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Effects of Shoot Clipping–Soil Disturbance Frequency and Tuber Size on Aboveground and Belowground Growth of Purple and Yellow Nutsedge (*Cyperus rotundus* and *Cyperus esculentus*)

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Purple and yellow nutsedges are two of the world's worst weeds, reproducing asexually by rhizomes that can develop into new shoots or tubers. These tubers are the storage organs for carbohydrate reserves that are replenished by growing shoots and exhausted by new shoot, root plus rhizome, and basal bulb production. Based on the biology of both species, we hypothesized that the regenerative potential of purple and yellow nutsedge would decrease, with increasing shoot clipping–soil disturbance (SCSD) frequency and decreasing tuber size. To test this hypothesis, greenhouse experiments were conducted in pots to determine the effect of SCSD frequency and tuber size on aboveground and belowground growth of purple and yellow nutsedges. Five viable tubers of two tuber category sizes (small, 0.40 ± 0.05; and large, 0.80 ± 0.05 g of tuber fresh weight) were subjected to four SCSD frequencies (weekly, biweekly, monthly, and none) for 12 wk. SCSD was performed by clipping the emerged nutsedge shoots followed by manually disturbing the soil. SCSD at biweekly or weekly intervals reduced purple nutsedge proliferation, regardless of initial tuber size. However, monthly SCSD did not suppress purple nutsedge as effectively as weekly or biweekly SCSD, and less proliferation occurred with small tubers than with large tubers. In contrast, yellow nutsedge proliferation was equally reduced with monthly or more-frequent SCSD, regardless of initial tuber size. Even weekly soil disturbance for 12 wk failed to eradicate all small or large tubers in either species. Thus, yellow nutsedge is managed more easily than purple nutsedge with less-frequent tillage or cultivation. However, tillage or cultivation alone during a 12-wk period will not likely eradicate either nutsedge species from infested soil.

Nomenclature: Purple nutsedge, *Cyperus rotundus* L. CYPRO; yellow nutsedge, *Cyperus esculentus* L. CYPES.
Key words: Mechanical weed control, nutsedge biology, organic production system, regenerative potential.

Cyperus rotundus y *Cyperus esculentus* son dos de las peores malezas del mundo, las cuales se reproducen asexualmente por rizomas que pueden desarrollar nuevo tejido aéreo o tubérculos. Estos tubérculos son órganos de almacenaje de reservas de carbohidratos, los cuales son mantenidos por la parte aérea en crecimiento de la planta y son desgastados por la producción de nuevos puntos aéreos, raíces más rizomas y bulbos basales. Basados en la biología de ambas especies, nosotros planteamos la hipótesis de que el potencial regenerativo de *C. rotundus* y *C. esculentus* disminuiría, al incrementarse la frecuencia de poda del tejido aéreo y la perturbación del suelo (SCSD) y al disminuirse el tamaño de los tubérculos. Para evaluar esta hipótesis, se realizaron experimentos de invernadero en macetas para determinar el efecto de la frecuencia de SCSD y el tamaño del tubérculo sobre el crecimiento del tejido aéreo y subterráneo de *C. rotundus* y *C. esculentus*. Se sometió cinco tubérculos viables de dos categorías de tubérculo según el tamaño (pequeño, 0.40±0.05; y grandes, 0.80±0.05 g tubérculo fresco wt^{-1}) a cuatro frecuencias de SCSD (semanal, bisemanal, mensual y ninguna) durante 12 semanas. SCSD se realizó cortando las hojas de plantas emergidas de *C. rotundus* y *C. esculentus* e inmediatamente después perturbando el suelo manualmente. SCSD realizado a intervalos semanales o bisemanales redujo la proliferación de *C. rotundus* sin importar el tamaño del tubérculo. Sin embargo, SCSD mensual no fue tan efectivo como SCSD semanal o bisemanal, y menos proliferación ocurrió con tubérculos pequeños que con tubérculos grandes. En contraste, la proliferación de *C. esculentus* fue reducida de la misma forma con SCSD mensuales o a intervalos más frecuentes, sin importar el tamaño del tubérculo. La perturbación semanal del suelo durante 12 semanas no fue suficiente para erradicar todos los tubérculos pequeños o grandes en ninguna de estas especies. De esta forma, con labranza y cultivo menos frecuentes se puede manejar *C. esculentus* más fácilmente que *C. rotundus*. Sin embargo, la labranza y el cultivo solos durante un período de 12 semanas probablemente no erradicará ninguna de estas especies en suelos infestados.

Purple and yellow nutsedges are two perennial problematic weeds in many crops worldwide. Yield losses ranging from 30 to 89% caused by both nutsedge species in numerous crops have been well documented (Keeley and Thullen 1975; William and Warren 1975). The weediness of nutsedge species is mainly associated with their underground tubers (Bendixen and Nandihalli 1987; Stoller and Sweet 1987). These tubers are perennating organs, which store carbohydrates and facilitate asexual reproduction (Horowitz 1972; Smith 1972; Stoller and Weber 1975). A single parent tuber of purple nutsedge can produce 99 tubers in 12 wk (Rao 1968). Similarly, a single tuber of yellow nutsedge can produce more than 360 tubers within 16 wk (Webster 2005). Because tubers are vital to the success of nutsedge species,

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successful management strategies should concentrate on depleting existing tuber reserves and suppressing new tuber production (Stoller et al. 1972).

Tillage is one of the common and historical methods for weed management. Tillage helps to reduce the regenerative potential of perennial weed species (McWhorter and Hartwig 1965) and, therefore, is beneficial in nutsedge management. Tillage severs the connection of tubers from the aerial shoots, roots, and other tubers in chains (purple nutsedge only), bringing them close to the soil surface or burying them in deeper soil layers. As a result of tillage, nutsedge plants are subjected to (1) carbohydrate starvation because of loss of shoots; (2) nutrient and moisture starvation because of loss of roots; (3) desiccation of shoots, roots, and tubers when exposed to sun light; (4) injury from temperature extremes when exposed to an open environment on the soil surface; and (5) dormancy because of low diurnal thermal fluctuations at deeper soil layers (Glaze 1987; Miles et al. 1996; Smith and Mayton 1938, 1942; Stoller and Sweet 1987).

Most purple and yellow nutsedge tubers generally occur within the top 15 cm of the soil (Stoller and Sweet 1987; Siriwardana and Nishimoto 1987; Tumbleson and Kommedahl 1961). The shallow distribution of tubers in the soil makes them vulnerable to tillage operations. Nutsedge tubers can regrow after tillage but at the expense of carbohydrate reserves, resulting in decreased vigor with each successive regrowth (Stoller et al. 1972). Purple nutsedge shoot growth and tuber production were reduced by applying mechanical control measures at repeated intervals, and the subsequent regrowth was proportional to the frequency of the shoot removal (Horowitz 1972). In Georgia, weekly tillage during summer months reduced the yellow nutsedge tuber population by $> 70\%$ (Johnson et al. 2007). Thus, frequent, shallow tillage should be practiced to minimize the nutsedge infestation.

Although tillage can be performed by many types of equipment, the effectiveness depends on the implement used. For example, primary tillage implements, such as a moldboard plow, inverts soil, which can uproot the growing weeds or bury them deep but does not break the connection of shoots, roots, and rhizomes to tubers. Buried shoots that remain intact to tubers with roots and rhizomes can reemerge after tillage. Therefore, a tillage operation that can provide severing of shoots, roots, and rhizomes from tubers will be more effective in controlling purple and yellow nutsedges. High-speed rotary tillers can perform this action and, therefore, can be a valuable tool for mechanical control of nutsedge species.

Previous studies have described the effect of tillage on tuber dynamics; however, information about the relationship of tuber size and tillage frequency and tuber viability and shoot growth is meager. Frequent shoot removal in the absence of soil disturbance can lead to rapid depletion of small tubers from soil (Santos et al. 1997); however, this study simulated mowing rather than tillage. If purple and yellow nutsedge competitiveness is related to tuber size (Stoller and Wax 1973; Stoller et al. 1972), it would be advantageous to understand the effect of tillage frequency on tuber dynamics in soil. The objective of this research was to determine the effect of SCSD frequency on aboveground and belowground growth parameters of infestations initiated by either small or large tubers of purple and yellow nutsedge.

Materials and Methods

An experiment was conducted in 2005 and repeated in 2006 at Clemson, SC. Purple nutsedge tubers were collected from the Cherry Research Farm at Clemson, and yellow nutsedge tubers were purchased (Azlin Seed Company, Leland, MS 38756). After removing the roots and rhizomes from purple nutsedge tubers, both purple and yellow nutsedge tubers were submerged in water for 12 h for homogenous imbibition to avoid any moisture effect on weight. Tubers were classified into two size categories based on fresh weight per tuber: small (0.40 ± 0.5 g) and large (0.80 ± 0.5 g). Tubers were allowed to sprout for 3 d at 28 to 30 C in trays filled with moist sand, covered with wet paper towels. Sprouted tubers of each nutsedge species with uniform shoot length were selected by tuber size for planting. Simultaneously, the nonsprouted tubers were also selected for planting. The nonsprouted tubers were included in the experiment to simulate field conditions in that not all tubers in the field are in a sprouted condition. The viability of nonsprouted tubers was confirmed by their firmness and white flesh inside, which was judged by examining a small incision on the tubers.

For each nutsedge species, experiments were organized in a randomized complete-block design with a 4 by 2 factorial arrangement of treatments, replicated four times. The treatment factors consisted of four SCSD frequencies (weekly, biweekly, monthly, and none) and two tuber sizes (small, 0.40 ± 0.05; and large, 0.80 ± 0.05 g). Because tubers were allowed to sprout for 3 d, the first weekly shoot clipping and soil disturbance was performed 4 d after tuber planting in pots. Soil used for the experiment was a Congaree silt loam soil (fine-loamy, mixed active, nonacid, thermic Oxyaquic Udifluvents) with 1.5% organic matter and a pH of 6.1. Soil was filled up to 15-cm height in the pot. Five viable tubers (three sprouted and two nonsprouted) of each size category were placed in premoistened soil to a 5-cm depth in a 3.8-L, 15.5-cm-diam, 20-cm-deep, plastic pot. The plants were grown in a greenhouse under controlled environment with 30/24 C day/night temperatures and 16/8 h light and darkness periods, simulating day and night condition. Both species were fertilized with a complete fertilizer (Peters Professional Water Soluble Fertilizer, 20-10-20 [N–P–K], The Scotts Miracle-Gro Company, Marysville, OH 43041) and irrigated with an overhead sprinkler three times a week. All weeds, except purple and yellow nutsedge, were removed from the pots by hand.

Purple and yellow nutsedge shoots were clipped at the soil surface, and bagged before each soil disturbance. Shoot clipping was performed before any soil disturbance to simulate the effect of soil tillage using a high-speed rototiller under field conditions. A high-speed rototiller can perform soil disturbance and severing of shoots, roots, or rhizomes from tubers at same time. The harvested shoots were oven-dried at 60 C for 7 d, and biomass was totaled for the 12-wk period to express the shoot biomass per pot. The soil disturbance operation in the each pot was performed by removing the soil from the pot and manually mixing it in a separate plastic pan. Disturbed soil was transferred back into the pot without loss of tubers. At termination of the experiment after 12 wk, the belowground tubers, roots, and rhizomes were collectively harvested by rinsing the soil through a 2-mm sieve. After cleaning the belowground biomass, tubers were separated from the roots and rhizomes and tested for viability by checking their firmness and the flesh color after cutting the tuber. A firm tuber with > 10% of white flesh inside was considered viable. Roots plus rhizomes were oven-dried and weighed for biomass quantification.

Data were analyzed separately for each nutsedge species. Data for each growth parameter were subjected to ANOVA. SCSD frequency and initial tuber size were treated as fixed effects, and experimental run and replications within runs were random effects. In addition, orthogonal, polynomial, trend contrasts were used to test whether increases in SCSD frequency had a linear, quadratic, or cubic response for each growth parameter and whether those responses were different between small and large size tubers. Contrast coefficients were determined based on the unequal spacing of the SCSD levels using PROC IML in SAS (SAS 9.1 statistical software, SAS Institute Inc., Cary, NC 27513). All statistical analyses were performed at the 5% level of significance using SAS.

Results and Discussion

Purple Nutsedge. Trend contrast indicated that shoot biomass and tuber production from small and large purple nutsedge tubers decreased quadratically with increasing SCSD frequency (Table 1). Based on ANOVA, shoot biomass and tuber numbers were influenced by the interaction of tuber size and SCSD frequency. Based on the Fisher's Protected LSD tests, maximum shoot biomass was produced in the undisturbed condition (without SCSD), regardless of tuber size. Compared with the undisturbed condition, monthly SCSD reduced shoot biomass from large tubers by 58% (11.1 g pot^{-1}), but that was 1.9 times greater than that produced by small tubers in monthly SCSD. Shoot biomass production during the 12-wk period was lowest ($\leq$ 1.8 g pot^{-1}) with weekly and biweekly SCSD, regardless of tuber size.

Purple nutsedge tuber production from small and large tubers decreased in a quadratic manner with increasing SCSD frequency (Table 1). Tuber production was similar within each SCSD frequency, except for monthly disturbance where the initial large-sized tubers produced more tubers than did initial small-sized tubers. Similar to shoot biomass, tuber production by purple nutsedge was greatest in the absence of SCSD, with no effect of initial tuber size. When allowed to grow undisturbed for 12 wk, the initially planted five tubers

Table 1. Purple and yellow nutsedge aboveground and belowground growth at 12 wk after transplanting as influenced by frequency of shoot clipping and soil disturbance (SCSD) and initial tuber size (TS), averaged over two experimental runs.[a]

		Purple nutsedge			Yellow nutsedge		
TS[b]	SCSD[c]	Shoot biomass[d]	Tuber number[e]	Root + rhizome biomass[f]	Shoot biomass[d]	Tuber number[e]	Root + rhizome biomass[f,g]
		g pot^{-1}	no. pot^{-1}	g pot^{-1}	g pot^{-1}	no. pot^{-1}	g pot^{-1}
Large	1	0.5 d	4.3 c	< 0.1 d	0.5 d	0.1 c	< 0.1
	2	1.8 d	3.5 c	0.1 d	2.2 d	0.1 c	< 0.1
	4	11.1 b	44.5 b	1.3 c	8.7 c	0.5 c	< 0.1
	None	27.6 a	110.6 a	7.5 a	53.5 a	92.3 a	15.8
Small	1	0.4 d	2.6 c	< 0.1 d	0.3 d	0.1 c	< 0.1
	2	1.0 d	3.0 c	< 0.1 d	1.2 d	0.9 c	< 0.1
	4	5.9 c	14.0 c	0.3 cd	7.3 c	0.4 c	< 0.1
	None	25.3 a	102.6 a	4.9 b	39.4 b	59.6 b	12.0
ANOVA[h]		P-value					
TS		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SCSD		0.0022	0.0031	0.0138	< 0.0001	< 0.0004	0.1408
TS × SCSD		0.0372	0.0066	0.0454	< 0.0001	< 0.0001	0.0945
Trend contrast[i]		P-value					
Linear SCSD		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Quadratic SCSD		0.2219	0.5913	0.0507	< 0.0001	< 0.0001	< 0.0001
Cubic SCSD		0.0291	0.0386	0.7125	0.3244	0.4514	0.6793
		P-value					
TS × Linear SCSD		0.3540	0.6257	0.0055	< 0.0001	< 0.0001	0.0153
TS × quadratic SCSD		0.0081	0.0018	0.7552	0.1243	0.1035	0.5223
TS × cubic SCSD		0.4175	0.1142	0.7616	0.6897	0.9907	0.9553

[a] Means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.
[b] Size of tubers initially planted: large, 0.80 ± 0.05 g; small, 0.40 ± 0.05 g.
[c] Shoot clipping and soil disturbance frequency for 12 wk: 1, weekly; 2, biweekly; 4, monthly.
[d] Cumulative weight of sprouted shoots produced during the 12-wk period.
[e] Total number of viable tubers harvested at the end of the 12-wk period.
[f] Dry wt of total roots plus rhizomes harvested at the end of the 12-wk period.
[g] The large tuber-size mean was 3.95 g pot^{-1} vs. the small tuber-size mean of 3.01 g pot^{-1}, which represents a significant difference.
[h] A P value < 0.05 indicates statistical significance at the 5% level.
[i] Trend contrasts were used to test whether increase in SCSD frequency had any linear, quadratic, or cubic response for each growth parameter.

produced 106.6 tubers pot^{-1}, averaged over tuber size. Monthly SCSD reduced the tuber production from large and small tubers by 58 and 87%, respectively, compared with no SCSD. Tuber production further decreased by $\geq$ 96% following weekly and biweekly SCSD, regardless of tuber size.

Root plus rhizome biomass production from purple nutsedge tubers decreased linearly with increasing SCSD frequency (Table 1). Based on ANOVA, root plus rhizome biomass was influenced by the interaction of tuber size and SCSD frequency (Table 1). Without SCSD, large tubers produced 7.5 g pot^{-1} root plus rhizome biomass in 12 wk, which was 1.5 times greater than that produced by small tubers (4.9 g pot^{-1}). However, in disturbed soil (monthly, biweekly, and weekly SCSD), root plus rhizome biomass was reduced to $\leq$ 1.3 g pot^{-1} with no effect for tuber size.

Initial tuber size did not significantly affect shoot biomass and tuber production of purple nutsedge in the absence of SCSD for 12 wk. A plausible reason for this is that, when allowed to grow without disturbance for 12 wk, small purple nutsedge tubers replenish their carbohydrate reserves continuously from the growing photosynthetic shoots, thereby maintaining shoot biomass production similar to large tubers over time. At monthly SCSD, the difference between large and small tubers could be due to two possible causes. First, it could be attributed to higher carbohydrate reserves or more sprouting buds in large, compared with small, tubers, which could result in a difference in shoot biomass before any SCSD at the 4 wk interval. Second, a 4-wk period may not be enough to replenish the carbohydrate reserves in small tubers to produce shoot biomass equivalent to large tubers after 12 wk. Similarly, Bangarwa et al. (2008) reported that tillage at 3-wk intervals was more detrimental on small than it was on large purple nutsedge tubers. Hence, monthly disturbance was less effective on large tubers than it was on small purple nutsedge tubers. However, weekly and biweekly disturbances were equally effective at reducing shoot biomass and tuber density of purple nutsedge, regardless of tuber size.

Yellow Nutsedge. Trend contrast indicated that shoot biomass, tuber production, and root plus rhizome biomass of small and large yellow nutsedge tubers decreased linearly with increasing SCSD frequency (Table 1). Based on ANOVA, shoot biomass and tuber numbers were influenced by the interaction of tuber size and SCSD frequency (Table 1). A maximum shoot biomass of 53.5 g pot^{-1} was produced by large tubers in the absence of SCSD during the 12-wk period, which was followed by small tubers (39.4 g pot^{-1}) under no SCSD. Monthly SCSD reduced shoot biomass production from large tubers to 8.7 g pot^{-1}, which was similar to that produced by small tubers (7.3 g pot^{-1}) under monthly SCSD. Increasing SCSD frequency to biweekly and weekly intervals further reduced shoot biomass production to $\leq$ 2.2 g pot^{-1} for both small and large tubers.

The initial large yellow nutsedge tubers produced the most tubers (92.3 tubers pot^{-1}) during the 12-wk period without any SCSD, which was 1.6-times greater than that produced by small tubers under the same conditions (Table 1). However, SCSD at monthly or lesser time intervals sharply reduced the tuber density to $\leq$ 0.4 tuber pot^{-1}, regardless of initial tuber size. Similarly, in a field experiment, no difference was observed in tuber production by yellow nutsedge when subjected to either weekly or monthly tillage regimes (Johnson et al. 2007). Root plus rhizome biomass production by yellow nutsedge tubers followed the similar trend as followed by tuber production (Table 1).

Large tubers produced higher shoot biomass compared with small tubers in the absence of disturbance, which could be associated with greater carbohydrate reserves and more sprouting buds on large tubers than on small tubers (Santos et al. 1997; Stoller and Wax 1973; Stoller et al. 1972). Higher shoot biomass could have resulted in faster replenishment of carbohydrates in parent tubers followed by reproduction of new tubers. As a result, tuber production was greater in large than in small tubers over the 12-wk period in the absence of disturbance. Taylorson (1967) also reported that carbohydrate reserves in yellow nutsedge tubers increased with increased shoot growth rate. However, once any SCSD occurred, either monthly or more frequently, shoot biomass or tuber production after 12 wk was not different in either tuber size. New tuber production in yellow nutsedge generally starts 8 wk after sprouting (Tumbleson and Kommedahl 1961); hence, a 4-wk period is not sufficient to produce new tubers. Therefore, reduction in carbohydrate-replenishing shoot regrowth and lack of new tuber production resulted in no difference in tuber and root plus rhizome production from either tuber size with any disturbance. These results indicate yellow nutsedge tubers are equally sensitive to soil disturbance, whether weekly, biweekly, or monthly, regardless of tuber size. The high sensitivity of yellow nutsedge to a tillage event could be explained by the fact that more than 60% of carbohydrate reserves of the tubers are exhausted after the first tillage event, and subsequent growth occurs on the expense of the remaining carbohydrate reserves in the tubers (Stoller et al. 1972).

Based on the present experiment, it is concluded that purple nutsedge infestation from small tubers can be managed by monthly SCSD. The SCSD technique used in this experiment can simulate a high-speed rototiller in a field situation. In a previous experiment, the site at Clemson, SC, was naturally infested with 88% small (< 0.50 g) and 12% large (> 0.50 g) purple nutsedge tubers (Bangarwa et al. 2008). Therefore, the purple nutsedge population under these situations can be managed by monthly rototillage operations, albeit the frequency of rototillage should be increased to biweekly intervals to manage purple nutsedge infestations from large tubers. In contrast, yellow nutsedge tubers are equally sensitive to monthly, biweekly, or weekly tillage events. Therefore, yellow nutsedge is comparatively easier to manage than purple nutsedge by timely designed rototillage operations. Although effective, tubers of either size of either species were not eradicated even under weekly SCSD regimes for 12 wks. Hence, an effective program would most likely involve integrating tillage with other control measures to manage nutsedge populations long term.

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