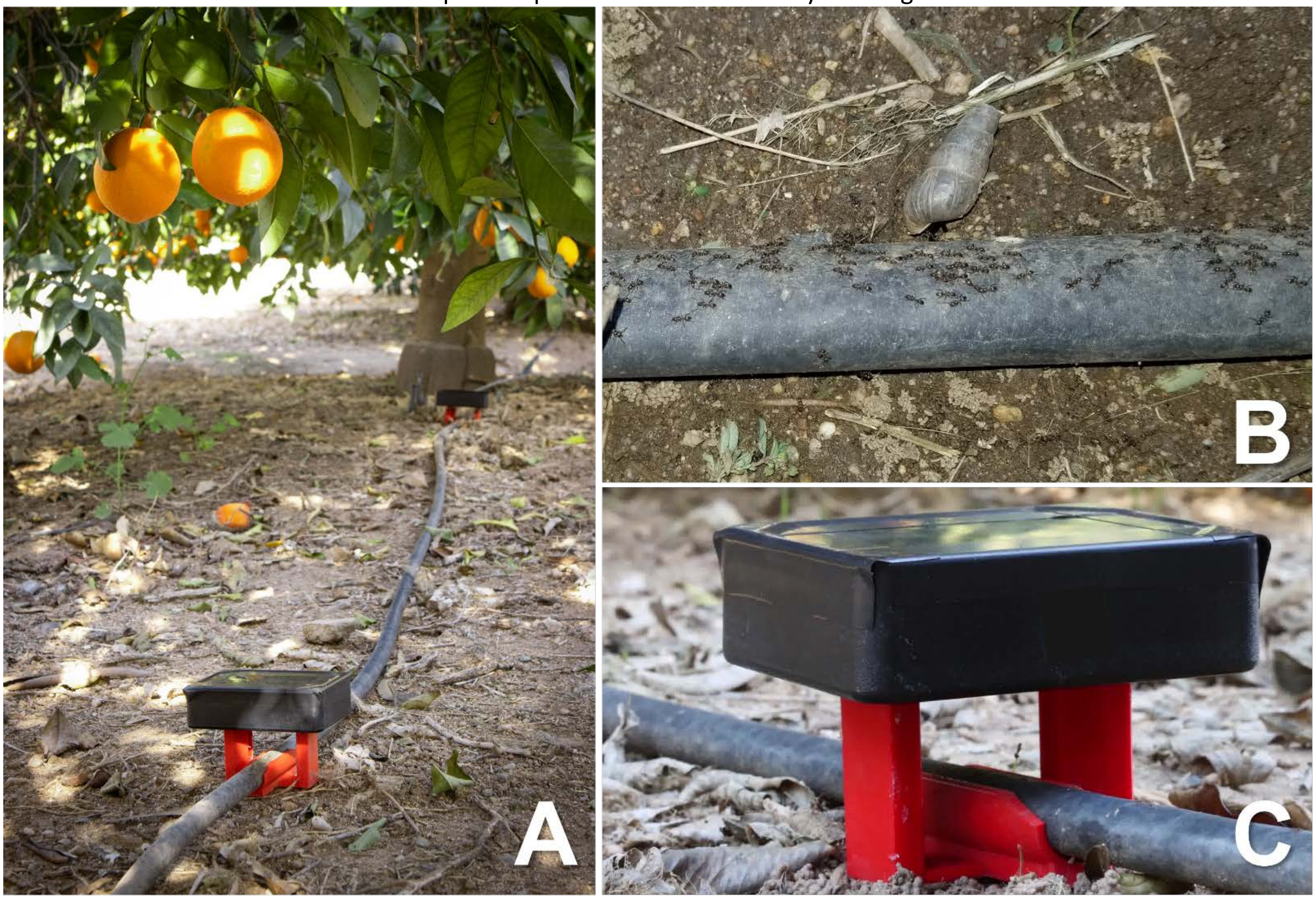


**Figure 2.** (A) Infra-red sensor (IRS) clamped onto an irrigation line in a commercial citrus orchard. (B) Argentine ants use polyethylene irrigation lines that sit on the soils surface as "super-highways" to move from underground nests to tree canopies where they collect honeydew. (C) Close-up of IRS counting Argentine ants running on irrigation lines. (Photos by Mike Lewis and Mark Hoddle, UC Riverside).

### *Hydrogel baits provided targeted and highly effective Argentine ant control in citrus orchards*

Chlorpyrifos, the industry standard insecticide for AA control, was recently banned in California because it poses significant risks to human health (CDPR 2019a, b). In response to this ban, we developed biodegradable hydrogel beads (HGBs) as an alternative highly specific treatment that targets AA (**Fig. 3**) (Schall et al. 2018). HGBs contain a 25% sucrose solution, and an ultra-low dose of insecticide (0.0001%). HGB's are applied to the ground under citrus trees and spread out so foraging AA can rapidly find them. Ants imbibe sugar water laced with insecticide, return it to the nest to feed brood and queens which kills them. Consequently, HGB's may provide a superior alternative to plastic liquid bait stations for delivering toxins to AA as bait stations are cost-prohibitive for mass use in orchards (McCalla et al. 2020). Our lab has demonstrated that both thiamethoxam and an organically approved spinosad formulation are highly efficacious when delivered to AA using HGBs infused with sugar water that is laced with insecticide. Within 2-3 days of HGB applications, AA colonies collapse, and AA densities are reduced by >95% in comparison to untreated plots (Schall et al. 2018). Rapid (< 5 days) long term (> 3 months) control of AA results from repeated HGB applications (~3-4 applications ~3 weeks apart over summer). Once AA are controlled long-term reductions in densities of SSPs in citrus results because natural enemies are able to more effectively control SSP's in the absence of AA (Schall & Hoddle 2017;

McCalla et al. 2020). We are currently determining the minimum amounts of HGBs, and frequency of applications needed to optimize AA control at the lowest costs to growers.


**Figure 3.** (A) Close-up of Argentine ants (*Linepithema humile*) feeding from an alginate hydrogel bead filled with toxic liquid bait. (B) Argentine ants imbibing sugar water infused with an ultra-low concentration of insecticide contained with biodegradable hydrogel beads. (Photos by Mike Lewis, UC Riverside).

### *Using flowering plants to enhance natural enemies of ACP and SSPs in citrus orchards*

Our previous work has shown that natural enemies, especially hover flies (syrphids), respond strongly to flowering alyssum (*Lobularia maritima*) and buckwheat (*Fagopyrum esculentum*) (Irvin et al. 2021). Field work has also shown that ACP in citrus plots with flowering plants suffer significantly greater levels of natural enemy attack, especially by predatory hover fly larvae, when compared to plots lacking flowering plants (Irvin et al. 2021). Hover fly larvae are dominant predators attacking ACP nymphs and other SSPs in citrus (Kistner et al. 2016, 2017). *Tamarixia radiata*, a tiny parasitic wasp has been imported into California from the Punjab of Pakistan to attack ACP nymphs (Hoddle et al. 2022) also feed from buckwheat flowers (Irvin & Hoddle 2021). We have also found that hoverflies in southern California are most active in spring and fall and this is when flowering plants are most beneficial to them. This finding is important as ACP (and SSP) populations are greatest in spring and over fall also (Milosavljević et al. 2021). Sowing flowering plants late-February and re-sowing in early-September would synchronize hoverfly activity with ACP population increases. We are currently assessing the efficacy of flowering plants in multiple commercial citrus orchards to the magnitude of reductions in populations of ACP and SSP densities when cover crops are present and absent.

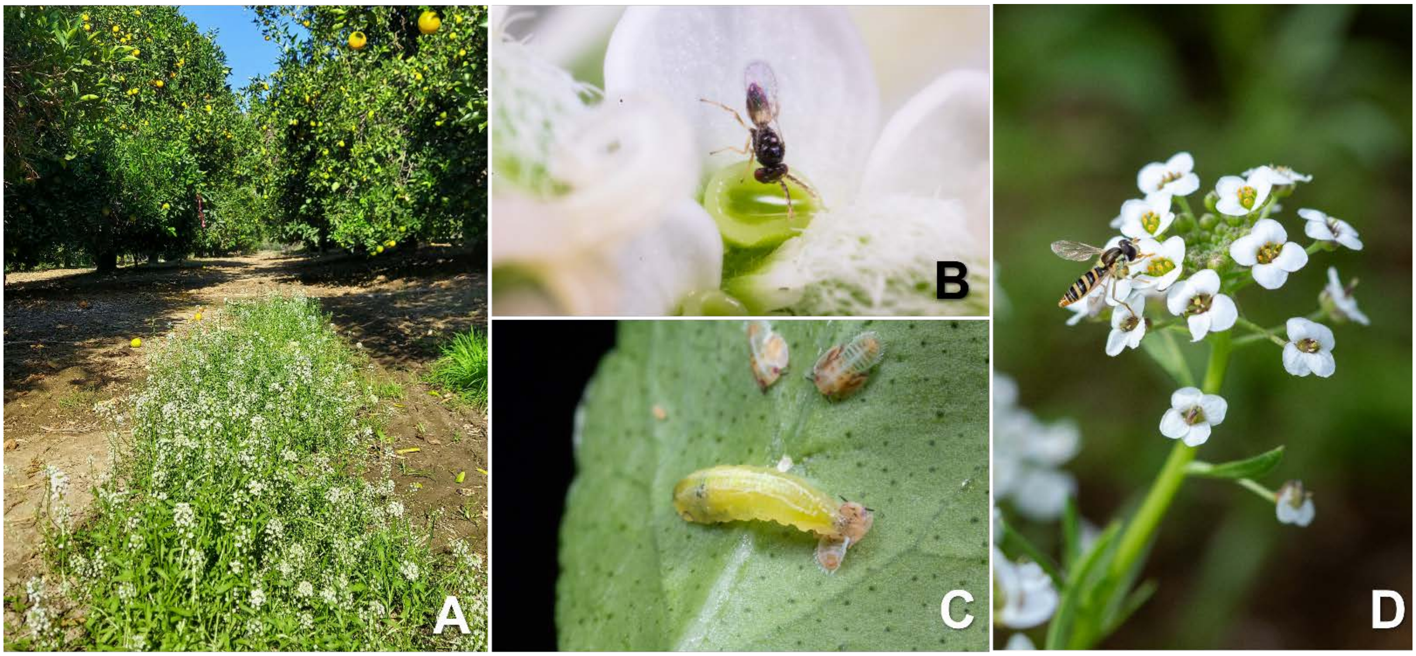


**Figure 4.** (A) Flowering alyssum (*Lobularia maritima*); (B) *Tamarixia radiata* feeding from a buckwheat (*Fagopyrum esculentum*) flower; (C) a hover fly larva feeding on an ACP nymph.; (D) Hoverfly adult feeding from an alyssum flower. (Photos by Mike Lewis, UC Riverside).

### *Take home messages*

IPM of AA and SSP's in citrus, include ACP, requires new and innovative approaches if long-term sustainable management is to be achieved. To achieve this, we are working on developing a package that combines three tools, HGBs, IRS, and flowering plants that enhance monitoring of AA (IRS), provides targeted highly specific control of AA (HGBs) that in turn relieves natural enemies from pressure of foraging ants which permits them to increase the free pest management service that they provide in citrus orchards. These agroecosystem services provided by natural enemies can be further enhanced through resource provision, cover crops, which provide pollen and nectar to natural enemies. This combination of tools, IRS, HGBs and cover crops, synergizes IPM of AA and biocontrol of sap sucking pests infesting California-grown citrus.

## References

[CDPR] California Department of Pesticide Regulation (2019a) California acts to prohibit chlorpyrifos pesticide. https://www.cdpr.ca.gov/docs/pressrls/2019/050819.htm

[CDPR] California Department of Pesticide Regulation (2019b) Chlorpyrifos interim recommended permit conditions. https://www.cdpr.ca.gov/docs/enforce/compend/vol_3/append_o.pdf

Hoddle, M.S., Hoddle, C.D., Morgan, D.J.W., Milosavljević, I. 2022. Successful Biological Control of Asian Citrus Psyllid, *Diaphorina citri*, in California. USDA-FHTET, Morgantown WV.

Irvin, N.A., Hoddle, M.S. 2021. The effects of floral nectar, extrafloral nectar and hemipteran honeydew on the fitness of *Tamarixia radiata* (Hymenoptera: Eulophidae), a parasitoid of *Diaphorina citri*. Biological Control, 163, 104753.

Irvin, N.A., Pierce, C., Hoddle, M.S. 2021. Evaluating the potential of flowering plants for enhancing predatory hoverflies (Syrphidae) for biological control of *Diaphorina citri* (Liviidae) in California. Biological Control, 157, 104574.

Kistner, E.J., N. Melhem, E. Carpenter, M. Castillo, M.S. Hoddle. 2016. Abiotic and biotic mortality factors affecting Asian citrus psyllid (Hemiptera: Liviidae) demographics in southern California. Annals of the Entomological Society of America 109: 860–871.

Kistner, E.J., M. Lewis, E. Carpenter, N. Melhem, C.D. Hoddle, V. Strode, J. Oliva, M. Castillo, M.S. Hoddle. 2017. Digital video surveillance of natural enemy activity on *Diaphorina citri* (Hemiptera: Liviidae) colonies infesting citrus in the southern California urban landscape. Biological Control 115: 141–151.

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Schall, K.A., Tay, J.W., Mulchandani, A., Choe, D.H. Hoddle, M.S. 2018. Harnessing hydrogels in the battle against invasive ants. Citrograph 9: 30-35.

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## Irrigation Stress and Early-Navel Fruit Maturity

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To maximize profits in the early navel orange market, growers need to have large fruit size and sufficient yellow-orange color and a high enough sugar-acid ratio to meet or exceed the legal minimum harvesting standards. Growers of early-maturing navel oranges in Kern County use different strategies to produce these oranges. Some growers irrigate at full evapotranspiration rates nearly up to harvest with the belief this will maximize fruit size, while others begin deficit irrigating a month or two prior to harvest to maximize development of sugar and color to promote earlier maturity. Little information exists in the literature to assist growers in making decisions related to producing early maturing navels such as Beck, Fukumoto and Thompson Improved. To determine the effects of late season irrigation stress, I, along with two University of California co-researchers Blake Sanden and Dr. Mary Lu Arpaia, participated in an experiment to elucidate some of the trade-offs that relate to irrigation strategies and early navel fruit production. The research was conducted from 2006 through 2008 in a cooperating grower's Beck orchard at the extreme southern end of the San Joaquin Valley. Our generous and patient cooperating growers were George and Colby Fry.

Three different irrigation treatments, defined as low, mid and high, were developed based on the relative amounts of irrigation water applied to the test plots. Each plot consisted of 10 trees in a central row, bordered by ten similarly irrigated trees in the two adjacent rows. Each treatment was replicated five times. The same irrigation treatment was applied to the same plots for the first two years, while in the third year the low treatment was changed to the high treatment to provide information on how rapidly the trees would recover from stress. The different irrigation treatments were administered by using irrigation emitters with different flow rates and by differentially shutting off water to some treatments as needed to achieve desired stress levels. Between growing seasons, the top three feet of soil profile was refilled with water during the winter and differential irrigation began in early August. Measurable differences in tree shaded stem water potential among treatment usually were noted by early September. In the second year of the experiment (2007), the low and mid-irrigation treatments applied approximately 38 and 71 percent, respectively on average, of the water of the high treatment. Water potential measurements made mid-day on shaded, interior leaves demonstrated that good separation was achieved among the three differential treatments. In 2007, for example, shaded stem water potential measurement in early September were about -9, -12, and -18 bars for the high, mid and low irrigation treatments, respectively and at harvest in mid-October were -12, -18, -24, respectively. Neutron probe measurements also demonstrated that trees differentially depleted available water stored in the soil as the season progressed (data not shown). In 2007, differences in applied water among the treatments were large. Including the increased quantity of water applied to refill the soil profile in the winter, 3.55, 2.58 and 2.11 acre feet of water on a per acre basis, were applied to the high, mid and low irrigation treatments respectively, from October 30, 2006, to harvest, October 15, 2007. Rainfall was minimal.

Again, using 2007 as an example, as the level of applied water decreased, soluble solids (i.e. sugars) and titratable acid, were greater at harvest, although the sugar acid ratio was not different (see Table 1).

Table 1. Effect of irrigation treatment on juice, soluble solids, and titratable acid of Beck navel orange fruit in the southern San Joaquin Valley. Fruit harvested October 15, 2007.

| Sample Date | Juice Percentage, by weight | | | Soluble solids concentration, % | | | Titratable acid concentration, % | | | Sugar/Acid Ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | low[1] | mid | high | low | mid | high | low | mid | high | low | mid | high |
| 10/14 | 26 a[2] | 26 a | 28 a | 11.9 c | 10.2 b | 9.5 a | 1.4 b | 1.1 a | 1.1 a | 8.9 a | 9.7 a | 9.0 a |

[1] Low, mid and high refer to the relative amounts of applied irrigation water constituting the three irrigation treatments. The quantity of applied water on an acre basis was 2.11, 2.58, and 3.55 acre feet, for the low, mid and high treatments from the end of October 2006 until October 15, 2007.

[2] Values in the same cell followed by different letters are significantly different by Fisher's protected LSD test at P ≤ 0.05.

Rows in the experimental orchard were oriented east and west. Fruit on the south side of the tree had higher soluble solids concentration and sugar/acid ratio than fruit on the north side of the tree, regardless of irrigation treatment. Fruit juiciness, either measured as weight of juice to weight of fruit (see Table 1) or volume of juice per weight of fruit (results not shown) were not different among irrigation treatments, suggesting the increase in sugars and acid was the result of osmotic adjustment and not fruit dehydration. We were also interested in seeing if the differential irrigation treatments influenced eating quality of the fruit. To test this idea, we provided fruit from the highest and lowest irrigation treatments of 2007 and 2008 to volunteer panelists at the UC Kearney Ag Center and asked if they could detect any differences between the fruit. Results from both years showed that the panelists could not detect differences between the two irrigation treatments. This suggests that the increase in soluble solids in the low irrigation treatment was not sufficient to influence eating quality.

In 2007, yield and grade decreased as the amount of applied water decreased (see Table 2).

| Table 2. Effect of irrigation treatment on yield, and grade of Beck navel orange fruit in the southern San Joaquin Valley. Fruit harvested October 15, 2007 | | | | | |
|---|---|---|---|---|---|
| Irrigation treatment | Yield lbs/tree | Fruit/tree number | Fruit grade, % in category | | |
| | | | Fancy | Choice | Juice |
| low[1] | 261[2] a[3] | 566 a | 53.4 a | 41.6 c | 5.0 b |
| mid | 297 b | 584 a | 61.9 b | 33.9 b | 4.2 ab |
| high | 358 c | 646 b | 67.9 c | 28.8 a | 3.3 b |

[1] Low, mid and high refer to the relative amounts of applied irrigation water constituting the three irrigation treatments. The quantity of applied water on an acre basis was 2.11, 2.58, and 3.55 acre feet, for the low, mid and high treatments from the end of October, 2006 through October 15, 2007.

[2] Each value is the average of separate samples of 10 oranges from the north and south side of the trees in each of 5 replicated plots for each irrigation treatment, except on 10/15 in which 10 oranges were removed at random from the fruit of each plot as it passed through the pack line after harvest.

[3] Values in the same cell followed by different letters are significantly different by Fisher's protected LSD test at $P \leq 0.05$.

Fruit in the high and mid irrigation treatments peaked on size 56 per carton and on size 72 per carton in low treatment (data not shown). The decrease in fruit grade at pack-out appeared to be largely due to a more oblong shape. The negative yield, fruit size and grade effects measured in the low and mid treatments in 2007 were probably the cumulative result of deficit irrigation in Years 1 and 2 and not just Year 2 alone. Reduced rates of irrigation hastened development of fruit color compared to the high irrigation treatment (see Table 3) and this occurred every year.

| Table 3. Percent of Beck navel orange fruit in three color categories in response to irrigation treatment at harvest on October 15, 2007 in the southern San Joaquin Valley. | | | |
|---|---|---|---|
| irrigation treatment | green | yellow-orange | orange |
| | --------- percent of fruit in each color category------------ | | |
| low[1] | 58.0[2] a[3] | 42.0 c | 0.0 a |
| mid | 78.8 b | 21.2 b | 0.0 a |
| high | 92.2 c | 7.8 a | 0.0 a |

[1] The quantity of applied water on an acre basis was 2.11, 2.58, and 3.55 acre feet, for the low, mid and high treatments from the end of October 2006 until October 15, 2007.

[2] Each value is the average percentage of fruit in each color category. Each fruit was evaluated automatically by instrument as it passed through the packline at the UC Lindcove Research and Extension Center at Lindcove. Values were calculated from all the fruit harvested from three trees in each of 5 plots.

[3] Values in the same column followed by different letters are significantly different by Fisher's protected LSD test at $P \leq 0.05$.

The deleterious effects on yield, and grade on the trees in the low-irrigation treatments suggested that not much would be gained by continuing this level of stress for a third season in the same plots. In 2008, the low irrigation treatment was replaced by a high irrigation treatment and, at harvest, yield by weight and fruit numbers were not different from the control high-irrigation treatment.  This observation demonstrated that the Beck navels rebounded quickly from the low irrigation stress of 2006 and 2007. The mid-level irrigation stress of 2006 and 2008 was less severe than that of 2007, and yield and fruit quality was not as adversely affected as in 2007.

This study provides information on some of the trade-offs that might be expected among fruit yield, size, grade, sugar and color in relation to reduced irrigation as harvest approaches. More detailed information from the trial can be found at the following link: https://doi.org/10.21273/HORTSCI.46.8.1163. How growers respond to this information will depend on their approach to profiting in the early navel market and how much water will be available for irrigation. If reducing water use is the primary goal of the grower, while minimizing effects on yield and fruit quality compared to fully irrigated orchards, work by Dr. Goldhamer, UC irrigation specialist, demonstrated that regulated deficit irrigation in the mid-May through mid-July time period would be the best strategy. The authors gratefully acknowledge the Citrus Research Board for its financial support of this project.

# HIGH DENSITY CITRUS PLANTING

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Increasingly, orange and mandarin growers in the San Joaquin Valley (SJV) of California are planting trees at much higher densities than was the case even 15 years ago. Not much data is available in the literature on yield and fruit quality that results from high-density citrus plantings as opposed to the more historic open plantings. Planting density, to some extent, is affected by the choice of variety and rootstock as some combinations of these are naturally slower growing and slower to crowd. Tree density in orchards is often increased where soil texture, soil depth or irrigation quality limit growth as trees are slower to crowd each other. Regardless of the reason for slower growth, a slow-growing tree increases the length of time that the grower benefits from the initial higher density at that site in relation to the greater cost of planting, tree size maintenance and the cost of possible eventual tree removal. Tree spacing experiments are difficult to conduct and take many years to obtain complete results. It is worthwhile to look at older efforts, to see what information may be gleaned from these. In general, for most of our varieties, the results of an older experiment on tree spacing, are probably as meaningful today as when the test was conducted. A tree density trial, using Frost Nucellar on Troyer rootstock, was conducted in Kern County, beginning in 1961 through 1974 by Boswell et al. These researchers used a number of tree spacings as follows: 9’ x 11’ (i.e. 9’ between trees in row and 11’ between rows), 9 x 15, 9 x 18, 9 x 22, 11 x 11, 11 x 18, 11 x 22, 15 x 15, 15 x 18, 22 x 22 (see Figure 1).

*Figure 1. Arial view of the Boswell et al. tree spacing trial in Kern County when the trees were about 8 years old.*

Some of the parameters that these researchers evaluated were as follows:

- Yield
- Net income
- Fruit size
- Rate of color development of the fruit
- Intensity of color development of the fruit
- Development of the fruit sugar/acid ratio

Results from this experiment were published at intervals in various publications as follows:

- Various research reports
- Platt, R.G. 1973. Planning and planting the orchard, p. 48-81. In W. Reuther (ed.). The Citrus Industry, Volume III. Div. of Agric. Sci., Univ. of Calif. , Berkeley, Calif.
- Boswell. S.B, C.D. McCarty, K.W. Hench and L.N. Lewis. 1975. Effect of tree density on the first ten years of growth and production of 'Washington' navel orange trees. American Society for Horticultural Science 100:370-373

Not surprisingly most of the very close spacings had to be modified before the end of the experiment. I will quote from Volume III of the Citrus Industry, from page 68 in a chapter written by Robert Platt who describes the early results of the experiment up to 1969 as follows:
"Boswell et al., (1970), report that the two closest spacings, 9 by 11 feet and 11 by 11 feet, had to be thinned on the diagonal to one-half the original stand following the third harvest in 1966-67 because of loss of yield due to crowding and shading out of lower branches. The skirts on the remaining trees regrew, however, and increased production per acre is reflected in the 1968-69 harvest. Blocks with 15- and 18-foot spacings between rows required hedging to maintain adequate illumination and allow sufficient working space in row middles. All trees were topped to a 13-foot height in 1967 and maintained at this height with subsequent topping. They found that pruning to avoid crowding reduced yield (*per tree*) in proportion to the amount of foliage removed."

### *TREE DENSITY AND NET INCOME*

As expected, orange yield was higher in some of the plots with higher tree density in the first five years of production (1965 – 1969), but plots with lower tree densities tended to catch up in the following five years of production (1970 - 1974) as shown in Table 1. However, the 11' x 22' and 15' x 18' spacings remained slightly ahead in terms of yield after 10 years of bearing.

Table 1. Frost Nucellar fruit yield in tons/acre given as the average yield per year for the time periods shown. Kern County.

| Tree spacing, ft. | 1965-1969 | 1970 – 1974 | 10-year average |
|---|---|---|---|
| 22 x 22 | 6.7 | 7.1 | 6.9 |
| 15 x 18 | 9.3 | 6.0 | 7.7 |
| 11 x 22 | 10.6 | 4.8 | 7.7 |

Net income, the amount of money made by the grower after subtraction of costs such as tree, tree planting, tree removal with excessive crowding, fruit harvest, hedging and topping, frost control, nitrogen fertilizers and irrigation, are shown for some spacing plots in Table 2.

Table 2. Net Income after 10 bearing years for Frost Nucellar navels (in 1970's dollars). Kern County, 1965-1974.

| Tree Spacing, ft. | Net income after total costs, $ |
|---|---|
| 22 x 22 | 5957[1] |
| 15 x 18 | 5653 |
| 11 x 22 | 7335 |
| 9 x 11 | 2704 |

[1]Multiply by 6.0 to calculate values in today's dollars (2022)

In general, then, some of the more practical higher planting densities increased early and total yield and net income in the first decade of the fruit-bearing years. However, a number of plots with the very highest tree densities had to be reconfigured by thinning early due to excessive tree crowding. Over the time period of this study, the 9' x 11' spacing had a $1712 ($10,000 in today's dollars) tree removal cost and a five times higher tree and tree planting costs. Maximization of net income requires a balance between minimizing total costs and maximizing yield and fruit quality. This study was conducted with a single cultivar on Troyer rootstock. The success of a given tree spacing, partially at least, is a function of the cultivar selection and the rootstock, but growers are limited by the cultivars and rootstocks available. Most combinations produce full-sized trees, but some, such as scions on the rootstock C-35 do it more slowly. The performance of a given orchard may be a financial delight for the manager during the first years of production in terms of yield but a nightmare as the orchard grows older and decisions and expenses related to preventing tree-crowding increase.

## *OTHER OBSERVATIONS MADE IN THE FIRST FIVE YEARS OF BEARING IN THIS EXPERIMENT*

Fruit size parameter: Average individual fruit size was larger in the 22'x 22' spacing.

Fruit color parameter: Orange color developed first in the 22' x 22' tree spacing. Fruit color was delayed as much as 45 days in closes tree spacings.

Color intensity parameter: Orange color was more intense in 22' x 22' spacing.

Sugar/acid ratio parameter: Higher sugar/acid ratio in 22' x 22' spacing. Trees spaced 9' x 11' were 11 days later in reaching legal maturity.

These observations suggest the following for growers seeking to influence fruit quality parameters. For larger fruit size plant trees further apart. For smaller fruit size (which may be desirable for marketing of some mandarins, for example), plant trees closer together. For a sweeter, earlier orange, plant trees further apart. For earlier color development and intensity, plant trees further apart. In general, to hasten fruit maturity overall, plant trees further apart. Finding a "perfect" plant spacing for meeting multiple objectives for fruit quality and yield may not be possible. For example, let's assume the objective of a new mandarin planting is to maximize profits by adjusting spacing for an early-maturing mandarin cultivar as follows:

| Desired parameter | Suggested tree density |
|---|---|
| Early, more intense color | LOW |
| High early sugar/acid ratio | LOW |
| Small/moderate (i.e. cute) fruit size | HIGH |
| High initial yields | HIGH |

As can be seen in the table above, maximizing earliness is at odds with producing high initial yields of smaller sized fruit. It may be possible to take advantage of higher yields of early-maturing fruit by initially planting to a higher density, which would be followed by future tree thinning once the trees began to crowd. However, experience suggests that unless the orchard is thinned in an early and timely manner, a considerable yield reduction occurs in the first couple of years post-thinning until the trees fill in the open spaces. Contrarily, if the objective was to maximize lateness with a late-maturing cultivar, high tree density may be the way to go. High density should produce smaller fruit size, further delay maturity and produce high initial yields.

While no one plants Frost Nucellar navels anymore, there were considerable acreages of these planted in Kern County in the 1970s on an 11’ x 22’ spacing. This variety was an early attempt to grow a variety relatively free of viruses and viroids. By the time I saw orchards like these in 1990, as evidenced by the old stumps, most of these orchards had been thinned to a 22’ x 22’ spacing. So why were these orchards thinned? One obvious indication that the trees in an orchard are over-crowding is the inability of pickers to pass from one row to another in between adjacent trees in the row during harvest. A later indication is when the lowest parts of the tree canopy of the tree, called the “skirts”, start “rising”. As trees grow taller, less light reaches the lower canopy due to shading, finally reaching a level that will not support branch growth. Rising skirts means that the fruit bearing surface of the tree is getting further from ground level, which increases harvest costs and makes effective foliar pest control applications more difficult and costly. In general, if the lowest hanging branches of the skirt are five feet from the ground, five feet of the upper canopy can be topped. This action will bring the height of the bearing canopy closer to the ground without a loss of bearing volume. By carefully managing tree height, the tree canopy can be used as a tool to provide sufficient shade to control weed growth on the orchard floor without limiting the productive fruit bearing area of the orchard and without requiring unnecessarily long ladders that can reduce harvest efficiency (i.e. fruit picked per unit time) and increase risks of injury.

## Eric Mussen, Apiculturist Passes

Celebrated honey bee authority Dr. Eric Carnes Mussen, an internationally known 38-year California Cooperative Extension Specialist and an invaluable member of the UC Davis Department of Entomology and Nematology faculty died June 3. He was 78.

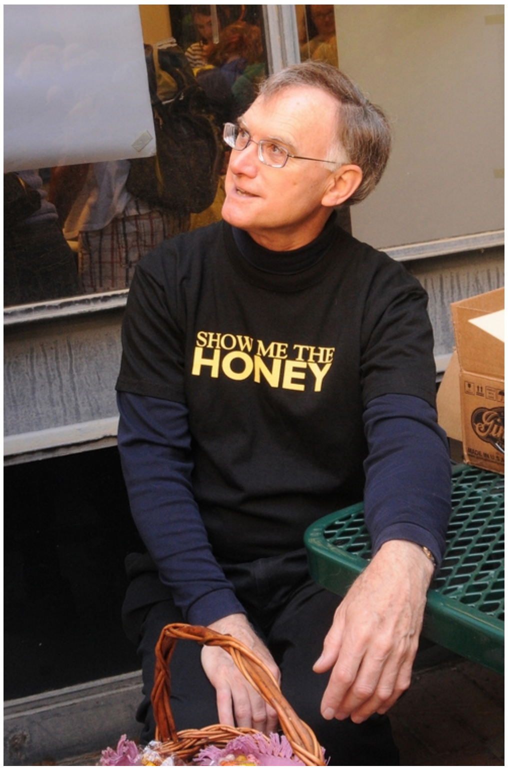
“Eric was a giant in the field of apiculture,” said **Steve Nadler,** professor and chair of the UC Davis Department of Entomology and Nematology. “The impact of his work stretched far beyond California.”

Dr. Mussen, known to all as “Eric,” joined the UC Davis entomology department in 1976. Although he retired in 2014, he continued his many activities until a few weeks prior to his death. For nearly four decades, he drew praise as “the honey bee guru,” “the pulse of the bee industry" and as "the go-to person" when consumers, scientists, researchers, students, and the news media sought answers about honey bees.

Colleagues described Mussen as the “premier authority on bees and pollination in California, and one of the top beekeeping authorities nationwide,” “a treasure to the beekeeping industry," and "a walking encyclopedia when it comes to honey bees.”

Mussen's longtime friends and colleagues--bee breeder-geneticist **Susan Cobey** of Washington State University (WSU), a former manager of the Harry H. Laidlaw Jr. Honey Bee Facility, UC Davis, and her husband, **Timothy Lawrence**, WSU associate professor and county director, WSU Extension, Island County--are heartbroken. “Eric is an icon of the beekeeping industry and beyond, a career shaper, problem solver, the information man who always had an answer or would find one, and, always given with integrity, regardless of the issue, biological or political, to whoever posed the question and need," Cobey said. "His contributions, impact and love from the people he touched will live, continuing to contribute and benefit their lives. His spirit is with us."

"As an Extension professional, Eric set the standard that I tried to emulate," said Lawrence. "We had very different approaches but our goals were similar: give people the information they need to make the best decision, based on the current body of scientific knowledge for their given circumstances. Instead of telling folks how to do something, he would listen and guide them on the science and let them make the decisions (and mistakes) on their own. He did this with Sue and me, and we greatly benefited from his mentorship. I observed him apply this approach from hobbyists to large-scale professional beekeepers. He was the preeminent Extension Professional."




Extension apiculturist Eric Mussen coordinated the honey tasting at the UC Davis Picnic Day for years. His favorite honey? Starthistle. This image is from 2013. (Photo by Kathy Keatley Garvey)

Born May 12, 1944, in Schenectady, N.Y., Mussen received his bachelor's degree in entomology from the University of Massachusetts (after declining an offer to play football at Harvard) and then obtained his master's degree and doctorate in entomology from the University of Minnesota in 1969 and 1975, respectively. Mussen credits his grandfather with sparking his interest in insects. His grandfather, a self-taught naturalist, would take his young grandson to the woods to point out flora and fauna.

Bees became his life, and Mussen thoroughly enjoyed his career. For nearly four decades, Mussen wrote and published the bimonthly newsletter, *from the UC Apiaries*, and short, topical articles called *Bee Briefs*, providing beekeepers with practical information on all aspects of beekeeping. His research focused on managing honey bees and wild bees for maximum field production, while minimizing pesticide damage to pollinator populations.

During his tenure as the state's Extension apiculturist, Mussen traveled to beekeeping clubs throughout California, addressing some 20 beekeeping organizations a year. For 10 years, he also conducted the California State 4-H Bee Essay Contest, disseminating guidelines, collecting entries and chairing the judging.

Mussen was a longtime board member of the California State Beekeepers' Association and a consultant for the Almond Board of California. He co-founded the Western Apicultural Society, serving six terms as president, the last during the 40th anniversary conference at UC Davis in 2017. He also was involved in the formation of the American Association of Professional Apiculturists and held the offices of president or treasurer of that association for many years. He was a scientific advisor to the UC Davis Honey and Pollination Center. He will be remembered by avocado growers for keeping their honey bee colonies healthy and beekeepers up to date in their management.

# Topics in Subtropics



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