Purple Nutsedge Management in Florida Strawberry with Herbicides and a Modified Florida 3-Way Fumigation Program

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SUMMARY. The “Florida 3-way” consists of chloropicrin 35% + 1,3-dichloropropene 65% followed by minicoulters application of metam potassium. We evaluated the efficacy of a modified version of the Florida 3-way in which chloropicrin 35% + 1,3-dichloropropene 65% was used as primary bed fumigant and consisted of different drip tape application timings (at the time of bed formation and 2 weeks after bed formation) of metam potassium or the use of herbicides (sulfentrazone and s-ethyl dipropylthiocarbamate) as the supplemental application for the control of purple nutsedge (*Cyperus rotundus*) in strawberry (*Fragaria × ananassa*) fields. Efficacy of modified Florida 3-way was not significantly different from standard Florida 3-way; however, supplemental herbicide such as s-ethyl dipropylthiocarbamate and sulfentrazone provided better purple nutsedge control than supplemental metam potassium application in one of two experimental growing seasons. Addition of metam potassium to the chloropicrin 35% + 1,3-dichloropropene 65% did not result in additional purple nutsedge control in Florida 3-way, which indicates the limitations of this approach.

Strawberry (*Fragaria × ananassa*) is a high-value crop grown on 10,000 acres in Florida with a production value of \$282 million (U.S. Department of Agriculture, National Agricultural Statistics Service, 2018). Florida is the second largest strawberry producer in the United States after California. Methyl bromide (MB) was the most widely used fumigant in Florida strawberry production before it started to phase out in 2005 due to its ozone depletion potential. MB moved readily through the soil and provided excellent control of diseases, weeds, and nematodes (Duniway, 2007). None of the commercially fumigants available today

move as readily through the soil or control as broad a spectrum of pests.

Purple nutsedge (*Cyperus rotundus*) is widespread in more than 90 tropical and subtropical countries, affecting 52 crops worldwide (Bendixen and Nandihalli, 1987). It is a troublesome weed in Florida strawberry production as well (Boyd and MacRae, 2018). If left unchecked, purple nutsedge may induce crop losses of 90% in garlic (*Allium sativum*), 60% in okra (*Abelmoschus esculentus*), 60% in carrot (*Daucus carota*), 50% in tomato (*Solanum lycopersicum*), 40% in cucumber (*Cucumis sativus*), 40% in green bean (*Phaseolus vulgaris*), and 35% in cabbage (*Brassica oleracea* var. *capitata*). Purple nutsedge density up to 200 plants/m² is directly proportional to the shoot dry weight and fruit

yield loss in tomato and pepper (*Cap-sicum annuum*) (Morales-Payan et al., 1997; William and Warren, 1975). The ability of purple nutsedge to expand laterally, form persistent patches, and penetrate plastic mulch makes it the most troublesome weed to control in plasticulture production in the south-eastern United States (Webster, 2005).

The “Florida 3-way” consists of shank application of chloropicrin 35% + 1,3-dichloropropene 65% (Telone C-35; Corteva Agriscience, Wilmington, DE) or 60% chloropicrin + 40% 1,3-dichloropropene (Pic-Clor60; Tris-Est Ag Group, Tifton, US) followed by a minicoulters application of metam sodium (metam-Na) or metam potassium (metam-K) (Noling and Cody, 2012). This is the modified version of the “Georgia 3-way” in which 1,3-dichloropropene is placed 30 to 37 cm deep, and chloropicrin is applied 20 to 25 cm deep from the bed top followed by bed compression. Metam-K or metam-Na is applied immediately using a minicoulters or shanks at 10-cm depth, and beds are recompressed (Culpepper, 2007). These “3-way” approaches often provide similar levels of broad-spectrum pest control as MB, and the associated cost is significantly lower (MacRae, 2010).

The fumigation approach for purple nutsedge control in Florida is the combination of different fumigants such as 1,3-dichloropropene + chloropicrin; dimethyl disulphide (DMDS) + chloropicrin; and DMDS + metam-Na or metam-K (Boyd et al., 2017). Chloropicrin 35% + 1,3-dichloropropene 65% is the one of the widely used industry standard fumigants for strawberry growers in Florida. This fumigant targets nematodes and soil-borne diseases but does not have an herbicidal effect (Minuto et al., 2006). A supplemental application of metam-K using a minicoulters or

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.0731	fl oz/acre	L·ha ⁻¹	13.6840
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
6.8948	psi	kPa	0.1450

drip tape injection in addition to chloropicrin 35% + 1,3-dichloropropene 65% may improve purple nutsedge control (Santos and Gilreath, 2007). A minicoulter consists of multiple coulters spaced 10 cm apart in staggered rows and places the metam-K at 10 cm deep. Metam fumigants have limited horizontal movement and higher downward movement, particularly with the use of single drip tape in sandy soil (Ou et al., 2006). This is attributed to the low vapor pressure of metam-K, which determines the capacity of metam-K to move in the soil. Multiple injection points improve metam distribution across the bed top, and the shallow injection depth places it where most of the weed seeds and tubers occur (Dittmar et al., 2018). This technology enhances distribution across the bed top and does not require additional water for application. Metam-K is more typically applied via injections into the drip irrigation system which can result in poor distribution but does not require the purchase of new application technology, reduces worker exposure to the fumigant (Ajwa et al., 2002), and provides flexibility to the growers in terms of application timings.

There are limited herbicide options available for purple nutsedge control in strawberry. S-ethyl dipropylthiocarbamate (EPTC) applied at 2.91 kg·ha⁻¹ can provide up to 74% control of purple nutsedge (Reed et al., 2016), whereas sulfentrazone applied pre- or postemergence provides >75% purple nutsedge control at 0.11 to 0.28 kg·ha⁻¹ (Grichar et al., 2003). These herbicides could be a component of an integrated weed management program, replacing supplemental metam-K. Replacement of metam-K with herbicides would lower input costs, and distribution is typically not an issue.

The major objectives of this project were to compare the effect of 1) supplemental metam-K application using a 14-disk minicoulter vs. drip tape injection, 2) different timings of supplemental metam-K application, and 3) different supplemental herbicides vs. metam-K applications for purple nutsedge control in strawberry fields.

Materials and methods

Field trials were conducted at the University of Florida Gulf Coast Research and Education Center

in Wimauma (lat. 27.76°N, long. 82.23°W) during the 2016–17, 2017–18, and 2018–19 strawberry production seasons. The soil type at the experimental site is a Myakka fine sand (Siliceous Hypothermic Oxyaquic Alorthod) slightly acidic (pH 6.5–6.8), and low in organic matter (0.9% to 1.2%).

Field preparation included disc cultivation and leveling, followed by bed formation using a bed press. Bed dimensions were 4-ft center-to-center spacing, 28 inches wide at the top, and 12 inches tall. The plot length was 50-ft linear bed length. All plots were treated with chloropicrin 35% + 1,3-dichloropropene 65% as a primary bed fumigant at 300 lb/acre using a two-shank fumigation rig at 8-inch depth in the bed. Primary bed fumigant was the fumigant used at the time of bed formation. Chloropicrin 35% + 1,3-dichloropropene 65% was used to suppress the soilborne pathogen and nematodes with the limited control of purple nutsedge (Minuto et al., 2006). The bed formation and primary fumigation occurred on 10, 20, and 17 Sept. for the 2016–17, 2017–18, and 2018–19 production seasons, respectively.

The field was subdivided into four blocks based on the anticipated soil moisture level during the production season. Treatments were then arbitrarily assigned to each block. In 2016–17, 60 gal/acre metam-K [potassium N-methyldithiocarbamate 54% (K-PAM HL; AMVAC Chemical Corp., Newport Beach, CA)] was applied 1) using a minicoulter at the time of bed formation, 2) through the drip tape within 24 h after bed formation and plastic application, and 3) through the drip tape 2 weeks after bed formation (WAB). In the 2017–18 and 2018–19 production season, two additional herbicide treatments were added including 4) 4 fl oz/acre sulfentrazone [sulfentrazone 40% (Spartan 4F; FMC Corp., Philadelphia, PA)] and 5) 32 fl oz/acre EPTC [S-ethyl dipropylthiocarbamate 88% (Eptam 7E; Gowan Co., Yuma, AZ) over the bed top using carbon dioxide pressurized backpack sprayer immediately before laying plastic. The backpack sprayer was calibrated to deliver 0.78 L·min⁻¹ and was equipped with a single flat-fan nozzle (8002VS; Teejet Spraying Systems

Co., Glendale Heights, IL) at 35 psi. Beds were covered with virtually impermeable film (Blockade; Berry Plastics, Evansville, IN) with a single drip tape (Chapin drip tape-BTF; Jain Irrigation, Haines City, FL) buried 1 inch deep at the center of the bed. All experiments included a control that was only fumigated with chloropicrin 35% + 1,3-dichloropropene 65% at the time of bed formation that was expected to kill soilborne pathogens and nematodes but not the purple nutsedge. Soil moisture content at the time of treatment application ranged from 15% to 20% water by volume.

‘Florida Radiance’ strawberry transplants were planted in the middle 15-ft area of 50-ft-long plot. The plants were placed in two rows per bed with 14 inches between rows and plant-to-plant spacing of 16 inches at 3 to 4 WAB. Planting occurred on 5, 18, and 15 Oct. for the 2016–17, 2017–18, 2018–19 strawberry seasons, respectively. Purple nutsedge shoots that penetrated the plastic mulch were counted in the transplanted area 5, 10, and 20 WAB using a 0.3 × 0.3-m quadrat. Marketable fruit was harvested two times per week starting from late December to mid-February.

The PROC GLIMMIX procedure was used to determine the effect of treatments on purple nutsedge population density and strawberry yield in SAS (version 9.2; SAS Institute, Cary, NC). Block was treated as a random effect and the treatment as a fixed effect. Repeated-measure analysis was used for the purple nutsedge population density and fruit yield, which were collected at multiple times. Purple nutsedge population density data were transformed using the lognormal distribution function in the model statement; however, means presented in Table 1 are the back-transformed means. Tukey’s procedure was used to separate means whenever appropriate.

Results and discussion

The treatment by date interaction for purple nutsedge was not significant in 2015–16 ($P = 0.99$) and 2016–17 ($P = 0.56$) but was significant in 2017–18 ($P = 0.01$). Therefore, purple nutsedge population densities are presented separately

Table 1. Effect of different supplemental metam potassium (metam-K) fumigation application techniques and herbicides in purple nutsedge population density in the strawberry field trials conducted at Wimauma, FL, in 2016–17, 2017–18, and 2018–19 production seasons.

Treatment ^z	Purple nutsedge density (plants/m ²) ^y									Strawberry yield (kg·ha ⁻¹) ^y		
	2016–17			2017–18			2018–19					
	5	10	20	5	10	20	5	10	20			
	WAB	WAB	WAB	WAB	WAB	WAB	WAB	WAB	WAB			
(35% pic + 65% 1,3-D) (NTC)	1	5	147	1	117	108	19	70	121 a ^x	18,164	16,255	9,547
(35% pic + 65% 1,3-D) + metam-K with minicoulter	3	6	163	3	109	133	6	74	92 a	18,610	16,012	8,486
(35% pic + 65% 1,3-D) + metam-K (drip)	1	6	137	1	87	122	14	21	28 b	16,284	16396	9,517
(35% pic + 65% 1,3-D) + metam-K (drip)	0	3	131	1	51	90	2	69	118 a	17,846	17,713	10,188
(35% pic + 65% 1,3-D) + sulfentrazone	NA	NA	NA	2	67	77	15	38	52 b	NA	17,038	9,672
(35% pic + 65% 1,3-D) + EPTC	NA	NA	NA	0	98	63	8	13	23 b	NA	18,250	12,993
F value	3.52	0.99	0.09	1.10	0.26	0.40	0.85	2.18	5.35	0.3	0.4	0.26
P value	0.06	0.44	0.96	0.40	0.90	0.84	0.50	0.11	0.005	0.83	0.84	0.93

^zpic = chloropicrin; 1,3-D = 1,3-dichloropropene; NTC = nontreated control; EPTC = S-ethyl dipropylthiocarbamate. metam-K at 60 gal/acre (561.2 L·ha⁻¹) was applied by the drip-tape injection method at the time of bed formation, after 2 WAB. Herbicides sulfentrazone at 4 oz/acre (0.28 kg·ha⁻¹) and EPTC at 32 oz/acre (2.24 kg·ha⁻¹) were sprayed on the bed top after primary bed fumigation immediately before laying the plastic mulch. Herbicide treatments were not included in 2016–17 strawberry production season.

^y1 plant/m² = 0.0929 plant/ft², 1 kg·ha⁻¹ = 0.8922 lb/acre.

^xMeans within a column followed by the same letter are not significantly different according to Tukey's test at $P < 0.05$.

WAB = weeks after bed formation; NA = not applicable.

for each weed assessment date for all years. Supplemental fumigants and herbicides did not affect ($P > 0.05$) purple nutsedge population density in any of the three production seasons compared with the control except at the final weed assessment at 20 WAB ($P = 0.005$) in the 2018–19 production season. Supplemental herbicide applications had the lowest purple nutsedge population density (<80/m²) at 20 WAB in 2017–18, but the difference was not significant (Table 1).

In 2018–19, herbicides EPTC and sulfentrazone consistently had a significantly lower number of purple nutsedge than other treatments at 20 WAB (Table 1). This indicates that preemergence herbicides in conjunction with fumigants may be a more effective option than the Florida 3-way. Previous research found similar trends. For example, incorporation of herbicides such as pebulate, S-metolachlor, and napropamide in addition to chloropicrin 17% + 1,3-dichloropropene 83% (Telone C-17, Corteva Agriscience) showed significant purple nutsedge control in a field trial (Gilreath et al., 2004) compared with

chloropicrin 17% + 1,3-dichloropropene 83% alone. In our study, supplemental metam-K was beneficial in only one of three production seasons. We are uncertain why seasons varied because all three seasons were comparatively similar in terms of soil moisture, rainfall, and temperature. The results are similar to those of Boyd et al. (2017) where supplemental metam-K did not provide additional benefit in terms of purple nutsedge control and tomato yield when 1,3-dichloropropene + chloropicrin was used as the primary bed fumigant. Furthermore, sequential application of metam fumigant and chloropicrin 35% + 1,3-dichloropropene 65% did not result in a synergistic effect for weed control or higher berry yield in California strawberry fields (Fennimore et al., 2003; Trout and Ajwa, 1999).

Lack of efficacy of our supplemental treatments observed in these experiments may be due to the prolific reproductive capacity of purple nutsedge and high nutsedge density (>100/m²) in the experimental sites. Additionally, one tuber can produce

up to 36 plants and 332 tubers over 16 weeks and is capable of forming 6-m-diameter patch containing 19,000 plants and 7000 tubers within 1 year (Anderson 1999). In this context, nontreated regions in the soil bed could result in inconsistent control and high purple nutsedge population densities over time.

Metam application timing had no effect on control levels achieved. It was hypothesized that delaying injections for 1 week would give the tubers the opportunity to sprout. Reed et al. (2016) reported that herbicides such as EPTC and fomesafen are more effective against purple nutsedge when they are applied at the tuber sprout stage. There was no significant difference between supplemental metam-K at the time of bed formation and after 2 weeks of bed formation in their effect on purple nutsedge control; however, tubers were not extracted to observe if they had sprouted at the time of application.

Effectiveness of treatments on purple nutsedge control in the experiment were based on the aboveground

number of purple nutsedge shoots piercing through the plastic mulch; however, these numbers are affected by not only fumigation treatments but also the natural underground nutsedge tuber population existing in the experimental plot. The underground tuber population was not determined, which may be different across the experimental plots. This is one limitation when weed control is determined based on natural weed population, which was addressed by selecting the experimental sites with a history of a homogenous weed population.

None of the treatments affected ($P > 0.05$) total strawberry yield in any of the three production seasons. There was no apparent adverse effect on strawberry growth and no visual strawberry injury (data not shown).

The supplemental applications of metam-K at 390 kg·ha⁻¹ after chloropicrin 35% + 1,3-dichloropropene 65% did not improve purple nutsedge control compared with chloropicrin 35% + 1,3-dichloropropene 65% alone. Herbicides were also ineffective in 2 of 3 years with rates of control for sulfentrazone and EPTC at 51% and 80%, respectively, in 2018 and 2019. We conclude that the Florida 3-way and modifications of this management system did not effectively control purple nutsedge or improve strawberry yield.

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