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High temperatures and durations of exposure reduce nutsedge (*Cyperus* spp.) tuber viability

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Soil solarization has been proposed as an alternative to methyl bromide for controlling nutsedges. Little is known, however, about the relationship between soil solarization and nutsedge tuber viability. Combinations of elevated temperatures and durations of exposure were evaluated for their effect on purple nutsedge and yellow nutsedge tuber viability and new tuber production in growth chamber studies. Estimates of the duration of exposure at each temperature that reduced nutsedge growth parameters 50% (TT_{50}) were supplied by log-logistic regression analysis. Nutsedge tuber viability was reduced when temperatures were ≥ 45 C. Relative to purple nutsedge, yellow nutsedge tuber viability had smaller TT_{50} values for 45, 50, and 55 C. Tuber viability TT_{50} at 60 C was similar for both nutsedges. The TT_{50} for production of new purple nutsedge tubers at 50 C was larger than that for yellow nutsedge. However, there were no differences between species in TT_{50} values for new tuber production at higher temperatures. With sufficient durations of exposure, both purple and yellow nutsedge tubers were killed at temperatures ≥ 50 C. However, application of these data to field situations in Georgia may be limited using present technology because the soil temperature cannot be raised to high enough levels for acceptable solarization effects.

Nomenclature: Purple nutsedge, *Cyperus rotundus* L. CYPRO; yellow nutsedge, *Cyperus esculentus* L. CYPES.

Key words: Methyl bromide alternative, purple nutsedge, solarization, yellow nutsedge.

The Georgia vegetable industry encompasses 17 crops grown on approximately 80,000 ha and is currently valued at $631 million per year (Doherty et al. 2002). The foundation for management of multiple pests, including weeds, in many of these crops has been methyl bromide. However, this fumigant is suspected to contribute to ozone depletion, and its use is scheduled to cease in 2005 (USDA-ARS 1999). Once methyl bromide use is eliminated, there is a concern that nutsedges will be unmanageable in crops requiring fumigation because there are few alternatives to methyl bromide (Harrison and Fery 1998). Nutsedges are among the most troublesome weeds of vegetable crops in the southern United States and in the world (Holm et al. 1977; Webster 2002; Webster and MacDonald 2001). In crop production systems, purple and yellow nutsedge rely on tubers as the primary means of reproduction (Horowitz 1992; Lapham and Drennan 1990; Smith and Fick 1937). Purple nutsedge tuber production is initiated early in the growing season, approximately 6 to 8 wk after foliar emergence (Hauser 1962a). This correlates with flower initiation (Hauser 1962a). Five successive generations of purple nutsedge can occur within a growing season (Horowitz 1972). Over a growing season, approximately 100 purple nutsedge tubers and 6,900 yellow nutsedge tubers were produced from one initial tuber (Hauser 1962b; Rao 1968; Tumbleson and Kommedahl 1961). Successful management of purple and yellow nutsedge must eliminate tuber viability or inhibit new shoot and tuber production (Horowitz et al. 1983; Patterson 1998).

Treatments that use elevated temperature (e.g., solarization, steam, and electromagnetic radiation) have been proposed as alternatives to methyl bromide for management of various pests (Chellemi et al. 1993; Elmore 1991; Kumar et al. 1993; Mavrogianopoulos et al. 2000; Stapleton 2000). Exposure to 65 C for 30 min will eliminate many economically important soil-borne plant pathogenic fungi, nematodes, insects, and weeds (Pullman et al. 1981). Death of organisms is dependent on temperature and duration of exposure, also known as thermal time (Katan 1981). However, few studies have evaluated the relationship between lower temperatures and the duration required for effective pest control (Pullman et al. 1981; Stapleton 2000).

The use of polyethylene mulch to heat the soil to temperatures lethal to pests has been studied in the past and has had variable success for a wide range of pests. Two weeks of solarization, in which the average maximum temperature did not exceed 49.5 C at a depth of 5 cm, suppressed emergence of common purslane (*Portulaca oleracea* L.), henbit (*Lamium amplexicaule* L.), and field bindweed (*Convolvulus arvensis* L.) greater than 88% at 8 mo after treatment (Horowitz et al. 1983). A 1-wk midsummer solarization in Mississippi using polyethylene mulch reduced seed viability of several weed species 53 to 95% (Egley 1983). Temperatures under the plastic mulch at a soil depth of 1.3 cm (depth at which seeds were planted) exceeded 60 C for 4 h during mid-afternoon. However, purple nutsedge suppression was variable, and in some instances, solarization treatment stimulated purple nutsedge emergence (Egley 1983). Elevated temperatures due to solarization were shown to increase the number of sprouting purple nutsedge tubers by 23% (Miles et al. 2002).

Although solarization has reportedly reduced nutsedge

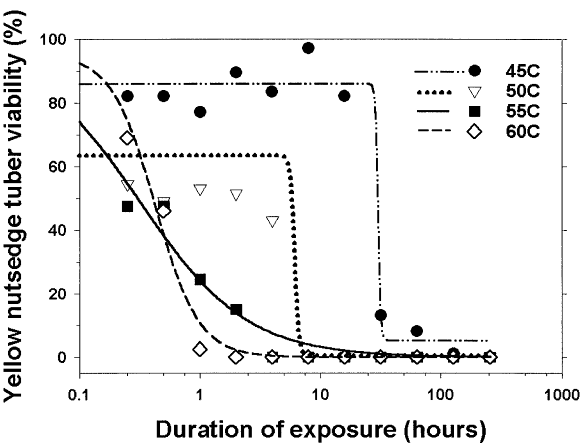

Figure 1. The effect of duration of exposure to elevated temperatures on yellow nutsedge tuber viability. See Table 1 for regression parameter estimates, standard error, and R^2 for each temperature regime.

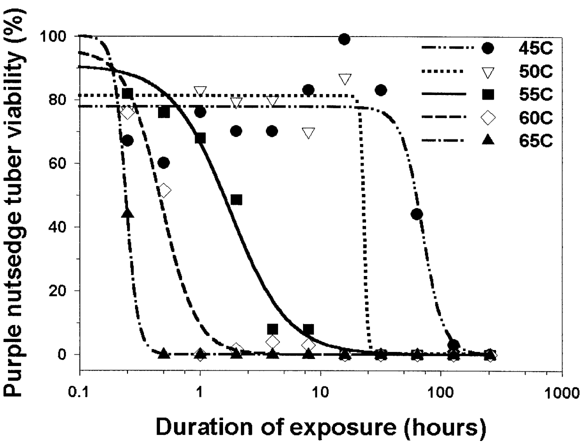

Figure 2. The effect of duration of exposure to elevated temperatures on purple nutsedge tuber viability. See Table 1 for regression parameter estimates, standard error, and R^2 for each temperature regime.

populations (Chellemi et al. 1997; Hejazi et al. 1980; Ricci et al. 2000) and the effect of temperature on tuber mortality has been investigated (Chase et al. 1999b; Rubin and Benjamin 1984), little is known about the relationship between temperature and duration of exposure, and nutsedge tuber viability and new tuber production. The objectives of this study were to determine this relationship.

Materials and Methods

Tubers of purple and yellow nutsedge were presprouted in potting media to ensure viability. Tubers were trimmed of roots and shoots and placed in disposable petri dishes[1] between two moistened filter papers,[2] and the dish was sealed with laboratory film.[3] An experimental unit consisted of one petri dish with 25 tubers. Yellow nutsedge tubers used had an average weight of 6.4 g and a diameter of 0.9 cm. Purple nutsedge tubers had an average weight of 14.3 g, and the egg-shaped tubers had an average diameter of 0.8 cm and length of 1.2 cm.

Purple nutsedge tubers were placed in a heating chamber[4] set at constant temperatures (± 1 C) ranging from 35 to 65 C in 5 C increments, whereas temperatures for yellow nutsedge treatments ranged from 35 to 60 C in 5 C increments. Experimental units were exposed to each temperature for durations of 0, 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64, 128, and 256 h on a log scale (with a multiplier of 2). After treatment, tubers were planted in 15-cm-diam pots filled with a mixture of vermiculite and sphagnum peat moss (35:65) and watered as needed for 28 d. At the conclusion of the study, wire mesh (2.8 holes cm^{-2}) stretched across a wooden frame was used to separate the tubers from the potting media. Viability of treated tubers was evaluated 28 d after treatment. Viable tubers were characterized by having at least one emerged shoot; those without shoots exhibited visible signs of decay. Production of new tubers by the treated parent tubers during the 28-d growth period was quantified.

Data were analyzed using analysis of variance; lack of a significant treatment by trial interaction indicated that data could be combined over trials of the study. Data were then analyzed using log-logistic regression (Seefeldt et al. 1995). The relationship between dependent variables (i.e., tuber viability and new tuber production) and duration of exposure at each temperature was fit to the log-logistic model:

$$y = C + \left[\frac{D - C}{1 + \left(\frac{x}{TT_{50}}\right)^{b}}\right] \qquad [1]$$

where C = the mean response at the highest time interval, D = the mean response of the nontreated control, TT_{50} = duration (in h) of exposure providing 50% response, and b = slope of the line at TT_{50} (Seefeldt et al. 1995). This type of analysis is common when describing the effect of herbicide dose on plant growth; however, it also is well suited to evaluate the effect of the treatments in the current study. Differences among TT_{50} parameter estimates were evaluated using a t test:

$$t = \frac{TT_{50\text{A}} - TT_{50\text{B}}}{\sqrt{\text{SE}_{\text{EstimateA}})^2 + (\text{SE}_{\text{EstimateB}})^2}} \qquad [2]$$

where the numerator is the difference in TT_{50} values, and the denominator is the standard error of the difference of the TT_{50} values (Glantz and Slinker 2001).

Results and Discussion

Tuber Viability

Viability of nutsedge tubers was reduced when exposed to treatments of 45 C and greater (Figures 1 and 2). The relationship between tuber viability and duration of exposure for each of the temperatures was described by a log-logistic regression for yellow nutsedge (R^2 = 0.58 to 0.89) and purple nutsedge (R^2 = 0.77 to 0.90). Yellow nutsedge tuber viability was more sensitive to thermal time than was purple nutsedge viablility. Yellow nutsedge tuber viability was reduced by 50% (TT_{50}) when exposed to 45, 50, and 55 C for 30, 6, and 0.3 h, respectively (Table 1). Purple nutsedge exposed to 45, 50, and 55 C had relatively higher TT_{50} values (as indicated by t test) of 71, 23, and 1.8 h, respectively. The I_{50} for tuber viability at 60 C was similar (0.4 to 0.5 h) for both nutsedges. There were no detectable relationships between yellow and purple nutsedge tuber vi-

TABLE 1. Parameter estimates, with standard errors in parentheses, of the log-logistic regression from Figure 1 describing the influence of elevated temperatures and duration of exposure on purple nutsedge and yellow nutsedge tuber viability.

Species	Temperature	*C*	*D*	TT_{50}	*b*	R^2
	C			h		
Purple nutsedge	45	0.1 (5.2)	77.8 (1.8)	71.2 (6.00)[a]	5.0 (1.6)	0.77
	50	0.4 (2.9)	81.3 (1.8)	23.2 (1.50)[a]	30.8 (5.4)	0.87
	55	0.0 (3.3)	90.8 (3.9)	1.8 (0.20)[a]	1.8 (0.3)	0.87
	60	0.0 (2.0)	95.7 (4.2)	0.5 (0.03)	3.0 (0.5)	0.90
	65	0.0 (2.2)	100.0 (5.5)	0.2 (0.03)	0.5 (2.1)	0.82
Yellow nutsedge	45	5.3 (2.7)	85.9 (1.6)	30.4 (9.40)[a]	42.7 (21.3)	0.89
	50	0.4 (4.1)	63.4 (4.3)	6.2 (1.10)[a]	25.7 (7.1)	0.58
	55	0.0 (4.1)	98.4 (8.5)	0.3 (0.10)[a]	1.0 (0.3)	0.72
	60	0.0 (3.1)	95.4 (9.1)	0.4 (0.10)	2.4 (0.6)	0.74
	65	—	—	—	—	—

[a] Estimate of TT_{50} for purple nutsedge is significantly different from estimate of TT_{50} for yellow nutsedge within a temperature level, as indicated by *t* test.

ability and duration of exposure at 35 and 40 C (data not shown).

The duration of exposure required to kill all the yellow nutsedge tubers was 16, 8, and 2 h for 50, 55, and 60 C (Figure 1). Previous research conducted in a growth chamber indicated that 100% yellow nutsedge mortality was achieved after 6 d under alternating temperatures of 60 and 40 C (each for 12 h) (Hejazi et al. 1980). Death of all purple nutsedge tubers occurred after 64, 16, 16, and 0.5 h exposure to 50, 55, 60, and 65 C, respectively (Figure 2). Previous research demonstrated that purple nutsedge tubers were killed when exposed to 50 C for 96 h, whereas exposure for 48 h at 50 C had no effect on tuber viability (Smith and Fick 1937). Tuber viability also was observed to be eliminated when purple nutsedge was exposed to ≥ 60 C for 1 h (Smith and Fick 1937). Purple nutsedge tuber mortality occurred after exposure to 90 C for 0.5 h, whereas exposure to 50 and 60 C for 0.5 h reduced tuber viability only 10 to 20%, respectively (Rubin and Benjamin 1984). In the current study, nutsedge tubers were pregerminated to ensure viability and minimize variability. However, this procedure also may have maximized tuber sensitivity to heat treatments relative to dormant tubers and could account for the differences among values reported in the literature and the current study.

Previous research demonstrated that upper temperature thresholds for nutsedge emergence were different under oscillating temperatures relative to constant temperatures (Miles et al. 1996). Oscillating temperatures of 45 and 26 C (day and night, respectively) slowed down and those of 50 and 26 C (day and night, respectively) prevented purple and yellow nutsedge emergence (Chase et al. 1999b), whereas in another study a constant temperature of 44 C prevented purple nutsedge emergence (Holt and Orcutt 1996). Constant temperatures were selected for the current study to establish the minimum requirements for a treatment in which the soil temperatures would be raised for a short period of time. Evaluating these relationships under alternating temperatures also would provide valuable information.

New Tuber Production

The relationship between new tuber production and duration of exposure of parent tubers to 50, 55, and 60 C was described by a log-logistic regression for yellow nutsedge (R^2 = 0.80 to 0.95) and purple nutsedge (R^2 = 0.73 to 0.85) (Figures 3 and 4). A longer duration of exposure (24 h) to 50 C was required to reduce the production of new purple nutsedge tubers by 50% relative to yellow nutsedge (5 h) (Table 2). However, there were no detectable differences in

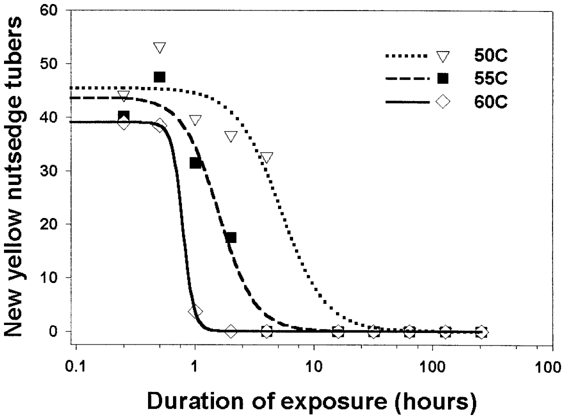

FIGURE 3. The relationship between duration of exposure to elevated temperatures and yellow nutsedge new tuber production. See Table 2 for regression parameter estimates, standard error, and R^2 for each temperature regime.

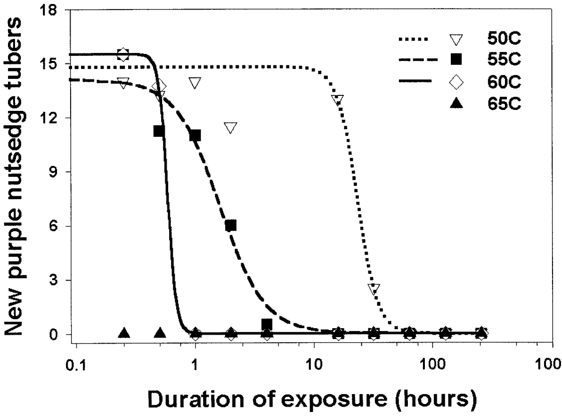

FIGURE 4. The relationship between duration of exposure to elevated temperatures and purple nutsedge new tuber production. See Table 2 for regression parameter estimates, standard error, and R^2 for each temperature regime.

TABLE 2. Parameter estimates, with standard errors in parentheses, of the log-logistic regression from Figure 2 describing the influence of elevated temperatures and duration of exposure on purple nutsedge and yellow nutsedge new tuber production.

Species	Temperature	C	D	TT_{50}	b	R^2
	C			h		
Purple nutsedge	50	0.0 (1.2)	14.8 (0.9)	23.5 (4.1)[a]	5.2 (2.5)	0.73
	55	0.0 (0.6)	14.1 (1.4)	1.6 (0.3)	2.3 (0.9)	0.80
	60	0.0 (0.5)	15.5 (1.3)	0.6 (0.4)	12.3 (38.0)	0.85
Yellow nutsedge	50	0.0 (2.9)	45.5 (3.4)	5.3 (1.4)[a]	2.3 (1.2)	0.80
	55	0.0 (1.8)	43.8 (3.6)	1.6 (0.2)	2.8 (1.0)	0.83
	60	0.0 (0.7)	39.0 (1.9)	0.8 (0.2)	9.5 (7.1)	0.95

[a] Estimate of TT_{50} for purple nutsedge is significantly different from estimate of TT_{50} for yellow nutsedge within a temperature level, as indicated by *t* test.

TT_{50} for new tuber production between species at higher temperatures (1.6 h at 55 C and 0.6 to 0.8 h at 60 C). Increases in duration of exposure at 35, 40, and 45 C did not affect yellow and purple nutsedge new tuber production (data not shown). Previous studies have not evaluated the effect of thermal time on new nutsedge tuber production.

Production of new tubers stopped after yellow nutsedge parent tubers were exposed to 50, 55, and 60 C for 16, 4, and 1 h, respectively (Figure 3). Exposure times required to eliminate yellow nutsedge tuber viability at 50 C were similar to those required to stop new tuber production. However, at higher temperatures new yellow nutsedge tuber production was stopped at durations that were half of those required to eliminate yellow nutsedge tuber viability. Durations of 64, 16, and 1 h halted production of new purple nutsedge tubers at 50, 55, and 60 C, respectively (Figure 4). The lowest tested duration of exposure (0.25 h) at 65 C halted production of new purple nutsedge tubers. Thermal times required to stop new purple nutsedge tuber production were similar to those needed to eliminate treated purple nutsedge tuber viability at 50 and 55 C. However, at 60 C new purple nutsedge tuber production was halted after 1 h of exposure, whereas 16 h were needed to eliminate purple nutsedge tuber viability. This is significant because nutsedges are prolific tuber producers.

Soil Temperatures

Average maximum bare-ground soil temperatures between 1991 and 2001 at Tifton, GA, were highest in July (Hoogenboom 2003). Temperatures ranged from 31.9 to 37.5 C at 5 cm, 29.0 to 34.3 C at 10 cm, and 28.0 to 31.3 C at 20 cm (Figure 5). Over this span, July 2001 had the highest average soil temperatures, with the highest daily maximum of 38.3, 32.8, and 28.9 C at 5, 10, and 20 cm, respectively (Figure 6). July 1998 had the lowest daily maximum soil temperatures over this span: 33.3, 29.8, and 28.8 C at 5, 10, and 20 cm, respectively (Figure 6). Maximum soil temperatures in June and August were 1.3 to 1.5 C, 1.0 to 1.6 C, and 0.6 to 1.6 C lower than those in July at 5, 10, and 20 cm, respectively (Figure 5). These bare-soil temperatures would not be adequate to reduce nutsedge tuber viability.

Black and clear polyethylene mulch raised soil temperatures (5- to 6-cm depths) 4 to 10 C and 10 to 11 C, respectively, relative to the bare-soil control in Louisiana and Florida (Chase et al. 1999b; Standifer et al. 1984). Soil temperatures were increased relative to nonmulched soil 10 to

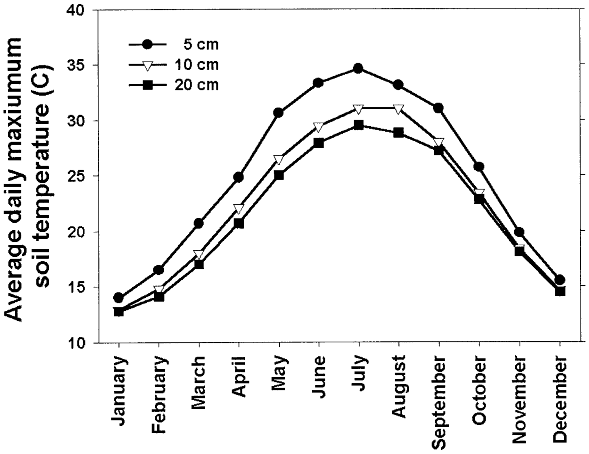

FIGURE 5. Average daily maximum soil temperatures from 1991 to 2001 at three depths in Tifton, GA (Hoogenboom 2003).

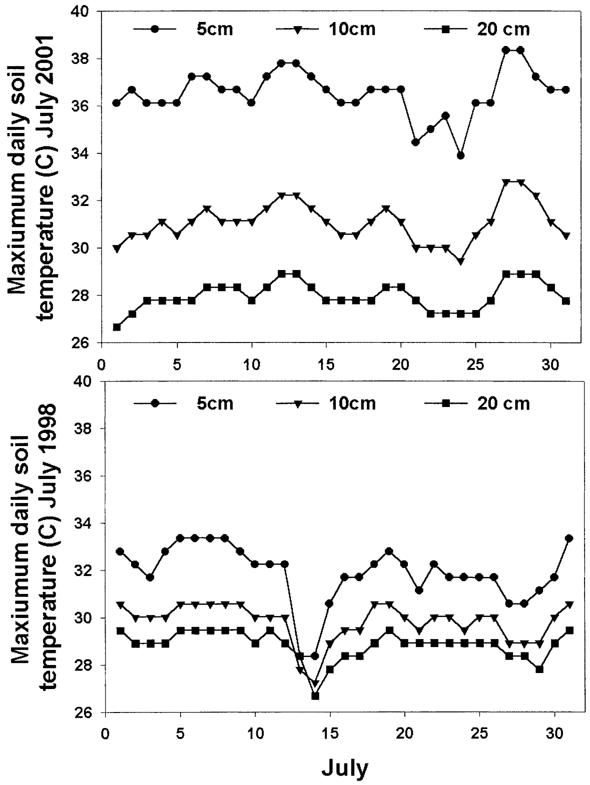

FIGURE 6. Maximum daily soil temperatures from July 1998 (coldest July between 1991 and 2001) and July 2001 (warmest July between 1991 and 2001) at three depths in Tifton, GA (Hoogenboom 2003).

14 C at 5 cm, 9 to 14 C at 10 cm, and 6 to 11 C at 20 cm in Israel using clear polyethylene (Rubin and Benjamin 1983). Solarization using clear polyethylene for 5 wk in Hawaii raised mean soil temperature at 15 cm by 5.8 C in spring and 7.2 C in summer relative to bare-soil plots (Miles et al. 2002). Applying these temperature increases under clear polyethylene mulch to the Tifton soil temperature data would raise the maximum temperature at 5, 10, and 20 cm to ≤ 53, ≤ 49, and ≤ 43 C, respectively. At these temperatures in plastic mulch solarization system, suppression of new tuber production might be possible because the I_{50} for new yellow nutsedge tuber production is 5 h at 50 C. Near the surface, these temperatures may begin to reduce nutsedge tuber viability and suppress production of new nutsedge tubers. However, although clear polyethylene raises soil temperatures, its use can be problematic in vegetable crop production. Light penetrates the clear polyethylene mulch, triggering the sharp-pointed sheath of leaves to unfurl and preventing nutsedge shoots from piercing the mulch (Chase et al. 1998). There is often enough light to support plant growth under clear mulch, resulting in the nutsedge plants lifting the mulch as they grow, potentially hindering crop production (Majek and Neary 1991).

Coupled with the difficulty in adequately increasing soil temperature, the distribution of nutsedge tubers in the soil profile poses a significant obstacle to the success of solarization in controlling nutsedge (Rubin and Benjamin 1983). Nutsedge tubers were distributed throughout the top 32 to 40 cm of the soil profile, with 99% of yellow and purple nutsedge tubers within the top 25 and 16 cm of the soil profile, respectively (Horowitz 1972; Siriwardana and Nishimoto 1987; Tumbleson and Kommedahl 1961). Purple nutsedge tubers planted at 5, 10, or 15 cm had a similar number of aboveground shoots after 6 wk of growth (Chase et al. 1999b). Because of the distribution of nutsedge tubers in the soil profile and their ability to emerge from deep in the soil profile, it would be difficult to adequately and evenly heat the soil profile to the necessary depths to eliminate nutsedge tuber viability. In addition, tubers that are not affected can quickly reinvade a treated area from adjacent nontreated row middles (Webster 2003).

Although there is a significant effect of heat and duration of exposure on nutsedge tuber viability, application of these data to field situations may be limited using present technology. Mulches with various optical properties exist that allow for greater efficiency in raising soil temperatures (Chase et al. 1999a; DeLuca et al. 1996; Ham et al. 1993; Mormile et al. 2001). However, it is not clear how effective these mulches would be in heating at least the top 16 cm of the soil profile for the prescribed thermal time interval. As the utility of an inundatory thermal time treatment appears limited, future research should evaluate the cumulative effect of diurnally fluctuating sublethal temperatures on nutsedge tuber viability and new tuber production.

Sources of Materials

[1] Extra-deep disposable polystyrene dishes (diameter, 10 cm; height, 2.5 cm), Fisher Scientific, 200 Park Lane, Pittsburgh, PA 15275.

[2] Whatman #3 filter paper, 9-cm diameter, Fisher Scientific, 200 Park Lane, Pittsburgh, PA 15275.

[3] Parafilm M Laboratory Wrapping Film, Fisher Scientific, 200 Park Lane, Pittsburgh, PA 15275.

[4] VWR Signature High Performance Horizontal Air Flow Oven, Model 1655-D, VWR International, 1310 Goshen Parkway, West Chester, PA 19380.

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