Influence of water regimes and herbicides for control of purple nutsedge (*Cyperus rotundus*)

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Abstract: Background: Purple nutsedge is a weed that has a tough profuse underground tuber system, and is predominantly a perennial species in many crops.

Objective: To evaluate the influence of different water regimes to the effectiveness of herbicides used for controlling the purple nutsedge.

Methods: Experiment was arranged in a Randomized complete block design (RCBD) with a two-factor factorial design and three replications. The net-house tests were conducted with six treatments and two different water regimes of “watered daily” and “watered weekly”. The tested herbicides were florypyrauxifen-benzyl, halosulfuron-methyl, 2,4-D and glyphosate.

Results: Water shortage reduced the weed control efficacy of four tested herbicides. Herbicide efficacy improved when plants were watered daily, the high level of sedge biomass reduction at 60 DAT observed in florypyrauxifen-benzyl (30 g ai ha⁻¹) and halosulfuron-methyl (50 g a.i ha⁻¹) treatment. Glyphosate (480 g ai.ha⁻¹) and 2,4-D (360 g ai.ha⁻¹) exhibited moderate control efficacy on purple nutsedge under daily watered condition.

Conclusions: The water regime was a critical component of purple nutsedge herbicide control program. Maintaining soil moisture by watering daily improved the herbicide efficiency and reliability for the management of purple nutsedge.

Keywords: Herbicide; Purple nutsedge; *Cyperus rotundus*; Water shortage stress; Weed management

Journal Information:

ISSN - 2675-9462

Website: <http://awsjournal.org>

Journal of the Brazilian Weed Science Society

How to cite:

Le D, Morell M.
Influence of water regimes and herbicides for control of purple nutsedge (*Cyperus rotundus*).
Adv Weed Sci. 2021;39:e20210085.
<https://doi.org/10.51694/AdvWeedSci/2021.000015>

Approved by:

Editor in Chief:
Carlos Eduardo Schaedler
Associate Editor:
Silvia Fogliatto

Conflict of interest: The authors declare no conflict of interest regarding the publication of this manuscript.

Received: January 13, 2021

Accepted: September 13, 2021

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1. Introduction

Purple nutsedge is one of the most competitive sedge species in many cropping systems of tropical agriculture. The weed is able to grow tough underground tubers within a few months, and one solo tuber can generate 750 new tubers under optimum condition after 24 weeks (Webster, 2005). Controlling purple nutsedge is a difficult and costly treatment because the herbicides kill only the above ground parts and leave the underground tubers undamaged. (Peerzada, 2017). Different methods have been studied to control purple nutsedge, including chemical herbicide and non-chemical options. Mulching with black polyethylene is an effective solution for controlling purple nutsedge (Webster, 2005). However, purple nutsedge may penetrate plastic mulch and reduce the efficacy of this management method (Boyd, Dittmar, 2018). Allelopathy could be considered as another method for controlling the purple nutsedge. Powder from *Eruca sativa* and *Brassica rapa* seed have demonstrated selective bioherbicide control of purple nutsedge in maize (Messiha et al., 2013). Crop-weed competition may suppress the purple nutsedge population in rice production. A rice seeding rate of 120 kg ha⁻¹ reduced tuber numbers by 48% and tuber biomass of purple nutsedge by 65% compared to a lower rice density of 60 kg ha⁻¹ (Chauhan, Opeña, 2012).

One critical task in purple nutsedge management is prevention of tuber accumulation in soil. Das et al. (2014) found the density of nutsedge at 200 shoots per m² reduced soybean yield significantly. The study result suggested nutsedge economic threshold in soybean was 19–22 shoots per m². Chemical herbicide is an effective solution to manage purple nutsedge. Many studies have been done to understand the effect of soil moisture on herbicide effectiveness. In general, drought stress reduces herbicide performance (Green, Obien, 1969; Chase, Appleby, 1979; Ahmadi et al., 1980). Halosulfuron-methyl is a common post-emergence herbicide for controlling purple nutsedge in sugarcane. When applied at 67.5 g a.i ha⁻¹ at 3–4 leaf stage of weed (45 days after planting), halosulfuron-methyl controlled 97.8% of purple nutsedge, and one application of halosulfuron-methyl controlled sedge more effectively than hand weeding 3 times in same season. (Chand et al., 2014). 2,4-D was one of the first herbicides used for controlling purple nutsedge in tropical crops since 1946 (Van Overbeek, Velez, 1946). However, the herbicide only killed the foliage and the tubers grew new shoots within 3 to 4 weeks (Loustalot et al., 1954, cited in Pereira, 1987) 2,4-D was a popular herbicide for controlling broadleaf weeds and sedges in India. However, Chand et al. (2014) found 2,4-D was not effective against purple nutsedge after being used continuously in sugarcane fields. Florypyrauxifen-benzyl is an arylpicolinate herbicide developed by Dow Agrosciences (Epp et al., 2016). The product

is registered for controlling grass and broadleaf in rice field at several countries around the world. The florpyrauxifen-benzyl is also effective in sedge weeds of different upland crops. The purpose of this study was to evaluate the efficacy of florpyrauxifen-benzyl versus commercial standards (halosulfuron-methyl, 2,4 D and glyphosate) on purple nutsedge under different water regimes.

2. Materials and methods

Purple nutsedge tubers were collected from a non-agriculture area in Tien Giang province, Mekong Delta of Vietnam. The experiments were conducted in net-house conditions and repeated during the summer 2018 at Corteva Agriscience research farm, Mekong Delta of Vietnam. The average temperature in the net-house was 29 °C (night time) to 37 °C (day time) during the experimental period. Plastic pots (40 by 40 by 30 cm) were used for planting the nutsedge tubers. The silty clay loam soil with a pH of 6.7 was collected from the same area where tubers were sampled. The soil was ground and mixed with chicken manure pellet at a ratio 9.0 kg soil and 0.5 kg manure. Tubers were washed and soaked in water for one hour to promote the tuber sprout growth before sowing. The tubers were watered daily until 18 to 23 days after sowing. Two viable tubers with an active shoot were transplanted into each pot. The average fresh weight was 3.9 g per tuber before transplanting. At 60 days after treatment, the tubers were collected and watered daily to assess their likely viability within two weeks. Tubers that could grow shoot were counted as alive tuber after herbicide treatment. Other weed species in pots were removed manually as soon as the unwanted seedlings appeared.

The experiment was performed as a RCBD (Randomized complete block design) with a two-factor factorial treatment design, three replications with two pots per replication, each pot contained two growing plants. The factor one was herbicides, with florpyrauxifen-benzyl at 15 g a.i ha⁻¹ and 30 g a.i ha⁻¹, halosulfuron-methyl at 50 g a.i ha⁻¹, 2,4-D at 360 g a.i ha⁻¹, and glyphosate at 460 g a.i ha⁻¹. Herbicides were applied at 2-4 leaf stage by a pressure sprayer (5 L) with a flat fan nozzle, the pressure was calibrated at 270 kPa during spray. The factor two was the water regimes (watered daily and watered weekly). During nursery stage, all pots received 250 ml water through drip irrigation daily until 30 days after sowing (DAS). After herbicide treatment, the pots were separated in two groups, group one was watered 250 ml per pot daily, and group two was watered 250 ml per pot once per week. The automatic watering timer was setup at 6:00 to 6:05 AM and 18:00 to 18:05 PM to minimize the evaporation by the sun heat.

Viable shoots were counted at 30 DAS or 0 Day after treatment (DAT) then again at 7, 30 and 60 DAT. Tuber population and tuber biomass per pot and average weight per tuber was assessed at 60 DAT (120 DAS). Soil moisture was measured by Extech Soil moisture meter MO750 at 0, 7, 30 and 60 DAT.

Data were verified for normality prior to analysis. The ANOVA test exhibited no interactions between treatments and two trial runs; Therefore, non-transformed data of two years were merged (a total of six replications) and subjected to Two-way ANOVA using the SPSS 20. Experiment was arranged in a RCBD with a two-factor factorial design and three replications. The experiments were conducted with six herbicide treatments as the first factor and two different water regimes of “watered daily” and “watered weekly” as the second factor. The interaction between water regimes and herbicides to plant growth parameters were analyzed by a linear regression model. Treatment means were compared with Tukey’s adjusted comparison at 0.05 significant level.

3. Results and discussion

3.1 Herbicide treatment and water regime affect the viable shoots of purple nutsedge

The two water regimes affected the number of purple nutsedge viable shoots in the experiment. At 0 DAT to 30 DAT, the sedge plants grew faster in the daily watered treatments compared to the watered-weekly plants (Table 1). By day 120th after transplanting, the daily watered plants grew an average of 33 shoots per pot, while the shoot density was 15.83 per pot in the weekly watered treatment.

In most cases, drought stress decreased the herbicide efficacy by reducing herbicide absorption and translocation (Rocha-Pereira et al., 2012; Miller, Norsworthy, 2018; Weller et al., 2019). Water regimes affected the activity of herbicides against purple nutsedge growth in this experiment. Regardless of different herbicide modes of action, the herbicide effectiveness significantly decreased

Table 1 – Influence of herbicide treatments under two different water regimes on purple nutsedge shoots at 0 to 60 days after treatment averaged over years.

Water regime	Herbicide treatment	Rate (g a.i ha ⁻¹)	Number of viable shoots (shoot per pot) after herbicide treatment at			
			0 DAT (day 30)	7 DAT (day 37)	30 DAT (day 60)	60 DAT (day 120)
Daily	Florpyrauxifen	15	1.83	1.83 abc	3.7 bc	12.33 bcd
Daily	Florpyrauxifen	30	1.5	0.17 d	0.5 c	1.67 e
Daily	Halosulfuron	50	1.67	0.67 bcd	0.83 c	3.5 de
Daily	Glyphosate	480	1.67	0.33 cd	2.83 bc	9 cde
Daily	2,4-D	360	1.5	0.5 cd	1.5 c	6.5 cde
Daily	Watered daily	N/A	2	2.5 a	13.5 a	33 a
Weekly	Florpyrauxifen	15	1.83	2.17 ab	6.83 b	19.5 b
Weekly	Florpyrauxifen	30	2.17	1.67 abcd	4.67 bc	11.33 bcde
Weekly	Halosulfuron	50	1.67	1.83 abc	3.17 bc	11.83 bcd
Weekly	Glyphosate	480	1.67	1.33 abcd	4.83 bc	12 bcd
Weekly	2,4-D	360	1.67	1.5 abcd	4.5 bc	11.83 bcd
Weekly	Watered weekly	N/A	1.67	1.67 abcd	6.33 b	15.83 bc
	p value		0.362	0.02	<0.001	<0.001

Means within columns followed by different letters are significantly different b in accordance with Tukey test at p<0.05.

*Daily: pot was watered 250 ml daily; weekly: pot was watered 250 ml once a week.

under less water supply condition. Purple nutsedge shoot regrew 30 DAT and shoot density at 30 DAT was similar when comparing herbicide treatments to the untreated control under a water regime. Florpyrauxifen-benzyl at 15 g a.i ha⁻¹ was not effective on purple nutsedge, the treatment suppressed the weed density at 7 DAA. However, the shoot count increased under both water regimes at 30 DAT. Florpyrauxifen-benzyl at 30 g a.i ha⁻¹ reduced weed density compared to florpyrauxifen-benzyl 15 g a.i ha⁻¹. At 60 DAT, purple nutsedge density was 1.67 shoots per pot in florpyrauxifen-benzyl 30 g a.i ha⁻¹ treatment watered daily. The drought stress reduced florpyrauxifen-benzyl efficacy in purple nutsedge, the average shoot was 11.33 shoots per pot at 60 DAT when plant was watered weekly. Daily watered treatments combined with florpyrauxifen-benzyl at the maximum rate resulted in the control of the shoots' majority 60 DAT.

Halosulfuron-methyl at 50 g a.i ha⁻¹ suppressed the nutsedge density under daily watered condition at 7 DAT to 30 DAT, plant density was < 0.83 viable shoots per pot. However, the plant density recovered to 3.5 shoots per pot at 60 DAT. Glyphosate at 480 g a.i ha⁻¹ reduced the weed growth regardless of water conditions at 7 DAT. However, the weed control efficacy of glyphosate was lower than the other tested herbicides at 60 DAT; sedge population in glyphosate treatment was 27.27% compared to the plant count in the untreated check. Similar to glyphosate, 2,4-D was effective against the nutsedge at 7 DAT and the efficacy lasted until 30 DAT. However, sedge recovered at 60 DAT; weed density of glyphosate and 2,4-D treatments was 9.0 and 6.5 plants per pot, respectively, by end of the experiment.

3.2 Herbicide treatment and water regime (soil moisture) effect on viable tuber number and tuber biomass at 60 DAT

Daily watering maintained a high soil moisture condition up to 60 DAT. Soil moisture ranged from 15.5% to 24.0% in daily watered treatments and 6.0% to 8.5% in pots watered weekly (Table 2). Water shortage impacted quantity and biomass of the purple nutsedge tuber. Plants daily irrigated produced 53.7 tubers compared to 45.3 tubers of the plants that received less water, however, the difference was statistically insignificant between two treatments; the daily watered tuber biomass was heavier than under drought stress. In this experiment, nutsedge plants consumed a significant amount of water from the soil. The soil moisture in the daily-watered untreated check was lower than the moisture in the herbicide-treated pots. The high density of 53.7 tubers and 33 shoots in the untreated pots was responsible for the difference in soil moisture.

Similar to the efficacy reduction in shoot control, the water regime influenced the herbicide effectiveness in nutsedge tuber biomass and quantity. Two months after application, the viable tubers found in florpyrauxifen-benzyl active at 30 g a.i ha⁻¹ treatment was 2.83 tubers per pot under good water supply. On the other hand, the tuber

population was 8.3 folds higher in the florpyrauxifen-benzyl treatment that received less water supply (Table 2). The result agrees with Miller and Norsworthy (2018), who reported the soil moisture correlated to the absorption, translocation, and weed control efficacy of florpyrauxifen-benzyl in *Cyperus esculentus*, *Echinochloa* spp. and *Sesbania herbacea*.

In the daily watered treatments of florpyrauxifen-benzyl at 30 g a.i ha⁻¹, most of shoots were controlled at 60 DAT. The herbicide also reduced viable tubers by 95% and the escape was low at 2.8 tubers per pot. However, the surviving tubers regrew new shoots after sowing back into soil. The re-infestation was more severe after glyphosate and 2,4-D application, in which the viable tubers were 18.3 and 13.3 shoots per pot, respectively. Halosulfuron-methyl reduced the tuber viability and tuber biomass by end of the experiment. Total tuber biomass in halosulfuron-methyl pot was 7.4 g and tubers average weight was 1.1 g per tuber. These results were similar to florpyrauxifen-benzyl at 30 g a.i ha⁻¹. The results of halosulfuron-methyl efficacy agree with Webster and Grey (2014). Halosulfuron not only kills the aerial plant part but also reduces the tuber viability of purple nutsedge.

The water and nutrient competition between the surviving plants did not impact the tuber quality. Herbicide effectiveness was a main factor affecting tuber biomass under different water regimes. When the weeds were well-watered, florpyrauxifen-benzyl and halosulfuron-methyl reduced the average tuber biomass at 2 months after application. On the other hand, the tuber biomass resulted from florpyrauxifen-benzyl at the minimum rate, glyphosate and 2,4-D treatments equals to the untreated control tuber biomass.

Table 2 – Influence of herbicides under two different water regimes on purple nutsedge tuber growth at 60 days after treatment averaged over years.

*Water regime	Herbicide treatment	Rate (g a.i ha ⁻¹)	Soil moisture at 60 DAT (%)	Viable tuber (60 DAT)	Tuber biomass at 60 DAT (g pot ⁻¹)	Tuber average weight at 60 DAT (g tuber ⁻¹)
Daily	Florpyrauxifen	15	20.7 ab	25.3 bc	51.8 b	2.18 a
Daily	Florpyrauxifen	30	23.3 a	2.8 e	3.7 d	1.05 b
Daily	Halosulfuron	50	24.0 a	6.7 de	7.4 d	1.1 b
Daily	Glyphosate	480	18.0 bc	18.3 bcd	36.5 bc	2.15 a
Daily	2,4-D	360	21.2 ab	13.3 cde	24.2 c	1.9 ab
Daily	Watered daily	N/A	15.5 c	53.7 a	95.0 a	1.78 ab
Weekly	Florpyrauxifen	15	8.5 d	45.3 a	50.7 b	1.15 b
Weekly	Florpyrauxifen	30	7.2 d	23.7 bc	32.0 bc	1.43a b
Weekly	Halosulfuron	50	8.2 d	22.8 bc	28.1 bc	1.27 b
Weekly	Glyphosate	480	9.2 d	31.3 b	37.1 bc	1.22 b
Weekly	2,4-D	360	7.2 d	32.3 b	38.0 bc	1.23 b
Weekly	Watered weekly	N/A	6.0 d	45.3 a	52.0 b	1.18 b
	p value		<0.001	<0.001	<0.001	<0.001

Means within columns followed by different letters are significantly different b in accordance with Tukey test at p<0.05.

*Daily: pot was watered 250 ml daily; weekly: pot was watered 250 ml once a week.

The soil moisture affected the herbicide efficiency when the plants received water daily. The correlation of viable shoot and tuber biomass to soil moisture under herbicide effect were presented in Figure 1 and Figure 2. In contrast, because of poor herbicides effectiveness under low water supply (Table 1 and Table 2), there was no correlation between soil moisture and the viable shoot or tuber biomass when the plants were watered weekly. The herbicide performance was less reliable under water shortage stress. Regardless of herbicide control effect in the plant, the viable shoot correlate to tuber biomass per pot ($R^2 = 0.68$) of all treatments at 60 DAT (Figure 3).

The florpyrauxifen-benzyl is a non-persistent herbicide in aerobic soil, the DT_{50} of florpyrauxifen-benzyl in aerobic soil is 15 days (Canturk et al., 2019). The metabolites of

florpyrauxifen-benzyl are also immobile in the aerobic soil because the metabolites bind strongly into the soil particles (EFSA et al., 2018). Miller and Norsworthy (2018) discovered that in *C. esculentus* the absorption of $[^{14}C]$ florpyrauxifen-benzyl was mainly foliar and then the herbicide was translocated into the root, while the root absorption and the consequent translocation from root to shoots did not occur. Therefore, the herbicide controlled the weed through foliar absorption rather than via root uptake. Reduction of weed tuber is critical to purple nutsedge management. Florpyrauxifen-benzyl affected tuber biomass and tuber population of the nutsedge in this study. However, to understand the mechanism of florpyrauxifen-benzyl on *C. rotundus* tuber, the future research should evaluate the florpyrauxifen-benzyl translocation from the nutsedge foliar to the plant root system.

From this study, one application of florpyrauxifen-benzyl or halosulfuron-methyl were effective in controlling purple nutsedge within 2 months. However, the effectiveness of two herbicides were reduced by the dry soil condition and the regrowth is a risk. Therefore, an additional non-chemical control method would be required to extend the weed-free condition. In case of unavailability of non-chemical control methods, the integration of different herbicides and an accurate weed control plan could help in controlling *C. rotundus*. Two herbicide treatments within 25 days interval (Scursoni, Satorre, 2010), or the application program of pre-emergence and followed by post-emergence (Yu et al., 2020) were effective to control purple nutsedge in the field. Application timing or spacing between treatments was an important factor to improve the weed management program. Henry et al. (2012) found delaying the 2nd spray to 2 to 4 weeks after initial herbicide treatment increased the purple nutsedge control 31 to 40% compared to 1-week waiting interval. The delay allowed the plant to regrow new fresh foliage and increase the herbicide uptake. Therefore, reducing the nutsedge infestation at later timing.

Figure 1 - The relationship between the number of viable shoots per pot and the soil moisture (%) of five herbicide treatments under daily watered regime, 60 day after treatment.

Figure 2 - The relationship between the tuber biomass per pot (gram) and the soil moisture (%) of five herbicide treatments under daily-watered regime, 60 day after treatment.

Figure 3 - The relationship between the number of viable shoots per pot and the tuber biomass per pot of all twelve treatments, 60 day after treatment.

4. Conclusions

Florpyrauxifen-benzyl at 30 g a.i ha⁻¹ and halosulfuron-methyl at 50 g a.i ha⁻¹ effectively reduced viable shoots of purple nutsedge under daily watering conditions. Florpyrauxifen-benzyl was an effective herbicide for nutsedge tuber management, as the shoot and tuber control lasted two months under daily watering conditions.

The halosulfuron-methyl was also a useful option if the water supply was sufficient. Glyphosate at 480 g a.i ha⁻¹ and 2,4-D at 360 g a.i ha⁻¹ were moderately effective on purple nutsedge by the end of the experiment. However, the efficacy of the two herbicides was limited in purple nutsedge tubers. Regardless of the post emergence herbicide treatment, water shortage reduced herbicide effectiveness

and reliability in purple nutsedge management program. Watering daily after herbicide treatment improved the efficiency of florpyrauxifen-benzyl and commercial herbicides for the management of purple nutsedge.

Authors'contributions

DL: contributed to the research implementation and writing of the manuscript. MM: contributed to the experimental design and revision of the manuscript.

Acknowledgments

Funding for this study was provided by Corteva Agriscience.

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