Weed Science

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Research Article

**Cite this article:** Boyd NS, Kanissery R, Reuss L (2025). Survey of weed flora in central and south Florida tomato fields. Weed Sci. **73**(e68), 1–7. doi: 10.1017/wsc.2025.10038

Received: 20 February 2025
Revised: 18 June 2025
Accepted: 4 July 2025

**Associate Editor:**
Shaun Sharpe, Agriculture and Agri-Food Canada

**Keywords:**
Broadleaf; fumigation; grass; herbicide; nutsedge; plasticulture

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# Survey of weed flora in central and south Florida tomato fields

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## Abstract

The first-ever survey of weed flora near season end in commercial tomato (*Solanum lycopersicum* L.) fields in central Florida was conducted during the 2021 to 2022 field seasons. Forty-seven fields were surveyed, which represents a total of 593 ha. Fumigation occurred on 94% of all surveyed fields, and fertility and water were applied via drip tape on 77% of the fields, with furrow irrigation occurring on the remaining fields. Preemergence herbicides were applied under the plastic mulch on 74% of the fields, and herbicides were applied in all row middles. A total of 62 weed species escaped weed management and were identified during the season-end survey. Purple nutsedge (*Cyperus rotundus* L.), common purslane (*Portulaca oleracea* L.), goosegrass [*Eleusine indica* (L.) Gaertn.], and smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb ex. Muhl.] occurred in the row middles of 74%, 70%, 68%, and 55% of all fields surveyed, and the same four species also had the highest relative abundance. Purple nutsedge (*Cyperus rotundus* L.), *E. indica*, *P. oleracea*, *D. ischaemum*, Florida pusley (*Richardia scabra* L.), and cutleaf evening primrose (*Oenothera laciniata* Hill) occurred in the transplant holes of 60%, 34%, 28%, 23%, 19%, and 15% of all fields surveyed. *Cyperus rotundus* had the highest relative abundance in the transplant holes by a large margin, followed by *O. laciniata*. Moving forward, this information will help tomato growers, extension agents, and weed scientists identify the key weeds that are likely to be problematic on tomato farms and will guide future weed management research programs.

## Introduction

Florida produces more fresh-market tomatoes (*Solanum lycopersicum* L.) than any other U.S. state, and in 2019 accounted for 60% of the total U.S. value of the crop (USDA-NASS 2020). In 2022, there were 8,903 ha of fresh-market tomatoes planted in Florida, and 8,498 ha were harvested, with an estimated production value of US$322.5 million (USDA-NASS 2022). The plasticulture production system has been widely adopted within the US fresh-market tomato industry. Weeds emerge between the raised, plastic-covered beds (row middles) and in the transplant holes, and *Cyperus* spp. can also emerge through the plastic mulch.

Tomato farms typically use integrated weed management programs that include cover crops or postemergence herbicides during the fallow period. During the cropping period, weeds in the row middle are typically controlled with a combination of preemergence and postemergence herbicides. Inadequate control can lead to yield loss, interference with harvest operations, increased labor associated with plastic removal, and increased issues with pest control (Boyd 2016; Sharpe and Boyd 2019). Management of weeds emerging on the raised bed typically includes the use of fumigants, preemergence herbicides applied under the plastic mulch, selective postemergence herbicides, and hand weeding. Unfortunately, weed management with preemergence herbicides under the plastic mulch tends to be inconsistent (Boyd and Reed 2016; Khatri et al. 2020) for unknown reasons, and growers rely on postemergence herbicides or hand weeding.

Weed surveys in a variety of crops have been used to identify the weed flora present at a given time point (McCully et al. 1991; Thomas 1985; Webster 2010). This information can enhance our understanding of important issues such as herbicide resistance (Boutsalis et al. 2012) and facilitate the development of improved management practices (Osten et al. 2007). The authors are unaware of any weed survey ever having been conducted in commercial tomato fields in Florida. Surveys conducted by the Weed Science Society of America provide valuable information on the most common and most problematic weeds (Van Wychen 2022). However, the survey is prone to observer bias due to reliance on expert opinions and also accounts for larger geographic areas and multiple crops within a given category. Consequently, the surveys have limited applicability to localized areas or individual specialty crops (Boyd and Reuss 2022).

The objective of this survey was to estimate the frequency, density, field uniformity, and relative abundance of weeds in commercial tomato fields in central and south Florida that occur in the row middles, transplant holes, and field edges. In addition, basic information related to weed management practices adopted by tomato growers in the region was collected.

## Materials and Methods

### Sampling Procedure

A targeted weed survey of 7 tomato farm operations in central Florida was conducted that covered a total of 47 tomato fields with 23 fields surveyed in the spring crop (April 2021) and 24 different fields surveyed in the fall crop (December 2021 or February 2022). The survey occurred on 593 ha of commercial tomato fields and included all major growers located in Hillsborough, Manatee, Hendry, and Collier counties. General production information related to bed spacing and irrigation methods were observed in the field by individuals conducting the survey. Farm managers were asked for information regarding fumigant usage, herbicides applied under the plastic mulch, and herbicides applied in the row middles for each field. Fields included in the survey were randomly selected from all fields within a given farm where tomatoes had been planted and had ripe tomatoes present on the vines. This stage was selected to enable us to survey weeds that survived current management efforts and thereby highlight research needs moving forward. Fields were surveyed following the methodology of McCully et al., (1991) and Thomas (1985), but data collection was modified to distinguish weeds occurring between the raised, plastic covered beds (row middles) and weeds emerging in the planting holes. To evaluate weed populations occurring in the row middles, 20 quadrats that were 1-m long and as wide as the row middle were randomly placed along an "inverted W" pattern spanning the entirety of each field. Row middle width ranged from 0.76 m to 1.09 m. The first quadrat was placed after walking 20 paces from one comer of the field, along the first leg of the "W". Five quadrats were placed along each of the four legs. The distance between quadrats varied with the size and shape of each field. As a result, larger fields had greater distances between quadrats. To evaluate weed populations emerging in the planting holes, weed data were collected from 100 planting holes in proximity to the quadrat placed in the row middle. Weeds located along the perimeter of the field were also identified and recorded, but not counted. Weeds of unknown identity were photographed and later identified by weed management experts or with the assistance of a dichotomous key (Wunderlin and Hansen 2011).

### Data Analysis

Quantitative measures, such as frequency, density, field uniformity, and relative abundance were used to evaluate the weed data. Frequency ($F$) is the percentage of fields ($f$) in which the species ($s$) occurs relative to the total number of fields surveyed ($T$). It was calculated as:

$$F_s = \left[\frac{f_s}{T\ (n = 47)}\right] \times\ 100 \qquad [1]$$

Frequency does not consider the density of a given weed species within a field or the size of the weeds that occur. Field uniformity ($U$) is the number of sample locations within a field in which species $s$ occurs ($q$) expressed as a percentage of the total number of samples taken in the given field ($t$). Uniformity within a given field where species $s$ occurred was calculated as:

$$U(\text{occurrence fields})_s = \frac{q}{t(n = 20)} \times\ 100 \qquad [2]$$

We calculated the average field uniformity for all fields where species $s$ occurred, which is referred to as $U$(occurrence fields), and the uniformity as a percentage of all fields present in the study ($T = 47$), which is referred to as $U$(all fields). $U$(occurrence fields) provides an estimate of the uniformity of the species within fields where it occurs, whereas $U$(all fields) provides an estimate of the uniformity of the species in tomato fields in central Florida.

Density within any given field was calculated as:

$$D_s = \left[\frac{\sum_{i=0}^{t} k}{t\ (n = 20\ )}\right] \qquad [3]$$

where $k$ is the total number plants species $s$ within a given field. Mean field density (MFD) for occurrence fields was calculated as:

$$\text{MFD}(\text{occurrence fields})_s = \left(\frac{\sum_{i=0}^{T} D_s}{T}\right) \qquad [4]$$

where the sum of the densities for species $s$ is divided by the number of fields where species $s$ occurs ($T$). MFD for all fields was calculated using the sum of the densities for species $s$ divided by the total number of fields present in the study ($T$ = 47). These two variables are referred to as MFD(occurrence fields) and MFD(all fields), respectively.

The relative abundance (RA) was also calculated to provide a unitless index of all species included in the survey (Thomas 1985). It was calculated as follows:

Relative frequency for species $s$ ($\text{RF}_s$):

$$\text{RF}_s = \frac{\text{frequency value}_s}{\text{sum of frequency values for all species}} \times 100 \qquad [5]$$

Relative uniformity for species $s$ ($\text{RU}_s$) was calculated using the uniformity calculation based on all fields surveyed and was calculated as follows:

$$\text{RU}_s = \frac{\text{field uniformity}_s}{\text{sum of field uniformity values for all species}} \times 100 \qquad [6]$$

Relative mean density for species $s$ ($\text{RMD}_s$) was calculated using the relative mean density for all fields included in the study and was calculated as follows:

$$\text{RMD}_s = \frac{\text{mean field density}_s}{\text{sum of field density values for all species}} \times 100 \qquad [7]$$

And RA for species $s$ was calculated as follows:

$$RA_s = RF_s + RU_s + RMD_s \qquad [8]$$

This formula allows the comparison of individual weed species relative to each other and assumes that relative frequency, uniformity, and density are of equal importance.

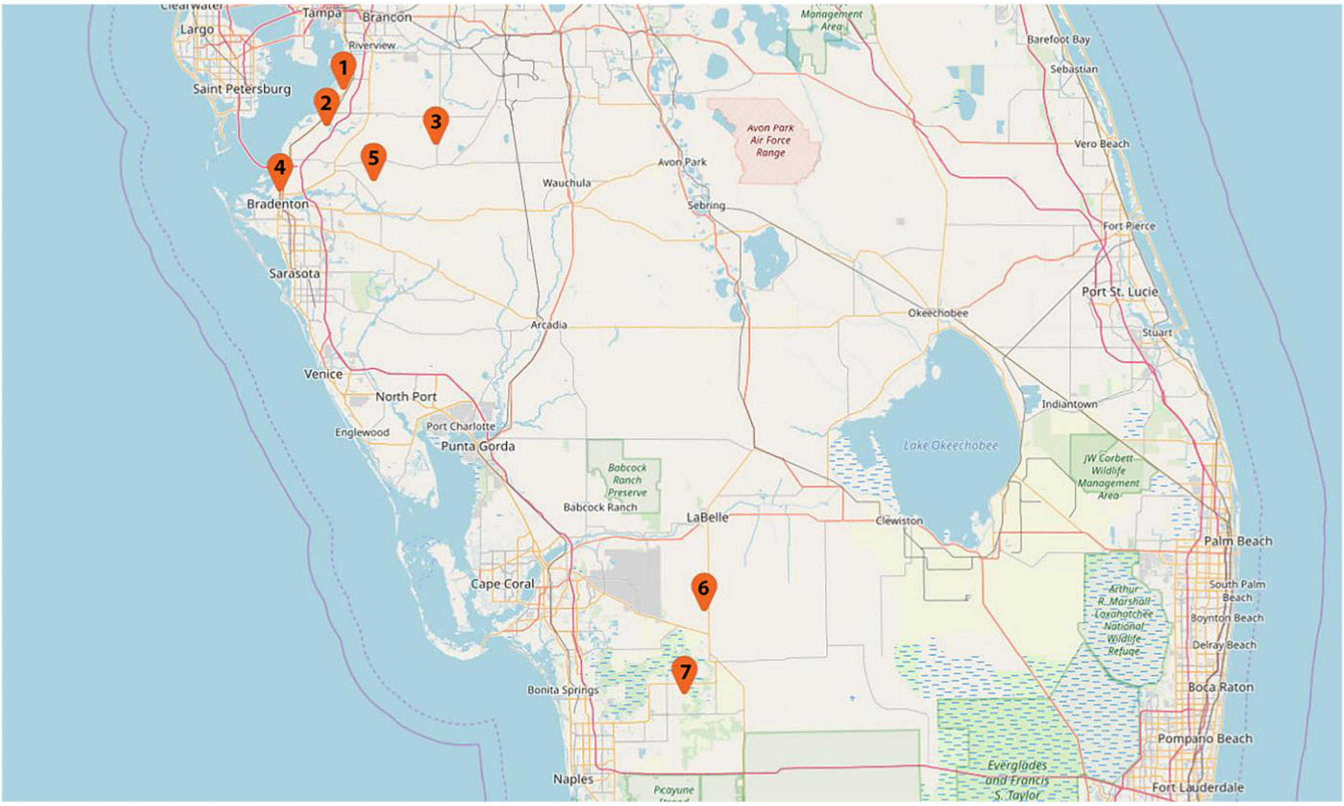


**Figure 1.** Location of surveys conducted on commercial tomato farms in central Florida during the 2021–2022 season.

## Results and Discussion

### *General Production*

A total of 593 ha of conventional tomato production fields in central Florida were surveyed (Figure 1). This survey covered the largest production regions in central Florida but did not include production in the south and northern portions of the state, which have different soil types and weather patterns. All surveyed fields used the plasticulture production system (data not shown). This system has been widely adopted, due in part to increased water and fertilizer use efficiency, enhanced weed control, and improved fruit yield and quality (Kapoor et al. 2022; Lamont 2017). Drip irrigation was installed in 77% of the surveyed fields, with the remainder relying on seepage irrigation to supply adequate water (data not shown). Just over 50% of the reported fields were fumigated with a combination of 60% chloropicrin (Pic) + 39% 1,3-dichloropropene (1,3-D) (Table 1). Seventeen percent of the fields were injected with Pic alone, and 17% were injected with 80% Pic + 20% 1,3-D and deep-shanked 1,3-D. Only 6% of the surveyed fields were not fumigated. This survey confirms the widespread adoption of the fumigated, plasticulture system in central Florida tomato production.

Preemergence herbicides were applied under the plastic mulch in 75% of all surveyed fields, with no preemergence herbicides applied in the remaining 25% (Table 2). *S*-metolachlor was applied in all fields where herbicides were applied under the mulch, with additional modes of action in some fields. The authors of this report are aware of growers that apply metribuzin and fomesafen under the plastic mulch, but these herbicides were not applied in the surveyed fields the years that the survey occurred. This survey indicates that growers are using very few modes of action beneath the plastic mulch. Tomato growers use preemergence herbicides under the plastic mulch at a much higher frequency than strawberry [*Fragaria* × *ananassa* (Weston) Duchesne ex Rozier ssp. *ananassa*] growers in the same region (Boyd and Reuss 2022). It is possible that the increased need for preemergence herbicides may partially be attributed to the hole type. Tomato growers punch a square hole in the plastic mulch, which leaves more exposed soil and a greater opportunity for weed recruitment than the narrow slit used by most strawberry growers.

We were unable to obtain herbicide programs for the space between the raised beds (row middles) for 8.5% of the surveyed fields, and the information gathered for the remaining fields was in some situations difficult to interpret (Table 3). Herbicide programs varied widely between farms, with most farms relying on tank mixes or herbicide rotations. Preemergence herbicides were applied in approximately 30% of the row middles. Paraquat was only used on 6% of the surveyed fields, whereas diquat was applied on 68% of the fields. The low adoption of paraquat likely reflects the increased regulation associated with the use of this active ingredient. Heavy reliance on HRAC Group 22 herbicides is concerning, as herbicide resistance to this mode of action has been reported in vegetable fields (Boyd et al. 2022). Glyphosate was used preplant on 17% of the fields. Tomato growers in Florida use multiple modes of action in row middles, with diquat included in the majority of herbicide programs. Row middle weed control remains a problem on many commercial tomato farms with no wide-scale adoption of defined herbicide programs. Row middle weeds are separated spatially from the crop, and consequently, they compete less than weeds on the bed top, but previous research has shown that they still reduce crop yield and quality (Gilreath and Santos 2004). In addition, row middle weeds serve as an alternative

https://doi.org/10.1017/wsc.2025.10038 Published online by Cambridge University Press

**Table 1.** The fumigants used on commercial tomato fields included in a weed survey conducted in central Florida in 2021 and 2022.

| Fumigant[a] | % of surveyed fields |
|---|---|
| 99% chloropicrin (Pic) | 17.0 |
| 97.5% 1,3-dichloropropene (1,3-D)[b] followed by 79.8% Pic + 19.5% 1,3-D | 17.0 |
| 59.6% Pic + 39% 1,3-D | 51.1 |
| No fumigant | 6.4 |
| Unreported | 8.5 |

[a]Fumigants were applied when raised soil beds were formed, immediately before laying the plastic mulch.
[b]This 1,3-D application was deep shanked on a flat field during the fallow period.

**Table 2.** The preemergence herbicides applied on the bed top of raised soil beds immediately before laying the plastic mulch on commercial tomato fields included in a weed survey conducted in central Florida in 2021 and 2022.

| Herbicide | HRAC group | % of surveyed fields |
|---|---|---|
| *S*-metolachlor | 15 | 40.4 |
| *S*-metolachlor + halosulfuron | 15,2 | 8.5 |
| *S*-metolachlor + rimsulfuron | 15,2 | 17.0 |
| *S*-metolachlor + rimsulfuron + halosulfuron | 15,2 | 8.5 |
| No herbicide applied | — | 25.5 |

food source for nematodes and an alternative host for plant pathogens (Dikova 2006; Goyal et al. 2012), interfere with harvest operations, and increase labor associated with plastic removal. There is a need for improved row middle weed management programs for tomato that are also designed to slow the development of herbicide resistance.

## Weed Survey

It is important to note that weed data were collected after the final herbicide application in every field. Therefore, our data provide information on the weeds that were not controlled by management efforts. Sixty-three weed species were identified, with more species present in the row middles than in the transplant holes. Sixteen species were observed in the field or on field edges that were not within the study quadrats (Table 4). The majority of these species tend to occur predominately in low-disturbance ecosystems, which probably explains occurrence on field edges with limited or no occurrence within the field where intensive cultivation occurs.

## Row Middles

A total of 37 broadleaf species, 7 grass species, and 2 sedge species were identified in the row middles, with no species present in every field (Table 5). Purple nutsedge (*Cyperus rotundus* L.), goosegrass [*Eleusine indica* (L.) Gaertn.], common purslane (*Portulaca oleracea* L.), smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. ex. Muhl.], and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv. ] had the highest relative abundance in the row middles. *Cyperus rotundus*, *P. oleracea*, *E. indica*, and *D. ischaemum* occurred in more fields than any other species and were present in 74%, 70%, 68%, and 55% of the fields surveyed (Table 5). Conversely, *E. indica*, black medic (*Medicago lupulina* L.), cutleaf evening primrose (*Oenothera laciniata* L.), *C. rotundus*, and

**Table 3.** Herbicide use on the bare soil between raised beds (row middles) on commercial tomato fields included in a weed survey conducted in central Florida in 2021 and 2022.

| Herbicides in row middles[a] | HRAC group | % of surveyed fields |
|---|---|---|
| Diquat, carfentrazone[b] | 22,14 | 8.5 |
| Diquat, carfentrazone, halosulfuron | 22,14,2 | 8.5 |
| Diquat, clethodim[b] | 22,1 | 13.0 |
| Diquat, carfentrazone, metribuzin[b] | 22,14,5 | 17.0 |
| Glyphosate pre-transplant | 9 | 8.5 |
| Halosulfuron[b] | 2 | 8.5 |
| Paraquat[b] | 22 | 6.3 |
| *S*-metolachlor + flumioxazin pretransplant fb diquat + clethodim | 15,14,22,1 | 4.2 |
| *S*-metolachlor + glyphosate pretransplant fb diquat+ metribuzin and/or clethodim + carfentrazone as needed | 15,9,22,5,1,14 | 8.5 |
| *S*-metolachlor + metribuzin pretransplant fb diquat, carfentrazone, halosulfuron as needed | 15,5,22,14,2 | 8.5 |
| Unreported | — | 8.5 |

[a]fb, followed by.
[b]Timing and frequency of applications not specified.

**Table 4.** Weed species observed in Florida tomato fields or on field edges that did not occur in the quadrats during a weed survey conducted in central Florida in 2021–2022.

| Scientific name | Common name | % of surveyed fields |
|---|---|---|
| *Bidens* spp. | Beggarticks | 17.4 |
| *Bothriochloa pertusa (L.) Willd.* | Pitted beard grass | 2.2 |
| *Carex aquatilis Wahlenb.* | Water sedge | 8.7 |
| Cenchrus echinatus L. | Southern sandburr | 21.7 |
| *Cyperus surinamensis Rottb.* | Surinam sedge | 6.5 |
| *Eupatorium capillifolium (Lam.) Small* | Dogfennel | 10.9 |
| *Lolium multiflorum Lam.* | Annual ryegrass | 6.5 |
| *Macroptilium lathyroides (L.) Urb.* | Wild bushbean | 4.3 |
| *Melilotus albus Medik.* | White sweetclover | 13.0 |
| *Melinis repens (Willd.) Zizka* | Natalgrass | 8.7 |
| *Nuttallanthus* spp. | Oldfield toadflax | 4.3 |
| Plantago major L. | Broadleaf plantain | 4.3 |
| Portulaca pilosa L. | Pink purslane | 10.9 |
| Rumex pulcher L. | Fiddleleaf dock | 2.2 |
| Sonchus oleraceus L. | Annual sowthistle | 2.2 |
| Urena lobata L. | Caesarweed | 2.2 |

*Galium* spp. occurred in 63%, 60%, 59%, 55%, and 50% of the quadrats in fields where the species occurred but were not as widespread across the region. This suggests that growers struggle to manage these species within localized fields for unknown reasons, and further management recommendations are needed. It is worth noting that the most widespread or localized problematic species in Florida tomato fields are quite different from the most common or most troublesome weed species identified by weed experts in fruiting vegetable fields (Van Wychen 2022). This is not surprising, as the Van Wychen survey covers a much wider geographic area and represents a higher crop diversity.

https://doi.org/10.1017/wsc.2025.10038 Published online by Cambridge University Press

**Table 5.** Frequency, field uniformity, density, and relative abundance of row middle weeds in commercial tomato fields at season end in central Florida during the 2021 and 2022 season.

| Scientific name | Common name | Frequency | Field uniformity | | Density | | Relative abundance |
|---|---|---|---|---|---|---|---|
| | | | All fields | Occurrence fields | All fields | Occurrence fields | |
| | | | % | | shoots m$^{-2}$ | | |
| Acer rubrum L. | Red maple | 4 | 0.2 | 5.0 | 0.0 | 0.1 | 0.6 |
| Aeschynomene aspera L. | Curly indigo | 4 | 0.9 | 20.0 | 0.1 | 1.3 | 1.1 |
| *Aeschynomene virginica (L.) Britton* | Joint vetch | 13 | 6.0 | 46.7 | 0.4 | 3.3 | 4.6 |
| Amaranthus albus L. | Amaranthus | 9 | 1.7 | 20.0 | 0.1 | 1.0 | 2.0 |
| Ambrosia artemisiifolia L. | Common ragweed | 43 | 15.1 | 35.5 | 0.9 | 2.2 | 12.9 |
| *Chamaecrista fasciculata (Michx.) Greene* | Partridgepea | 4 | 0.4 | 10.0 | 0.0 | 0.1 | 0.7 |
| *Chamaesyce hirta (L.) Millsp.* | Garden spurge | 9 | 1.0 | 11.3 | 0.0 | 0.1 | 1.6 |
| *Chenopodium album* L. | Lambsquarters | 2 | 0.2 | 10.0 | 0.0 | 0.1 | 0.3 |
| *Cynodon dactylon (L.) Pers.* | Bermudagrass | 13 | 3.8 | 30.0 | 0.4 | 3.1 | 3.9 |
| Cyperus esculentus L. | Yellow nutsedge | 11 | 4.5 | 42.0 | 0.4 | 3.3 | 3.8 |
| Cyperus rotundus L. | Purple nutsedge | 74 | 40.7 | 54.7 | 16.8 | 22.6 | 56.0 |
| *Dactyloctenium aegyptium (L.) Willd.* | Crowfootgrass | 6 | 0.7 | 11.7 | 0.0 | 0.3 | 1.1 |
| Daucus carota L. | Wild carrot | 9 | 4.0 | 47.5 | 0.5 | 5.6 | 3.6 |
| *Dichanthelium* spp. | Panicgrass | 2 | 0.2 | 10.0 | 0.0 | 0.3 | 0.3 |
| *Digitaria ischaemum* (Schreb.) Schreb ex. Muhl. | Crabgrass | 55 | 27.2 | 49.2 | 4.5 | 8.1 | 25.5 |
| Diodia teres Walter | Poorjoe | 6 | 3.0 | 46.7 | 0.5 | 7.3 | 2.8 |
| *Echinochloa crus-galli (L.) P. Beauv* | Barnyard grass | 32 | 14.0 | 44.0 | 5.3 | 16.7 | 19.3 |
| *Eclipta prostrata (L.) L.* | Eclipta | 43 | 14.9 | 35.0 | 0.9 | 2.2 | 12.8 |
| *Eleusine indica* (L.) Gaertn. | Goosegrass | 68 | 42.7 | 62.7 | 7.4 | 10.8 | 38.2 |
| *Emilia fosbergii Nicolson* | Cupids-shaving-brush | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.3 |
| *Erigeron canadensis* L. | Canadian horseweed | 19 | 4.8 | 25.0 | 1.1 | 5.9 | 6.4 |
| *Galium* ssp. | Galium | 4 | 2.1 | 50.0 | 1.1 | 24.8 | 3.4 |
| *Gamochaeta purpurea* (L.) Cabrera | Purple cudweed | 26 | 5.9 | 22.9 | 2.2 | 8.6 | 9.8 |
| *Hedyotis terminalis (Hook. & Arn.)* | Starviolet | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.3 |
| *Hygrophila* spp. | Smart swampweed | 6 | 0.3 | 5.0 | 0.0 | 0.1 | 0.9 |
| *Indigofera hirsuta* L. | Hairy indigo | 4 | 0.9 | 20.0 | 0.2 | 4.7 | 1.2 |
| *Ipomoea* spp. | Morningglory | 4 | 2.1 | 50.0 | 0.1 | 1.6 | 1.5 |
| *Leptochloa fusca* spp. | Sprangletop grass | 6 | 0.6 | 10.0 | 0.1 | 1.3 | 1.2 |
| *Ludwigia adscendens (L.) H.Hara* | Water primrose | 15 | 3.7 | 25.0 | 0.5 | 3.2 | 4.3 |
| Lythrum hyssopifolia L. | Hyssop loosestrife | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.3 |
| *Medicago lupulina* L. | Black medic | 2 | 1.3 | 60.0 | 0.4 | 17.6 | 1.5 |
| *Melilotus officinalis (L.) Lam.* | Yellow sweet-clover | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.3 |
| *Mimosa strigillosa Torr. & A. Gray* | Sunshine mimosa | 4 | 1.0 | 22.5 | 0.0 | 0.9 | 0.9 |
| Mollugo verticillata L. | Carpetweed | 17 | 1.9 | 11.3 | 0.1 | 0.3 | 3.2 |
| Oenothera laciniata Hill | Cutleaf evening primrose | 26 | 15.0 | 58.8 | 2.1 | 8.2 | 12.8 |
| Phytolacca americana L. | Common pokeweed | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.3 |
| *Portulaca lutea Sol. ex G.Forst.* | Native yellow purslane | 9 | 1.3 | 15.0 | 0.0 | 0.2 | 1.7 |
| *Portulaca oleracea* L. | Common purslane | 70 | 33.5 | 47.7 | 3.7 | 5.2 | 28.3 |
| Raphanus raphanistrum L. | Wild radish | 4 | 0.7 | 17.5 | 0.0 | 0.4 | 0.8 |
| *Richardia scabra* L. | Florida pusley | 17 | 6.9 | 40.6 | 0.9 | 5.1 | 6.4 |
| Rumex crispus L. | Curly dock | 9 | 3.3 | 38.8 | 0.1 | 0.7 | 2.6 |
| *Scoparia dulcis Sol. ex G.Forst.* | Sweet broom weed | 6 | 1.0 | 15.0 | 0.1 | 1.2 | 1.4 |
| *Senna didymobotrya (Fresen.) H.S.Irwin & Barneby* | Wild sensitive plant | 6 | 0.9 | 13.3 | 0.0 | 0.3 | 1.1 |
| *Solanum nigrum* L. | Black nightshade | 38 | 14.8 | 38.6 | 2.2 | 5.7 | 14.5 |
| *Persicaria maculosa Gray* | Ladysthumb | 6 | 0.7 | 11.7 | 0.0 | 0.1 | 1.1 |
| *Vitis* spp. | Grape | 2 | 0.1 | 5.0 | 0.0 | 0.2 | 0.3 |
| | Unknown | 9 | 1.6 | 37.5 | 0.1 | 1.5 | 2.0 |

Weed density in row middles tended to be low across all fields surveyed, which indicates that overall weed management programs are quite successful in tomato fields with densities ranging from 0.1 to 24.8 weeds m$^{-2}$. The species with the highest densities in fields where they occurred, although they were not widespread across the surveyed production region, were *Galium* spp., *C. rotundus*, and *M. lupulina* with densities of 25, 23, and 18 weeds m$^{-2}$. This suggests that tomato growers do not adequately control these species in the fields where they occur, but these species are only a problem within a few fields.

*Cyperus rotundus* had the highest relative abundance, with *C. esculentus* occurring far less frequently. *Cyperus rotundus*

**Table 6.** Frequency, field uniformity, density, and relative abundance of weeds in the transplant hole in commercial tomato fields at season end in central Florida during the 2021 and 2022 season.

| Scientific name | Common name | Frequency | Field uniformity | | Density | | Relative abundance |
|---|---|---|---|---|---|---|---|
| | | | All fields | Occurrence fields | All fields | Occurrence fields | 0.9 |
| | | % | | | shoots $m^{-2}$ | | |
| Acer rubrum L. | Red maple | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.9 |
| *Aeschynomene virginica L.* | Joint vetch | 6 | 0.9 | 13.3 | 0.0 | 0.3 | 3.5 |
| Amaranthus albus L. | Amaranth | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.9 |
| Ambrosia artemisiifolia L. | Common ragweed | 6 | 1.0 | 15.0 | 0.0 | 0.3 | 3.6 |
| *Chamaesyce hirta (L.) Millsp.* | Garden spurge | 6 | 2.0 | 31.7 | 0.3 | 5.3 | 6.6 |
| *Chenopodium album* L. | Lambsquarters | 4 | 0.2 | 5.0 | 0.0 | 0.1 | 1.8 |
| *Cynodon dactylon (L.) Pers.* | Bermuda grass | 6 | 0.4 | 6.7 | 0.0 | 0.1 | 2.8 |
| Cyperus esculentus L. | Yellow nutsedge | 4 | 0.3 | 7.5 | 0.0 | 0.2 | 1.9 |
| Cyperus rotundus L. | Purple nutsedge | 60 | 28.7 | 48.2 | 10.5 | 17.7 | 120.3 |
| *Digitaria ischaemum* (Schreb.) Schreb ex. Muhl. | Crabgrass | 23 | 2.3 | 10.0 | 0.1 | 0.2 | 12.3 |
| *Diodia teres Walter* | Poorjoe | 2 | 0.3 | 15.0 | 0.2 | 9.0 | 2.3 |
| *Echinochloa crus-galli (L.) P. Beauv* | Barnyard grass | 6 | 0.7 | 11.7 | 0.2 | 3.2 | 4.3 |
| *Eclipta prostrata (L.) L.* | Eclipta | 4 | 0.2 | 5.0 | 0.0 | 0.1 | 1.8 |
| *Eleusine indica* (L.) Gaertn. | Goosegrass | 34 | 9.5 | 27.8 | 0.5 | 1.5 | 28.2 |
| *Gamochaeta purpurea* (L.) Cabrera | Purple cudweed | 9 | 3.2 | 37.5 | 2.1 | 25.0 | 19.6 |
| *Hygrophila* spp. | Smart swampweed | 2 | 0.3 | 15.0 | 0.0 | 0.4 | 1.2 |
| *Ipomoea purpurea (L.) Roth* | Common morningglory | 2 | 0.1 | 5.0 | 0.0 | 0.1 | 0.9 |
| Mollugo verticillata L. | Carpetweed | 4 | 1.0 | 22.5 | 0.0 | 0.4 | 2.8 |
| Oenothera laciniata Hill | Cutleaf evening primrose | 15 | 6.9 | 46.4 | 2.7 | 17.9 | 30.1 |
| *Portulaca oleracea* L. | Common purslane | 28 | 5.0 | 18.1 | 0.1 | 0.4 | 17.7 |
| Raphanus raphanistrum L. | Wild radish | 4 | 0.2 | 5.0 | 0.0 | 0.1 | 1.8 |
| *Richardia scabra* L. | Florida pusley | 19 | 5.5 | 28.9 | 0.4 | 2.1 | 16.7 |
| Rumex crispus L. | Curly dock | 9 | 2.6 | 30.0 | 0.0 | 0.5 | 6.8 |
| *Solanum nigrum* L. | Black nightshade | 9 | 3.8 | 45.0 | 0.5 | 5.8 | 11.3 |

uniformity and density was relatively high, indicating that *C. rotundus* is widespread in tomato fields and is poorly managed where it occurs. This is somewhat surprising, given that growers have a range of effective management tools for this species, including glyphosate during fallow periods; fumigants; a range of preemergence herbicides that are known to suppress *Cyperus* spp.; and the option to apply postemergence halosulfuron, which is highly effective (Yu et al. 2020). The prevalence of this species may be partially attributed to its perennial growth habit and ability to puncture the plastic mulch. Our results indicate the need for improved season-long management options. These should include more intensive fallow programs, given that previous research has shown that fallow management is more important than in-crop fumigant selection (Yu et al. 2021). Cover crops suppress *Cyperus*, but not as effectively as glyphosate, which suggests there is a need for more research to develop fallow programs that integrate herbicides with cover crops (Monday et al. 2015).

*Eleusine indica* had the second-highest relative abundance, with widespread occurrence and relatively high uniformity and density. Populations of this species are resistant to paraquat, which was widely used historically in row middles and for crop termination and may partially explain the prevalence of this species (McElroy et al 2021). This species is susceptible to preemergence and postemergence herbicides registered for use in tomatoes, but potential resistance to the limited number of registered herbicides for tomatoes is cause for concern, and growers should ensure they adopt resistance-management approaches (Boyd et al. 2022).

*Digitaria ischaemum* was widespread across the surveyed area, but densities and uniformity within fields were relatively low, suggesting it does not pose serious issues. *Portulaca oleracea* is also widespread, and although the field uniformity was low compared with some of the more problematic species, it had the third-highest relative abundance, which suggests it is still a management problem. Conversely, *M. lupulina*, *O. laciniata*, and *Galium* spp. were not widespread, but field uniformity tended to be high, and *M. lupulina* and *Galium* spp. occurred at some of the highest densities. This suggests that both species are difficult to control when they occur, and further research is needed to identify effective management options.

### *Transplant Holes*

Overall, fewer species occurred in the transplant holes compared with the row middle, and densities tended to be lower (Table 6). *Cyperus rotundus*, *O. laciniata*, and *E. indica* had the highest relative abundance in the transplant holes. *Cyperus rotundus* occurred in 60% of the fields and occurred at a much higher frequency than all other species. *Eleusine indica*, *P. oleracea*, *D. ischaemum*, and *R. scabra* occurred in 34%, 28%, 23%, and 19% of the fields surveyed but tended not to occur at high densities (Table 6). *Cyperus rotundus*, *O. laciniata*, black nightshade (*Solanum nigrum* L.), and purple cudweed [*Gamochaeta purpurea* (L.) Cabrera; syn.: *Gnaphalium purpureum* L.] occurred in 48%, 46%, 45%, and 37% of the quadrats in surveyed fields where the species were present, suggesting current management approaches are ineffective within localized fields. *Gamochaeta purpurea*, *C. rotundus*, and *O. laciniata* occurred at the highest occurrence densities with 25, 18, and 18 weeds $m^{-2}$. As in the row middles, *C. rotundus* was one of the most widespread weeds in transplant holes that also occurred at high densities. There is a need to develop an overall management program for this species that encompasses row middles and bed tops. *Gamochaeta purpurea*, *O. laciniata*, and

https://doi.org/10.1017/wsc.2025.10038 Published online by Cambridge University Press

*S. nigrum* seemed to be a more prevalent problem in transplant holes than row middles, which suggests alternative management options are needed for these species.

Overall, our survey highlights the general effectiveness of weed management programs adopted by Florida tomato growers. This success is due in part to the diverse management practices that typically include herbicide programs during the fallow period, fumigation, plastic mulch, preemergence and postemergence herbicides, and hand removal in some situations. Research efforts moving forward should focus on developing management programs for; (1) species that occur at the highest relative abundance in row middles, including *C. rotundus*, *E. indica*, *P. oleracea*, *D. ischaemum*, and *E. crus-galli*; (2) species that occurred at the highest relative abundance in transplant holes, including *C. rotundus*, *O. laciniata*, and *E. indica*; and (3) species that had the highest densities where they occur, including *C. rotundus*, *E. indica*, *Galium* spp., *G. purpurea*, *M. lupulina*, *O. laciniata*, and *S. nigrum*. Increased reliance on herbicides in this crop also suggests the need for the development and promotion of integrated weed management programs that slow the development of herbicide resistance.

**Acknowledgments.** The authors would like to thank the members of the Weed Science team at the Gulf Coast Research and Education Center for their assistance with the project and the commercial tomato farms that granted access to their fields for data collection.

**Funding statement.** This research received no specific grant from any funding agency or the commercial or not-for-profit sectors.

**Competing interests.** The authors declare no conflicts of interest.

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