Introduction
Weeds can impact cultural operations, tree growth, and yields by altering the spray pattern of low-volume irrigation systems, intercepting soil-applied chemicals (fertilizer and agricultural chemicals), reducing grove temperatures during freeze events, and interfering with pruning and harvest operations. The presence of weeds in a citrus grove can also affect insect populations. Weeds growing around tree trunks may also create a favorable environment for pathogens that infect the trunk and roots. Weed species compete with citrus trees in many ways and with varying intensities; management of more competitive weeds such as Conyza bonariensis and C. canadensis, Sorghum halapensis, Paspalum dilatatum, and Ipomea purpurea should be prioritized. While some weeds (e.g., Tribulus terrestris, Xanthium strumarium, Urtica urens, Cirsium vulgare, and Picris echioides) may have low competitive effects on citrus trees, they can hinder labor operations and may also rank high for active management.

Citrus integrated pest management (IPM) programs typically utilize a combination of control practices, like cultural, mechanical, and chemical, to minimize competitive effects of weeds on crop productivity. Weed management can be an expensive part of the total citrus production program, but resources invested here can provide significant economic returns.

Proper weed identification is a critical in developing an effective management program. Weed species will vary with location, climate, season, soil type, previous site history, and current and past management programs.

A photo gallery of weeds, weed seedlings, and various weed anatomical features is available online through UC IPM at: http://www.ipm.ucdavis.edu/PMG/weeds_intro.html.

Additionally, an online identification tool is available through the UC Weed Research and Information Center at: http://weedid.wisc.edu/ca/weedid.php.

Scouting for weeds should be conducted in all areas in and near the grove, including tree rows, row middles, water furrows, ditch banks, fence rows, and adjacent perimeter locations. These sites may receive different cultural practices which can facilitate the persistence and spread of different weed species. Look for small isolated weed patches and manage them before they spread to other areas of the grove. Since weeds emerge all year long, schedule weed surveys throughout the year, especially after rains or soil disturbances. Scouting should occur even if weeds are not easily visible or their above-ground parts appear to be dead. Re-growth from perennial plants is common. If weeds are correctly identified in the seedling or vegetative stage, then proper control can be achieved through: 1) optimal treatment timing; 2) possible reduced herbicide application rate; and 3) reduced environmental impact from treatments. The weed species present will vary with season and location, because weeds are typically not distributed uniformly. For further information about characteristics used to identify, see the Weeds section of the UC IPM Citrus Pest Management Guidelines, http://www.ipm.ucdavis.edu/PMG. When scouting for weeds, records should be developed and recorded as to species abundance, location, and identity.

Preventive programs are often overlooked, but are an important component of cultural practices and are cost-effective. Practices, such as sanitation, spot spraying, and/or hand removal of weed escapes before they produce new seed are examples of prevention. While preventive programs may not stop the spread of all weed species, they can reduce the amount of weed pressure and the need for expensive chemical controls.

Citrus Weed Control with Indaziflam and Rimsulfuron Herbicides

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Figure 1. Indaziflam (2 fl. oz/A) in combination with rimsulfuron at 2 fl. oz/A applied in November provided excellent weed control for up to 4 months (front) while untreated checks had high weed densities (back).
species, these practices may slow the spread of undesirable species, thereby reducing long-term weed control costs.

Cultivation or tillage has been used in the past for many years in citrus production. Tillage is an effective method of controlling annual weeds effectively by severing weed stems and roots but is can be counterproductive for perennial weeds that can propagate vegetatively. Soil erosion concerns are cited as a reason why tillage use is decreasing as more groves are planted on raised berms. Also, citrus trees have a shallow fibrous root system and tillage increases risk of root and trunk damage. With the use of low-volume irrigation systems and closer in-row planting distances, tillage in both directions is no longer possible. Mechanical mowing is generally more expensive than tillage and can throw seed under the tree canopy, increasing weed pressure next to the tree trunk.

Herbicides used in a citrus are generally divided into two groups: 1) soil-applied (preemergence) herbicides that should be applied to fairly clean soil surfaces prior to weed emergence, and 2) foliar-applied (postemergence) herbicides that are applied after weeds have emerged. Preemergence herbicides are generally applied two to three times per year, so the maximum amount of herbicide is in the upper soil profile (0 to 2 inches) slightly before peak weed emergence. Herbicides applied too early, before weeds emerge, will not provide adequate weed control due to herbicide leaching or degradation on the soil surface or within the soil profile.

Preemergence herbicides must be incorporated (mainly by rainfall or irrigation) and are usually broadcast on the entire orchard floor since growers do not know where weeds will emerge and to reduce risk of frost damage. Growers using drip irrigation or microsprinkler irrigation have a difficult time adequately incorporating preemergence herbicides, so usually try to treat prior to predicted rainfall (Rector et al. 1998). Soil type can influence herbicide selection and rate used. Many preemergence herbicides including oxyfluorfen, pendimethalin, oryzalin, trifluralin, and metolachlor can be used on sandy soils without injuring citrus trees. Tree age is also an important consideration when selecting which herbicide(s) to use.

Postemergence herbicides are used to control weeds that escape control by preemergence herbicides or mechanical cultivation. Postemergence herbicides can be systemic or contact in activity. Systemic herbicides are moved within the target plant, killing the foliage and root system of the treated plant. Contact herbicides are active only on those parts of the weeds the herbicide comes into contact with. Hence, adequate spray coverage of the weeds is more critical than with systemic materials. These herbicides are effective on small annual weeds and usually only suppress growth of perennials. It should be noted that the majority of organic herbicides are contact herbicides. Glyphosate is a systemic postemergence herbicide in widely used in citrus due to its efficacy on many weed species and relatively low cost. However, continuous use of the same mode of action over time will likely lead to the development of resistant populations in some weeds species. Amongst other weed species, Conyza canadensis and C. bonariensis have both been reported to be resistant to glyphosate in California citrus.

To help reduce the likelihood of herbicide resistance development, herbicides with different modes of action should be rotated and/or mixed. New herbicides and rotations are needed to address the increasing occurrence of resistance among weeds in citrus orchards, and provide more effective and economic, season-long control while minimizing crop injury.

Rimsulfuron is a relatively new pre-post emergence herbicide registered for use in California citrus. It has both grass and broadleaf weed activity. Indaziflam, also recently introduced to

| Table 1. Potential injury ratings (1= none to 10= most severe) from direct spray (50 gal/acre solution) of herbicides on Satsuma mandarins. |
|---------------------------------|-----------------------------|-----------------------------|
| Treatments and rates per acre   | 1 week after treatment      | 5 weeks after treatment     |
| Untreated                       | 1                           | 1                           |
| Indaziflam, low concentration at 5 fl. oz | 1.58                   | 3.25                       |
| Indaziflam, low concentration at 5 fl. oz + rimsulfuron at 2 oz | 2.13                   | 3.5                        |
| Indaziflam, high concentration at 2 oz | 1.54                   | 3                           |
| Indaziflam, high concentration at 2 oz + rimsulfuron at 2 oz | 1.25                   | 2.25                       |
| Rimsulfuron at 4 oz             | 1.75                        | 1.75                       |

Figure 2. Slight curling and brown spotting of new leaves from a direct spray (drift simulation) of combination of rimsulfuron with indaziflam (left) compared to untreated leaves (right) at 1 week after treatment.
California citrus, has a pre-emergence activity against many common grasses and broadleaves. Both of these materials would fit into a rotation and/or herbicide mix. In 2016 and 2017 we conducted trials evaluating the efficacy and safety of these two materials in a citrus orchard.

Materials and Methods
Weed control. At a clay loam site (pH = 7.4) near Santa Paula, CA, the weed control efficacy of two product formulations of the indaziflam, (at 2 and 5 fl. oz/A)) was evaluated. These were applied alone or in combination with rimsulfuron at 2 fl. oz/A, which was also applied alone at 4 fl.oz/A, for a total of 5 treatments plus an untreated control. All of the treatments were applied to 90ft² plots either in November 2015 and 2016 or in February 2016 and 2017. Herbicide treatments were applied with a CO₂-pressurized backpack sprayer delivering spray solution via three flat nozzles in a volume equivalent to 50 gal/acre. Treatment plots in row middles had been previously treated with glyphosate and shallow cultivation. In November, no weeds germinated prior to application, while in February weeds germinated after winter rains in all plots. We evaluated weed densities at two, four, and six months after treatment (MAT).

Citrus injury potential. Even though the tested herbicides are applied to soil and should not come in contact with citrus foliage when applied properly we evaluated potential impact of herbicidal drift on citrus. In 2017 we have simulated severe drift by spraying all treatments (as described previously) to halves (aprox. 20 ft²) of the foliage of 6-8 ft tall Satsuma mandarins. Again, treatments were arranged according to a RCBD with four replications. At one and five weeks after treatment (WAT) we rated foliar injury on a scale from 1 (none) to 10 (most severe). Averages of four independent ratings on the same date were used to conduct statistical analyses as described previously.

Results and Discussion
Weed control. The most common weeds in the plots were little mallow (Malva parviflora), horseweed and hairy fleabane (Conyza spp.), field bindweed (Convolvulus arvensis), spurge (Euphorbia spp.), common lambsquarters (Chenopodium album), burning nettle (Urtica urens) and common purslane (Portulaca oleracea). All of the herbicide treatments were consistently effective in controlling broadleaf weeds compared to the untreated control regardless of the evaluation period (combined weed densities shown in Fig. 4). Indaziflam at both rates plus rimsulfuron provided superior control over other treatments for most weeds in both seasons and application timings. Although spurge was not controlled with this herbicide combination, we suspect that performance may be improved with the addition of a surfactant. Common purslane and field bindweed were least susceptible to herbicide treatments. Even though there was partial control of above-ground bindweed shoots, new growth regenerated from below-ground buds was not affected. Purslane seed bank in soil provided multiple germination cohorts and the seed germinated 2-4 MAT were likely not exposed to lethal herbicide concentrations and germinated and established. The efficacy of all treatments greatly diminished between two and six MAT. Additional herbicide applications and integrated control might have provided longer-term control.

Figure 3. Significant chlorosis and discoloration, particularly on new foliage observed at 5 weeks after direct spray (drift simulation) with indaziflam (left) compared to untreated leaves (right).
Citrus injury potential. Even with direct spray to foliage all treatments resulted in very low injury ratings at 1 WAT (Table 1). Rimsulfuron alone or in combination with indaziflam had slightly greater levels of injury that indaziflam at that time. However, at 5 WAT significant injury symptoms developed in treatments containing indaziflam and injury was greater at increased rate (Table 1). However, in all cases the drift that would result from soil application of any treatments is unlikely to cause significant injury, let alone negative effects on fruit production. Thus, we conclude that these herbicides can be applied safely in young citrus groves when drift is prevented.

In summary:

• Rimsulfuron, indaziflam and their combinations controlled most broadleaf weeds germinating from soil seedbank and those dispersed by wind to citrus furrows for up to 4 months. The higher rates were slightly more efficacious than lower rates. Rimsulfuron provided some control of field bindweed (above-ground parts).

• These herbicides control germinating weeds and do not have much activity on established weeds, and may need ‘burn-down’ partner for complete weed management program.

• Rimsulfuron and indaziflam have different mode of action than glyphosate (controls established weeds) and therefore are good tools in both weed and resistance management in citrus orchards.

• Both herbicides were safe to citrus when applied to soil but caution should be exercised to prevent drift to crop foliage. When in contact with young leaves rimsulfuron caused minimal injury but indaziflam caused extensive chlorosis in crop canopy.

• Application prior to rainy season (November) was very effective and may be preferred to application after rains (February) when many germinated weeds are established.

References


Figure 4. Total weed density per 90 ft² plot at two, four, and six months after treatment (MAT).