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Inside

Controlled Environment Agriculture

***by* James A. Bethke and Heiner Lieth**

Very early in my career, a group of us took a behind the scenes tour of Disney's Epcot Center (The Land) in Florida. We were there to visit with scientists who were experiencing difficulties with insect pests in their highly controlled agriculture environments. One such site was a tumbler with carrots and lettuce growing into the center of a cylindrical tumbler that was spinning with nutrient-filled water dripping over the roots growing on the outside of the tumbler. The illustration was how vegetables could be grown in space hydroponically and in artificial gravity. There were many other examples at the Center, but what they were demonstrating was growing plants in a highly controlled environment, potentially to be used in space and on other planets.

The term controlled environment agriculture (CEA) has many meanings. Wikipedia simply defines it as a technology-based approach toward food production. Some forms of protected cultivation use a covering over the plants, which can be anything from a fabric row cover to plastic covering

Editor's Note

This newsletter issue focuses on emerging horticultural technologies for growing plants in highly controlled environments. Our first feature article helps define this technology, which is often collectively called controlled environment agriculture (CEA). Artificial lighting, particularly with light emitting diode (LED) lights, and manipulating lighting to control plant growth and development are discussed in two other complementary feature articles. Lots of excitement exists about these technologies. There may be specialty uses for this lighting and in some of the more intensive forms of CEA, but we still need to figure out where it makes good economic and environmental sense. In "Science to the Grower," we discuss some of the potential limitations of CEA. We also include our regular columns and regional reports, and more.

◆ **Steve Tjosvold and Julie Newman**

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Fig. 1. Fig. 1. Lifted side and open-end hoophouses. *Photo*: **J. Bethke.**

a wooden or metal structure. The latter type of structure with covered plastic is often called a high tunnel or hoophouse (fig. 1) and is, by definition, unheated with no electricity (Cornell 2012). Some do deem this very minimal "control" to be enough to consider hoophouses as part of CEA. Additionally, attempts to grow plants without using direct sunlight have resulted in the development of technologies where plants are grown under lamp light and all growth variables are under some level of control. Such indoor production is also part of CEA.

Today, however, the trend is toward the development and establishment of controlled environments for all manner of horticulture, generally involving more monitoring and control, as well as considerable automation.

The ornamental horticulture industry has been using controlled environments for a very long time, in its most recognizable form, the greenhouse (fig. 2–3).

Fig. 2. Fully covered greenhouses with high roofs and the ability to vent hot air from the roof through insect screening. *Photo*: **J. Bethke.**

Fig. 3. Semi-automated propagation of cuttings grown in a greenhouse. *Photo*: **J. Bethke.**

Herein, we define CEA as the production of agricultural crops under modified, highly controlled conditions in greenhouses or indoor growing spaces using soilless culture (fig. 4), including hydroponics. This type of production can increase the capacity and economic viability of small commercial growers in California, particularly those located in urban and peri-urban (rural–urban transition zone) settings, because of the higher efficiency and lower demand for land and water resources. Clearly, CEA will likely play a critical role in addressing sustainable food systems initiatives throughout California. One key feature of this type of production is the continual recirculation of irrigation water, made possible by the crops growing with confined root zones. As such we also envision a substantial improvement in water-use efficiency.

Fig. 4. Crops produced in controlled environment agriculture (CEA), such the greenhouse hydroponic tomatoes shown in this photo, are grown under highly controlled conditions in soilless culture. *Photo*: **J. Bethke.**

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The new food system initiatives that concern the increased need for food production in urban environments and a more efficient food system (Gunders 2012) are complicated. Increasing the efficiency of our food system (Gunders 2012) and getting food from the farm to our fork eats up 10% of the total U.S. energy budget (Gunders 2012). The expanding interest in local food systems is based, in part, on avoiding the energy to transport fresh produce across the United States, thus reducing a significant carbon footprint. This interest has created a focus on something called food-miles and the development of urban agriculture (NYSERDA 2016). The goals of advocacy groups and local governments are to feed a greater amount of people, especially those that need it the most, with healthy fresh food. Indeed, near heavily populated urban centers in California there is a trend toward greenhouse production of fresh vegetables and herbs and many ornamental plant producers have been experimenting in that arena and have become successful.

Plant factories, warehouse farming, closed production systems and vertical farms, which can be located in any urban environment, are some of the approaches taken by various groups across the country to address the food system needs. They can utilize abandoned buildings or shipping containers located within urban areas (Kozai and Toyoki 2013, NYSERDA 2016) and convert them into multilevel food production systems. This approach is designed to produce local, fresh vegetables. In a general sense, systems such as these use hydroponics.

Challenges of CEA

The types of production systems outlined above have been studied by several institutions over the years, and researchers have numerous concerns regarding their efficiency and profitability. For instance, Cornell University (2012) has calculated that the sheer volume of energy that will be required to power the supplemental lighting and operate the other environmental controls will proportionally emit four times the carbon dioxide than the poundage of plants they produce. Research in recent years, however, has demonstrated that LED lighting technology reduces the carbon footprint dramatically.

Another factor is the space used in plant production. High land values and limited access to open spaces of sufficient size and shape are limiting factors that need to be considered in many areas, particularly large urban areas. Surrounding buildings may shade the crop in CEA systems that depend on sunlight. This reduces the types of agriculture grown in urban settings. One suggested solution is the use of vertical greenhouses, but horizontal greenhouses are likely a better alternative (Albright 2013) particularly if this means sharing sunlight among plants. As such, any vertical system will probably involve lamp lighting to provide all plants with photosynthetically active radiation. (Editor's note: see the next feature article on lighting in this newsletter issue for more about photosynthetically active radiation.)

Some CEA growers have been highly successful, especially in San Diego County, but several growers failed in the last few years due to poor preparation and poor pest management. CEA is common in other countries (all European countries, Japan, South Korea, etc.) and much of the pest management for protected culture of fruits and vegetables has been worked out. There are still significant challenges, however. One such grower in San Diego County was highly successful early on, but failed completely due to an insect-vectored disease. The system they were using was not prepared properly and sanitation was not a priority until it was too late. Clearly, these growers need assistance. From a research and education perspective, we have the expertise in many of the facets of controlled environmental agriculture, but additional UC expertise is needed in this field of study.

One economic factor that is relevant to all growers: the price of lighting, as well has what the lighting can do, is changing. LED lamps are dropping in price. The improvements in technology are resulting in longer life and better-adapted spectra. This is also pressuring the conventional manufacturers of high intensity discharge (HID) lamps to find

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better coatings to customize the spectrum for plant production. (Editor's note: see related feature articles on lighting for more about LED and HID lamps.)

Conclusions

CEA production has been growing very rapidly as an industry. Today there are 650 acres of greenhouse production representing 427 farmers in California with an estimated annual production value of $165 million. New indoor operations are starting throughout the state and growers are asking for advice. The growth in CEA is driven by increasing demand for locally produced, high quality food (within or near urban areas), a new generation of highly educated and technically savvy farmers, limited agricultural land and a friendly lending environment. Tremendous improvements in technology, primarily in the area of lighting systems, have made these types of production systems more accessible to operators of smaller-sized farms. However, small farm operators need a lot of technical and horticultural assistance from UC Cooperative Extension to succeed with these new tools.

Our goal is to develop a research and extension program that will help new and existing growers in California remain economically viable by increasing their production capacity, production efficiency and profitability through the use of CEA production systems. The creation of more local market opportunities could help increase access to healthy foods and enhance the vitality of local agriculture.

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LED Technology for Crop Production in Controlled Environments

***by* Yihe Zou and Heiner Lieth**

Light emitting diode (LED) technology has become widespread in all areas where lighting is important as a light source for agricultural crops in controlled environment facilities (greenhouses and indoor production). In horticulture, significant advances have been made in LED lighting over the past 20 years.

LED lamps were first used for plant production lighting as part of a research program on a space shuttle and station. Early on many advancements in LED lighting in the plant sciences were made by scientists in the Netherlands and Japan, with particular focus on seed germination, rooting of cuttings and tissue culture (Nijssen et al. 1990, Miyashita et al. 1995). LED technology has some inherent advantages over traditional forms of horticultural lighting such as incandescent, fluorescent and high-intensity discharge (HID) lamps. In particular, LED lamps tend to have long life, generate less waste heat and provide the potential for creating a perfect spectrum for plant growth. The improved energy use efficiency and reduced heat production make it possible to also position the lamps closer to the plants, offering new opportunities for plant production. These advantages have led to the increasing popularity of LED lamps in plant production, and many growers who are not using LED technology are considering it.

LED or HPS?

Energy costs can be significant in greenhouse production. Thus growers seek to find energy-efficient light sources for greenhouse lighting. Currently, high pressure sodium (HPS) lamps are the most popular lamps in greenhouse production, but various other HID lamp technologies are also being used. Generally HID lamps are marketed by how much wattage they consume because it is assumed that there is a proportional amount of usable light and that this proportion is the same for all lighting technologies. But with the development of LED technology this has changed dramatically. It has become possible to avoid generating any light with wavelengths shorter than 400 nanometers or longer than 700 nanometers, which is the range of wavelengths that is relevant in crop production because plants use only this range of wavelengths for photosynthesis. The light in this range is called photosynthetically active radiation (PAR), but it also happens to be the same range of wavelengths that humans can see (visible wavelengths). So for lamps that are specifically designed to enhance assimilation (photosynthesis) in plants, it is desirable to maximize the amount of energy that ends up as PAR.

Generally the first question growers want to address is the financial side of the picture. So the question arises: “Should growers switch from HID to LED lamps”? A life-cycle cost comparison of LED and HPS lamps by Meng and Runkle (2014) found that the effect on flowering in bedding plants with 150 W HPS lamp and 14 W LEDs is similar, while the cost over the life of the lamps is much lower with LED lamps than with HID lamps. Cost comparisons between LEDs and HPS by Singh et al. (2015) showed significant overall cost savings when using LED lamps for plant production over a 16-year period. Although their analysis showed that LED lamps cost more in the beginning, by the seventh year of use, the HPS lamps cost more than the LED lamps.

Effect of LED Lighting on Plant Growth

Various research projects have been conducted over the past 20 years on the effect of LED lamps for various types of plant growth. Table 1 shows some typical results from various LED research projects. Notably some researchers found greater accumulations of biomass through use of particular parts of the light spectrum. For example, adding far-red LED light to red LED light resulted in an increase in plant height and stem biomass of sweet pepper. For flowers, red LED light increased the dry weight of marigold seedlings. For tomato, blue

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Category	Plant	LED radiation	Effect on plant growth
Vegetable	Lettuce	RBW	Increased nutritional value and growth (Lin et al. 2013)
	Basil	B	Increased amount of essential oil (Amaki et al. 2011)
	White mustard, Spinach, Green onions	R + HPS lamps	Increased vitamin C content, (Bliznikas et al. 2012)
	Sweet pepper	R +Fr	Far-red light increased plant height with higher stem biomass (Brown et al. 1995)
Flower	Marigold	R	Increased dry weight of marigold seedlings (HEO et al., 2002)
		B	Increased stem length (HEO et al. 2002)
	Crown of thorns *(Euphorbia millii)*	B; R + Fr; B+ Fr	Stimulated flowering, (Hahn et al. 2006)
	Petunia, Snapdragon	R + Fr	Promoted flowering (Craig and Runkle 2012)
Fruit	Tomato	B	Increased fruit yield, improved quality and disease resistance (Xu et al. 2012)

Table 1. Effect of LED light on plant growth (Abbreviations: R=Red LEDs, B=Blue LEDs, W=White LEDs, G=Green LEDs, Fr=Far red LEDs)

LED light could increase fruit yield, improve quality and disease resistance. There are also examples of research results where the effect was on something other than biomass accumulation. For example, in vegetables such as lettuce, white mustard, spinach and green onions, red LED light increased nutritional value. For basil, blue LED light increased the amount of essential oil. The combination of red and far red LED light was helpful for the flowering of crown of thorns (*Euphorbia millii*), petunia and snapdragon. As such, the issues related to using LED lighting are more complex than the effect on photosynthesis, and there is much more to learn in this area.

Innovation Using Within-Canopy LEDs

One facet we are exploring at UC Davis is whether we can leverage some of the features of LED lighting technology to provide lighting to plants in ways that were not possible in the past. While traditional overhead lamps are too hot to place close to the foliage, we are investigating whether we can provide supplemental light with LED lamps directly within the canopy of plants, lighting leaves that generally are fully shaded. Our hypothesis is that we can raise the whole-plant photosynthesis by lighting leaves which would otherwise see no direct light. Fully shaded leaves generally provide very little to the plant, perhaps even consuming resources that the plant could use for growth.

Some research using within-canopy supplemental lighting has been done in vegetable crop production. In one example, within-canopy LED light promoted earlier tomato fruit production and allowed for a longer harvest period (Gómez and Mitchell 2013). When compared to traditional overhead light, within-canopy lighting in cucumber increased yield by 11% (Pettersen et al. 2010). Within-canopy lighting in cowpea produced twice as much edible biomass in comparison with an overhead-lighted system (Frantz et al. 2000).

Our current research at UC Davis is examining whether ornamental plant production can be enhanced with within-canopy lighting. We are designing an experiment to be installed in commercial greenhouse flower production facilities to evaluate the effect of lighting the bent canopy of roses and the underside of older leaves in gerbera production. We are also currently using potted gerbera and geraniums as model systems to test this approach on a smaller scale in our research greenhouses at UC Davis (fig. 1).

The LED lamps used in our research have red and blue light or a combination of various spectra consisting of red, blue and white light. Our preliminary results suggest that while the number of flowers produced in lighted geranium and gerbera are not significantly different than the unlighted controls, the stem number of geranium (branching) and the scape length of gerbera are affected, suggesting that it may be possible to manipulate flower quality. This research is still on-going, and we will be repeating the experiment to verify these preliminary results.

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Future for LED Lighting

Fig. 1. Test-model systems of geranium (left) and gerbera (right) using LED lighting. *Photo*: **Y. Zou.**

LED lighting technology has already shown many great advantages in controlled environment production. The diversity in spectra, high energy use efficiency, cool operating surface and long life suggest that LED lamps have the potential to become the dominant light source in protected agriculture, particularly in greenhouses or other types of indoor production. While LED lamps had the reputation in the past of being too expensive, it is relevant to note that economic feasibility is here today for many high-value horticultural crops. The cost of LED lighting has been declining regularly over time and it seems to still be going in that direction. As such, the question is not whether or not LED lighting is economically feasible, but rather for which crops does LED lighting make economic sense and when, ultimately, will it become economically feasible for your plants.

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Manipulating Plant Growth Responses with LEDs

by **Nicholas Claypool and Heiner Lieth**

A 2014 issue of UCNFA News included an article about LED lighting technology (Evans 2014) describing some of the exciting effects that light emitting diodes (LEDs) have on plant growth that could be used in horticultural production. Most discussions around lighting systems focus on photosynthetically active radiation (editor's note, see previous article for definition), with particular emphasis given to the economics of light production and initial investment costs. In this article, we focus on the effects of LED lighting in manipulating plant growth responses that are controlled by phytochrome, rather than overall plant growth as a result of photosynthesis. Phytochrome is a plant light receptor, a pigment that plants use to detect light. It is sensitive to light in the red (660 nm) and far-red (730 nm) regions of the visible spectrum. Phytochrome has two different chemical structures named after the color of light that they absorb: Pr (physiologically inactive form) absorbs red light and Pfr (physiologically active form) absorbs far-red light. The two forms of phytochrome are interconvertible and the change from one form to the other acts as a control mechanism to regulate various stages of plant growth.

Photoperiodic manipulation of flowering has long served as an integral management practice for floricultural production. Typically night interruption has been achieved with incandescent lighting because the incandescent light spectrum is suitable for converting the active form of phytochrome to the inactive form. This allows for the photoperiodic flowering responses that growers have come to rely on.

Outside of the photoperiodic response, growers typically do not control plant growth by manipulating the light spectrum. This is largely because the spectrum of a given light type is fixed. High pressure sodium (HPS) lamps, for example, all have more or less the same spectrum — a high portion of green and yellow-orange light with relatively little red or blue light. While these spectra can be modified to some extent with various coatings and engineering changes, the final spectra will be fixed. Thus HPS and other types of HID lamps in commercial greenhouses are primarily used to enhance photosynthesis and increase plant biomass, not for responses regulated by phytochrome.

LEDs provide a narrow bandwidth of light and come in a variety of wavelengths. This allows for the creation of custom light spectra, where the combination of diodes results in the overall light spectrum delivered. The spectrum can be further modified by adjusting the light output of diodes emitting a certain wavelength within a fixture, allowing for different spectral output for different stages of plant growth.

This customization enables more precise activation and control of the phytochrome response. Using *Arabidopsis* as a model plant, researchers have identified many other plant growth responses that can be controlled besides flowering, ranging from stem elongation and leaf area control to root development (Franklin and Quail 2010). By changing root development, one could conceivably also control nutrient uptake and growth rate.

Thus by adjusting ratios of certain wavelengths, compact plants with smaller, more numerous leaves could potentially be produced. This hypothesis is supported by research conducted by Hogewoning and colleagues (2012) who grew cucumber plants under a variety of light spectra and demonstrated clear differences in leaf size and plant compactness. Plants grown under red and blue LEDs (with no far red light) were the most compact while those grown under artificial sunlight (with a light spectrum that promoted inactivation of phytochrome) were the least compact; plants grown under artificial sunlight were similar in appearance to plants grown using red/blue/far-red LEDs in a ratio that induced

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the same phytochrome-balanced state as natural sunlight. This research demonstrates the importance of LED spectral customization. By adding far-red diodes the plants were encouraged to elongate, resulting in less compact plants than plants grown under red and blue LEDs without far red light.

Furthermore, phytochrome signaling based on the red to far-red light ratio represents just one light spectral quality response in plants. Plants also possess other light receptors that respond to ratios of blue to UV light and ratios of blue to green light. Each of these receptors controls different functions in the plant, with the strength of influence affected by the plant developmental stage. So, the plant may be relatively insensitive to certain signals during vegetative growth, but may increase in sensitivity during flowering and fruit development.

The information gleaned from *Arabidopsis* studies offers many potential horticultural applications. Plant appearance can be altered, since red to far-red ratio responses exist for petiole elongation and leaf color (Frank and Quail 2010). Likewise, both blue and red light can impact stem length and leaf area; also blue and red light signaling can influence flowering time, flower number and flower diameter (Frank and Quail 2010, Huche-Thelier et al. 2016). In addition to modification of appearance, the plant's growth rate can also be influenced, since these light signals also influence photosynthesis, nutrient uptake and plant defense (Frank and Quail 2010, Huche-Thelier et al. 2016).

While illumination is still needed in this area to determine the specifics — ideal spectral compositions for desired effects, range of possible effects and species limitations — the prospects for LED application in horticultural production is bright.

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SCIENCE TO THE GROWER: The cold, hard facts about plant factories with artificial light

***by* Richard Evans**

Some scientists are infatuated with technological toys, and they'll leap at an opportunity to put those toys to work in their research. For example, scientists have invested a lot of time and taxpayers' money to apply biotechnological techniques to modify corn in pursuit of efficient ethanol production, yet corn ethanol production remains a heavily subsidized industry. I think the energetics involved have always made biofuel production a questionable goal, but the quest provides plenty of research opportunities.

These days there is much buzz about "plant factories," which, in the extreme case, are buildings for growing plants under artificial light. I suppose a source of inspiration for these plant factories with artificial light (PFALs) is production of the one crop for which they are widely used: cannabis. Of course the cannabis grower's incentive is security; windowless buildings are more secure than greenhouses. Another source of inspiration is the knowledge that the world's human population is becoming increasingly urban, coupled with mounting concern about global climate change. The world's urban population now represents more than half of the total. Cities account for over 60% of human water use and 80% of human-produced carbon emissions (United Nations, 2012). It's not surprising, in the face of these numbers, that many people express a desire for local food self-sufficiency and crop production systems that allow for extraordinary environmental control and production efficiency.

The desire for local production has stimulated a search for innovative ways to produce crops in urban settings. Numerous schemes for rooftop gardens and vertical greenhouses appear now in scientific journals, including one design for a vertical greenhouse that would have 37 floors and a growing area of 57 acres (Banerjee and Adenaeuer 2014). However, skyscraper plant factories won't meet consumer demand. It has been estimated that it would take 30 times the area of New York City to feed its residents (van Iersel 2013). And cities occupy less than 4% of the world's land, so there is plenty of surrounding land available for crop production. With affordable land that can support less expensive production methods in fields or standard greenhouses beyond urban borders, does it make sense to build PFALs?

Surprisingly, most research publications about PFALs rely on rosy assumptions and invalidated models rather than hard data. Even a recently-published academic book on PFALs (Kozai and others 2016) is sparsely populated with hard numbers about production costs. We need an accounting of all energy, water and raw materials that go into and out of the production system, as well as transportation costs associated with shipping of raw materials and finished crops.

Sometimes local production seems sensible. Say you live at the South Pole and want a fresh salad to go with your penguin tacos. You're in luck! The South Pole Food Growth Chamber produces lettuce, herbs, tomato, pepper, cucumber, cantaloupe, edible flowers, aromatic plants and other greens at the Asmundsen Scott South Pole Station. This PFAL facility has been studied by Patterson and others (2012). The chamber features nutrient film and deep trough hydroponic systems, metal halide lamps and CO_2 injection. Sensor measurements of relative humidity, light, CO_2, temperature, and pH and electrical conductivity (EC) of the nutrient solution are used to monitor and control the chamber environment. It is a semi-closed system in which air is recirculated (except for what leaks out)

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and the nutrient system is tweaked as needed to maintain constant pH and EC, except for complete replacement every few months. Plant growth was near the theoretical maximum for the amount of light provided, but the energy required to grow it was equivalent to about 7.5 kWh per head of lettuce, which is substantial. The authors of the study don't go into this, but according to my rough calculations (available if you buy me a beer from a local craft brewer), the carbon footprint of producing the food locally is about three times the carbon footprint of growing it outdoors in Salinas and shipping it to the Costco at the South Pole.

The South Pole may seem an extreme example, and it certainly hasn't been urbanized yet, but Albright (2013) points out that the cost of artificial lighting — even supplemental lighting —almost never balances the cost (in dollars or carbon) of growing the crop in a more favorable climate and then shipping it long distances to consumers.

This topic reminds me of the many times academic visitors have asked me to arrange tours of the high-tech greenhouses they assume we use in California to grow our high-quality crops. They usually are disappointed when I show them the irrigated fields and standard greenhouses that most growers use. The truth is that a grower's annual profit on flowers or produce probably wouldn't cover the architect's fees for a PFAL design, and there is no good evidence that productivity would increase enough to pay for a plant factory's capital and operating costs.

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Nitrogen and water use of winter- and summer-growing succulents

by **Don Merhaut**

A new study, which has been funded by the California Association of Nurseries and Garden Centers (CANGC), is being conducted over a one-year period to determine nitrogen uptake patterns and water use of succulents from different native habitats.

Over the past several months our lab has been collecting plant material to represent "winter-growing" and "summer-growing" succulents that are usually commonly grown in the nursery trade. These terms are used loosely, given that our climate will cause some of these species to grow year-round or perform in different growth cycles than they would normally do in their native habitat. Our goal is to determine nitrogen and water needs throughout a one-year growth cycle, determining if there are differences between winter- and summer-growing succulents.

Fig. 2. *Sedum laxum* ssp *eastwoodiae*, red mountain stonecrop, is a native to southwestern Oregon and northwestern California. It is rarely available in nurseries, unlike the other plants in our study; it is listed by the California Native Plant Society as a Rare and Endangered Plant and by the Federal Government as Species of Concern. It is a succulent plant forming basal rosettes with leaves up to 1-inch long. Shown is the inflorescence, which is made up of many flowers with reddish or yellowish petals. *Photo*: **Jennifer Wheeler, BLM Arcata.**

Fig. 1. There are several cultivars available in nurseries that originated from *Crassula ovata* (jade plant), a native of South Africa. Shown is *Crassula ovata* 'Big Alice,' a cultivar with 3-inch long glossy-green leaves and a thin margin of red near the tips, growing 3- to 5-feet tall. *Photo*: **R. Baldwin, courtesy of San Marcos Growers.**

Plant Material and Their Origins

The majority of the plant species in our research study represent plants native to deserts, or seasonally dry tropical, subtropical or temperate climates. There are many factors that may influence the growth cycles and nutrient uptake patterns of these succulents. These factors include seasonal rain patterns, seasonal temperature fluctuations and day length patterns, as well as soil types.

Rainfall. Some climates have one wet and one dry season, such as California's coastal climate. However, other regions experience two or more wet and dry cycles per year, such as the Amazon. The Eastern Cape of South Africa, where *Crassula ovata* (fig. 1) is native, has a fairly uniform distribution of rainfall over the year.

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Growing Season	Succulent	Family	Habitat
Winter (Summer Dormant)	*Aeonium haworthii*	Crassulaceae	Morocco (Africa) and Canary Islands
Winter	Crassula ovata	Crassulaceae	Eastern Cape Province of South Africa
Winter	*Dudleya brittonii*	Crassulaceae	Coastal Baja, Mexico
Winter	*Haworthia attenuata*	Xanthorrhoeaceae	Eastern Cape Province, South Africa
Winter	*Maeriana sedifolia*	Chenopodiaceae	Nullarbor Plain, Southern Australia
Winter	*Portulacaria afra*	Didierearceae	South Africa along rocky slopes (Kalahari Desert)
Winter	*Sansevieria trifasciata hahnii*	Asparagaceae	Nigeria to Republic of the Congo, Africa
Winter	*Sedum laxum eastwoodiae*	Crassulaceae	Northern California, Southern Oregon, USA
Winter	*Sempervivum arachnoidium*	Crassulaceae	Southern Europe
Summer (Winter Dormant)	*Agave victoriae-reginae*	Asparagaceae (formerly Agavaceae)	Chihuahuan Desert, Mexico
Summer	*Aloe juvenna*	Xanthorrhoeaceae	Kenya, Africa
Summer	*Euphorbia (Pedilanthus) antisyphilitica*	Euphorbiaceae	Chihuahuan Desert
Summer	*Euphorbia (Pedilanthus) tithymaloides*	Euphorbiaceae	Chihuahuan Desert, Sonoran Desert, Caribbean and Virgin Islands
Summer	*Kalanchoe tomentosa*	Crassulaceae	Madagascar
Summer	*Opuntia argentiniana*	Cactaceae	Argentina
Summer	*Pachypodium lamerei*	Apocyanaceae	Madagascar
Summer	*x Pachyveria scheideckeri*	Crassulaceae	Metztitlan, Mexico
Summer	*Euphorbia milii*	Euphorbiaceae	Madagascar

Table 1. Winter- and summer-growing succulents from different native habitats to be used in our study to determine nitrogen uptake patterns and water use.

Daylength. Daylength is also quite variable, depending on proximity to the equator. Some species, such as *Sansevieria trifasciata*, are native to equatorial regions of West Africa where daylength is near 12 hours year-round, while other species such as *Opuntia argentiniana* (Argentina – Southern Hemisphere) and *Sedum laxum* ssp *eastwoodiae* (California – Northern Hemisphere, fig. 2) are native to latitudes 30° to 40°S and 40°N, respectively, where the shortest and longest days are 9 hours and 15 hours, respectively.

Temperature. Most succulents are from warm temperate to tropical climates. However, some succulent species are native to more alpine-like areas where a defined winter season does occur.

Soil Type. Soil type may not influence dormancy patterns, but nutrient uptake could be influenced. Most succulents are native to high mineral soils that are well drained. In this study we selected *Maireana sedifolia,* Australian Pearlbush *(*fig. 3), which is native to the alkali flats of the Western Australia desert. Other species, such as *Sansevieria*, are native to soils with more sediment.

Succulents Studied in Our Research Project

Based on the review of the literature and the inventory of several succulent nurseries in southern California, we developed a list of 18 different plant species that provide a general representation of the different world climates from which our ornamental succulents are native: 9 winter-growing and 9 summer-growing succulents (table 1). Though we originally proposed to do only 5 winter- and 5 summer-growing succulents, it became obvious that the plant palette diversity had to be increased so that most succulent native habitats are represented in the study. This should give a better understanding of growth and nitrogen uptake patterns when these plants are grown in artificial conditions of a greenhouse. Based on the results, we hope to refine fertilizer and water management for succulent production. Please stay tuned to future issues of *UCNFA News* for further developments in this study.

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Fig. 3. *Maireana sedifolia*, pearl bluebush, is a native to the alkali flats of Western Australia and thrives in well-drained alkaline soils. It is a small shrub typically to about 3 feet tall and wide, with upright-growing stems (left) and small succulent white leaves (close-up of foliage, right). *Photos*: **R. Baldwin, courtesy of San Marcos Growers.**

Don Merhaut is a UC Cooperative Extension Specialist for Nursery and Floriculture Crops, Department of Botany and Plant Sciences, UC Riverside.

DISEASE FOCUS:
Botrytis time

***by* Jim Downer**

While it is pretty clear that El Niño did not bring torrential rains to Southern California this year, we did have a fair number of "cutoff low storms" that brought isolated showers followed by cool weather (60°F or less). These are ideal conditions (cool and moist) for gray mold caused by *Botrytis cinerea* to develop in ornamental nurseries. While diseases caused by *Botrytis* are not aggressive on mature tissues or woody plants, the fungus rapidly attacks fleshy or juvenile tissues such as flower petals, new shoots or tender growth of bedding plants or other annual crops. This April, roses all over Ventura County suffered from rapid onset of Botrytis blight (fig. 1) because we had a cool, wet event during flowering of most roses.

Gray mold is an ascomycete fungus that produces abundant gray-colored mycelium and conidia or asexual spores. The perfect stage of the pathogen is rarely seen but the conidial or *Botrytis* stage is common in all nurseries and landscapes. *Botrytis cinerea* is in the Ascomycete family Sclerotiniaceae. Like its cousin *Sclerotinia sclerotiorum* (white mold or rot of bedding plants), it forms sclerotia (hardened, asexual resting structures) in decaying plant matter that has rotted as a consequence of infection and fungal colonization. Dead flowers and plant parts fall to the ground where sclerotia later form to insure survival of the pathogen. Sclerotia later germinate as hyphae to grow and form more conidia.

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Fig. 3. Botrytis blight rots rose flower buds and turns flower petals brown. *Photo*: **A. J. Downer**

Botrytis is a necrotrophic pathogen and relies on enzymes to rot plant parts. Infected tissues soon turn brown due to enzymatic degradation of the middle lamella, cell walls and cell contents. Evidence also suggests that *B. cinerea* causes a hypersensitive reaction in plants and programmed cell death by its host plant in response to infection (Williamson et al. 2007).

While Botrytis rot is largely regulated by weather conditions, growers can take steps to limit damage. When cool, wet storms are predicted during sensitive growing periods (times of new growth or flowering), there are many fungicides that will offer some protection to these tissues. Fungicides in the strobulurin group and many newer (such as fludioxonil) and older (such as triadimefon) fungicide active ingredients can provide control of gray mold; however fungicides in every FRAC (Fungicide Resistance Action Category) number listing are rated as moderate to high resistance risk materials, so it is wise to alternate active ingredients in any spray program or use combination products that employ active ingredients from more than one FRAC group.

Cultural methods of control are also helpful. Increasing plant spacing to allow for more air movement, less spore splashing and less plant-to-plant contact will slow the progress of *Botrytis* during prolonged cool periods. Cleaning up rotted plant debris caused by Botrytis blight or rots is essential in limiting the disease and preventing future outbreaks. While spores are mostly ubiquitous, they can concentrate in decayed plant matter, so sanitation by deadheading diseased flowers is helpful in controlling outbreaks.

Eventually, as weather warms, Botrytis blight fades from importance, but survives in litter or as sclerotia in soil until cool, wet weather returns.

Jim Downer is Environmental Hort Farm Advisor, UC Cooperative Extension, Ventura County.

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INSECT HOT TOPICS: Spotted lanternfly

***by* James Bethke**

This column focuses on insects that pose a threat to the ornamental plant production industry and have good potential for invasion and establishment in California.

Often one of my colleagues will warn us of a new invasive pest and a potential threat to the movement of ornamental plants if found in a nursery or other type of production site. Dan Gilrein from Cornell University in New York sent a notice to colleagues a while back about the spotted lanternfly, *Lycorma delicatula* (White). This invasive pest is not a fly but a type of planthopper (Hemiptera: Fulgoridae), which means it's another one of those insects with piercing-sucking mouthparts that can seriously damage various crops. Obviously, a find of spotted lanternfly in California would require a regulatory response and would likely cause quarantine and significant impacts on the movement of nursery stock. The spotted lanternfly is native to China, India and Vietnam, and it was introduced into Korea where it has become a major invasive pest. These insects have found their way to Pennsylvania and have spread to four counties. Although not in California yet, the spotted lanternfly is likely to make it here using methods similar to the gypsy moth because they lay their eggs on all kinds of things that can be transported. For instance, eggs can be found on firewood or wood products, brush or yard waste, remodeling or construction materials and waste, packing material like boxes, grapevines for decorative purposes, nursery stock and any outdoor household articles like lawnmowers, grills, tarps and other equipment, trucks or vehicles typically not stored indoors. This insect attacks many hosts including grapes, apples, stone fruits and other fruit tree crops, grapes (wild grapes too) and ornamentals such as, lilac, poplar, maples, walnut, oak, pines and roses. They are showing a preference for egg laying on tree of heaven (*Ailanthus altissima*), which is common in Southern California and can be used as a sentinel plant to monitor this species (Dara et al. 2015).

Fig. 1. Adult spotted lanternfly. *Photo*: **courtesy of Peter J. Jentsch, Cornell University.**

The spotted lanternfly is a relatively large insect at about an inch long, and it is red and white spotted (fig. 1). They aggregate on tree bark (fig. 2). Egg masses, containing 30 to 50 eggs deposited in 4 to 7 columns about an inch long and covered in yellowish-brown waxy deposits, adhere to flat surfaces. The first three instars have a black body and legs with white spots. The fourth instar retains the spots but has a reddish body with distinctive red wing pads.

Adults and nymphs feed on the phloem of young stems and bark and excrete large quantities of honeydew. They often aggregate and feed in groups causing a nuisance in parks and urban areas. Extensive feeding results in oozing wounds on the trunk and wilting and death of branches. Significant honeydew and sootymold deposits can be found around the base of trees. As with other honeydew

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producers, they attract ants.

Be on the lookout for this pest. It should be quite obvious when you see them and, as with other invasives, we'd like to detect this one early if we can.

Fig. 2. Spotted lanternfly aggregation on tree bark. *Photo*: **Lawrence Barringer, Pennsylvania Department of Agriculture, Bugwood.org.**

James A. Bethke is County Director and Farm Advisor for Nurseries and Floriculture, UC Cooperative Extension, San Diego and Riverside Counties.

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REGIONAL REPORT — UC Cooperative Extension

Santa Cruz/Monterey Counties

Evidence of pyrethroid insecticides and sediment in surface water in Lower Salinas River Watershed

by **Steve Tjosvold**

There is evidence that several water drainages in the lower Salinas River Watershed have levels of pyrethroid pesticides and sediment exceeding environmental standards. As a result, the Central Coast Regional Water Quality Control Board (CCRWQCB) is proposing new Total Maximum Daily Loads (TMDLs) in the Basin Plan and therefore this new management plan, if accepted, would be implemented in the Ag Order under which agricultural producers operate in the area. These findings and the resulting new TMDLs may be a harbinger of what might occur in other similar agricultural areas in which the nursery industry operates.

In a recent meeting held in Salinas, Peter Meertens, an environmental scientist with the CCRWQCB, and Kean Goh, the Environmental Program Manager with the California Department of Pesticide Regulation, showed data from a surface water monitoring program in the lower Salinas River watershed. In the years 2011 to 2015, 111 of the 159 samples in 13 water drainages were found with sediment levels exceeding toxicity standards. Four of the 13 water drainages had pyrethroid levels exceeding toxicity standards. Three out of the five pyrethroids detected in these drainages had levels exceeding toxicity standards (bifenthrin, permethrin and lambdacyhalothrin). The pyrethroid class of insecticides adhere readily to soil particles and generally move in surface water on suspended sediment. This insecticide class is relatively inexpensive and broad spectrum and their use has increased significantly over the past 30 years since the new generation pyrethroids were introduced to markets. Five herbicides and two fungicides were detected but these detection concentrations did not exceed toxicity standards. As we have known for many years, organophosphate (OP) insecticides have been found in surface water drainages associated with agriculture. For this project, all four of the organophosphate insecticides that were detected exceeded toxicity standards. The long history of OP insecticide use and detection in the Region was the driver for the current TMDLs to mitigate organophosphate toxicity. In a somewhat startling development, the newer insecticides methoxyfenozide and chlorantraniliprole were found in more than 40% of the samples. These are insect growth regulators targeted at worm pests and fortunately did not exceed toxicity standards. However, another newer insecticide, imidacloprid, was found in over 80% of the samples and exceeded toxicity standards in over 15% of those samples. Although there are no specific regulatory actions proposed to mitigate the potential impact of imidacloprid, these findings are indicative of the risk of movement of this and other neonicotinoid insecticides in surface water. The neonicotinoid class of insecticides, as with OP insecticides, do not readily adhere to soil particles and are dissolved in any water that might flow from production areas.

Findings of these studies are available at the CCRWQCB website http://www.waterboards.ca.gov/centralcoast/water_issues/programs/tmdl/docs/salinas/sed_tox/index.shtml (see link to "TMDLs," then link to "Salinas watershed sediment toxicity TMDL"). There will be a public hearing to consider adoption of the proposed TMDLs on May 12–13, 2016 in the Watsonville City Council Chambers. See the above link for more information.

Numerous insecticides and fungicides with active ingredients found in the lower Salinas River area drainage are used by nursery operators. Fortunately

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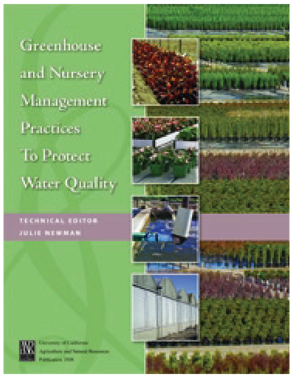
many nursery operators, where applicable, use runoff catchments to reduce or eliminate irrigation runoff from reaching surface waters. Vegetated drainage ditches and polyacrylamide may also be used to catch and hold suspended sediment before effluent flows off site. Irrigation management to minimize runoff from production areas and the use of integrated pest management to reduce the load of all pesticides generated by the nursery are essential (fig. 1).

Fig. 1. The irrigation runoff from nursery stock shown in this photo may contain pesticides that were applied to the crop. It is therefore critical that irrigation is managed to minimize runoff and that an IPM program to reduce pesticide loads is implemented.
Photo: **Courtesy of UC IPM.**



Greenhouse
and Nursery
Management
Practices
To Protect
Water Quality

TECHNICAL EDITOR
JULIE NEWMAN

For more information see *Greenhouse and Nursery Management Practices to Protect Water Quality*, ANR Publication 3508, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=3508.

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REGIONAL REPORT — UC Cooperative Extension

San Diego/Riverside Counties

Agave pests

by **James A. Bethke**

Several years ago, we received calls about an invasive mealybug on agave in Southern California (fig. 1), which has recently been identified to species by CDFA scientists (von Ellenrieder and Watson 2016) as *Pseudococcus variabilis* sp. n. (Hemiptera: Coccomorpha: Pseudococcidae). Since this species was not previously recorded in California, it was treated as an invasive mealybug and required regulation. Von Ellenrieder and Watson suggest that this mealybug is probably native to Mexico and has only recently moved into Southern California on Agavaceae, possibly through the nursery trade or directly into landscapes. It has been detected in nurseries in Los Angeles, San Diego, Santa Barbara and Riverside counties, and outdoors in landscaped areas in Los Angeles, San Diego and Santa Barbara counties. In Mexico, it has been recorded from Jalisco State infesting *Agave tequilana* but it most likely has a wider distribution and host range within Agavaceae.

Fig. 1. Agave mealybug at the base of agave leaves. These small potted plants were used in a trial while they were under quarantine. *Photo*: **J. Bethke.**

Fig. 2. Adult agave weevil on Mexican fencepost cactus *Pachycereus marginatus*, a nursery crop that was severely damaged by this insect. *Photo*: **L. Villavicencio.**

Soon after we addressed the agave mealybug, we received calls about agave weevil infestations. It was causing significant damage to a number of different cacti (fig. 2) and agave (fig. 3) at local nurseries and in landscapes in San Diego County. We observed the effectiveness of systemic treatments of imidacloprid on potted agave, but we are unsure how well that kind of treatment would work in the landscape. We were able to rear some of the weevils at the Center for Applied Horticultural Research, but we were unable to conduct any trials.

Fig. 3. Potted agave with severe agave weevil damage throughout the growing point. Note the agave weevil pupa to the lower left. *Photo*: **L. Villavicencio.**

REGIONAL REPORT: Riverside/San Diego Counties

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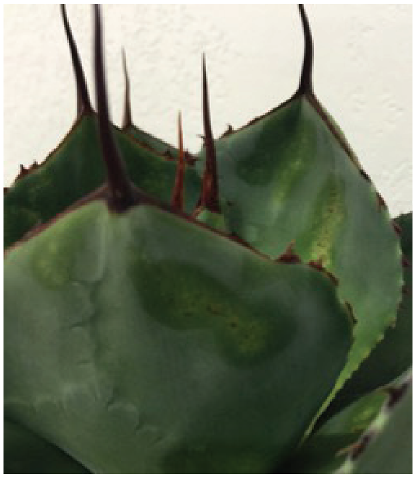

Fig. 4. Eriophyid mite damage on agave. This damage occurred while the leaves were pressed up against the growing point. The brown discoloration is similar to aloe mite damage, but doesn't grow into the gall-like tissues that is typical of aloe mites. *Photo*: **J. Bethke.**

Lastly and more recently, we have received a flurry of calls regarding disease-like damage on agave. When requesting photos (fig. 4), we noticed that the symptoms resembled aloe mite damage and checked the scientific literature for such occurrences on agave. Upon further investigation and confirmation microscopically, we determined that indeed there were eriophyid mites present, and that low infestation levels were present in several locations. Unfortunately, some of the samples contained mites that were causing damage far down into the growing point. Clearly, that damage would not be visible for about a year or until the leaves had flushed out. Some of the visible damage on the plants was barely noticeable, but on some plants the damage was severe. Each location also contained aloe plants with aloe mite damage, but apparently the mites on the agave plants are not aloe mites but are a different species of eriophyid mite. Eriophyid mites are well known for being host-plant specific, so it is not unusual to find two different mite species on two different but similar plant types. The damage on agave is less pronounced than typically found on aloe, but it is unsightly enough to make many plants unmarketable.

Eriophyid mites are commonly known as gall mites, bud mites, rust mites, erineum mites, witches' broom mites, blister mites and so on, referring to the symptoms caused by a particular species, and many times the damage resembles disease symptoms. Eriophyid mites are typically wormlike or spindle shaped and soft bodied. All eriophyid mites are plant feeding. They are extremely tiny; the majority of them are less than 300 microns long, and essentially invisible to the unaided eye. They can even be difficult to see with a stereomicroscope without 60X power. Like other mites, they have two body parts. They are, however, unique among mites in that they only have two pairs of legs throughout their life cycle. Our research has shown that preventive applications are necessary to avoid damage by these Eriophyids.

Be on the lookout for these pests, if you are growing agave.

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CDFA NURSERY ADVISORY BOARD REPORT

by **Loren Oki**

The CDFA Nursery Advisory Board (NAB) met in Sacramento on March 10, 2016. The agenda, as usual was packed, but here are some highlights:

There was a discussion of nursery inspections and the action that is taken when there is a detection of a regulated invasive organism. California is unique in that there is a county-based agricultural regulatory system, which other states do not have. The county commissioner's office conducts annual and other nursery inspections and may detect regulated pests. When there is a find during a county inspection, the relationship with CDFA is activated and the regulatory process is initiated. Unfortunately, most transport of illegal plant materials is by those that know better and are trying to avoid issues with declarations at point of entries associated with overseas travel.

The NAB meeting includes reports from representatives from different programs within CDFA. Following are summaries from a few of those reports:

New Pests – Jason Leathers, Primary Entomologist, CDFA

- *Scirtothrips dorsalis*, chilli thrips, is a B-rated pest, native to Southeast Asia and Australia. Polyphagous, it feeds on more than 200 plant species, causing leaf curling and vectoring viruses.
- *Zaprionus indianus*, striped vinegar fly, is a B-rated pest, native to Africa, the Middle East and southern Eurasia. It was discovered by a resident in Downey (Los Angeles County) last July and there have been unconfirmed reports at LAX and in San Diego. It has been in Florida since 2005 and is abundant in eastern U.S. vineyards. It feeds on undamaged figs, but is mostly a generalist on undamaged fruit. Since California is the primary fig producer in the United States, growing 96% of the nation's product, there is concern that if the pest were to establish it potentially could reduce fig yields by 40 to 80%.
- *Macrohomotoma gladiata*, curtain fig psyllid, is native to Taiwan, China and Japan. It was first found in an Orange County nursery last August and has since established in several residential and commercial landscapes in Anaheim. It has two main hosts, *Ficus microcarpa* and *F. retusa*. This insect produces copious wooly secretions and has overlapping generations.

Noxious weeds – Dean Keltch, Primary Botanist, CDFA

- *Sesbania punica* (*S. tripetii*), red sesbania, is native to South America. It was introduced in California through horticulture and has become a noxious wetland weed.
- *Arctotheca calendula*, capeweed, is an annual with dark purple disc flowers that distinguish it from *A. prostrata*, a related species that is often confused with *A. calendula*. This noxious weed is currently in Marin, Humboldt, San Mateo, Merced and Stanislaus counties.
- *Butomous umbellatus*, flowering rush, is a cold-tolerant noxious weed that is highly invasive in cool climates in wetland edges.
- *Calicotome spinosa*, spiny broom, is native to the Western Mediterranean region and has been newly discovered in an area north of Pasadena. It looks similar to other brooms, but is very thorny. It is likely fire promoting.

Marijuana cultivation

Amber Morris is the Branch Chief of the Medical Cannabis Cultivation Program and is working on establishing license and certification programs. Among the issues related to this crop, there is concern of the potential environmental impacts of its cultivation. Substantial coordination will be needed with the California Department of Pesticide Regulation (DPR), California Department of Fish and Wildlife (CDWF), State Water Resources Control Board (SWRCB) and other agencies.

The next NAB meeting will occur in August or September.
Coverage of the CDFA NAB is now a regular feature of the UCNFA Newsletter.

Loren Oki is UC Cooperative Extension Landscape Horticulture Specialist, Department of Plant Sciences, UC Davis.

CAMPUS NEWS

UNCFA Program Representative position changes hands

In mid-April, program representative Julie Tillman left UCNFA to accept a position at the UC Davis Seed Biotechnology Center. Although her time at UCNFA was brief, she very much enjoyed working with the program and group members.

At the same time, UCNFA welcomes new program representative Paulina Jacobs-Sanders. She brings with her a diverse professional background encompassing both business and journalism, having previously owned a business in downtown Davis and worked as a journalist in Santiago, Chile. Paulina has a deep love of language and as a Spanish speaker, has incorporated the language at every opportunity, whether educating her daughters in Spanish, hosting happy hour events with Spanish speaking friends, or writing for publications in Spanish. She received her Masters in English from San Francisco State University, and moved to Davis to raise her family. As UCNFA's program representative, she will be coordinating workshops and conferences, managing monthly administrative committee meetings, assisting with newsletter layout and production, and maintaining UCNFA's web site and social media presence.

New Publications from Agriculture and Natural Resources

compiled by Steve Tjosvold

Soils in Urban Agriculture: Testing, Remediation, and Best Management Practices

This new free publication outlines strategies for urban soil contamination assessment, testing and remediation; explains best management practices for urban agriculture; and discusses municipal policy concerning safe soils for urban agriculture.

Authors: R. Surls, V. Borel, A. Biscaro
Publication Number: 8552
http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8552

Pests of Landscape Trees and Shrubs, 3rd Edition

Completely revised and expanded, this comprehensive integrated pest management (IPM) resource is invaluable to nursery operators in identifying potential pest problems in the nursery and can be a complementary resource to Container Nursery Production and Business Management Manual, Pub 3540 and Integrated Pest Management for Floriculture and Nurseries, Pub 3402. This easy-to-use guide covers hundreds of pests including insects, mites, nematodes, plant diseases and weeds. The book's 435 pages present practical experience and research-based advice on topics including use of pest-resistant plants, cultural practices that keep plants healthy, conserving natural enemies to biologically control pests, efficient pest monitoring and use of selective pesticides. $37.00.

Author: Steve H. Dreistadt
Publication Number: 3359
http://anrcatalog.ucanr.edu/Details.aspx?itemNo=3359

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