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Spring Treatments of Diquat and Endothall for Curlyleaf Pondweed Control

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ABSTRACT

Spring treatments of the contact herbicides diquat and endothall were effective in reducing curlyleaf pondweed (*Potamogeton crispus* L.) shoot and root biomass, as well as suppressing turion production. An outdoor mesocosm study was conducted in the spring of 1999 in which plants were treated during three different periods using two rates of each product (either 1 or 2 mg ai L^{-1}). Water temperatures ranged from 16 to 23C during applications. All diquat applications reduced shoot biomass by 60% and root biomass by 60 to 90% compared to the untreated reference. Turion numbers decreased by 85%. All endothall applications reduced shoot and root biomass; however, early and mid-spring treatments provided better control than late spring treatments. Both the earlier endothall treatments reduced shoot and root biomass by 90% versus a 60% reduction in shoot and root biomass for the late spring endothall treatment. Consequently, turion numbers decreased significantly with the early and mid-spring endothall treatments (>90%), but not with the late spring endothall treatment. This study is further evidence that both diquat and endothall could be applied early in the growing season to reduce turion formation and provide for potential long-term control of curlyleaf pondweed.

Key words: Potamogeton crispus, herbicide, Aquathol® K, Reward®, chemical control.

INTRODUCTION

Curlyleaf pondweed (*Potamogeton crispus* L.) has become wide spread across the northern United States. Like other in-

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[3] Diquat applied as Reward®, Syngenta, Wilmington, DE and endothall applied as Aquathol® K, Cerexagri, Inc., King of Prussia, PA. Mention of a trade name is not intended to recommend use of one product over another.

vasive aquatic plants, curlyleaf pondweed produces axillary turions to survive. They break off the plant, float to another part of the lake or are deposited in the sediment, and sprout to generate new plant beds in the fall. Once formed, axillary turions are resistant to management techniques, which may make this plant more difficult to control than Eurasian watermilfoil (*Myriophyllum spicatum* L.; Bouldan et al. 1994).

Currently, herbicides are applied when curlyleaf pondweed becomes a nuisance in late spring or early summer after turions have formed. While these applications greatly reduce seasonal plant biomass, they have been ineffective at reducing turion numbers, and unsuccessful at long-term control. Long-term control could be achieved by applying herbicides in the springtime when water temperatures are cool to kill curlyleaf pondweed when plants are young, and prevent new turion formation. Moreover, early applications may improve the selective potential of broad-spectrum contact herbicides because fewer native plant species are actively growing in cooler water temperatures and, therefore, are less susceptible to herbicide treatments.

Contact herbicides, including diquat (6,7-dihydrodipyrido [1,2-a:2',1'-c] pyrazinediium dibromide) and endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid), applied as the dipotassium salt, are currently used to control curlyleaf pondweed in lakes. These herbicides are known to be less efficacious in cold water; however, in small-scale greenhouse studies, both diquat and endothall reduced shoot biomass and turion numbers with recommended application rates at water temperatures between 15 and 20C (Netherland et al. 2000). Although these plants were not killed, results from this study suggested that inhibition of turion production with even partial control of curlyleaf pondweed may be important to long-term plant management.

To further investigate the efficacy of herbicide treatments in cool water temperatures for control of curlyleaf pondweed, an outdoor mesocosm study was conducted in the spring of 1999. The objective was to determine if effective control was possible early in the plant's life cycle, and potentially reduce or eliminate subsequent turion formation. Results from this study would be helpful in making aquatic plant management decisions where curlyleaf pondweed is a nuisance.

MATERIALS AND METHODS

This study was conducted in late winter and spring of 1999 in an outdoor mesocosm system consisting of 21 tanks (1600 L in volume, 1-m deep with water depth = 50 cm) located at the US Army Engineer Research and Development Center, Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX (33°04'45'N, 96°57'33'W). Silty clay sediment was collected from a dried pond located at the LAERF, placed in plastic containers (8 L), and amended with 10 g ammonium sulfate (21-0-0) and one "Woodace" nutrient briquette (14-3-3). Three healthy apices (12 cm) of curlyleaf pondweed were planted in each container on 8 February 1999. Sixteen containers were then placed in each mesocosm, and plants were allowed to establish healthy growth four weeks before initial herbicide applications.

Diquat and endothall[3] were applied at different rates during the spring as water temperatures warmed (Table 1). Three tanks were used per application, including a reference which was used for comparing biomass and turion production in the absence of herbicide application. Herbicide applications occurred in March, April and May. In March, curlyleaf pondweed plants were still young (plant height = 12 cm) and target water temperatures were 15C. In April, plants were bigger (plant height = 25 cm) and target water temperatures reached 20C. In May, plants had reached the water surface (plant height = 50 cm) and target water temperatures were 25C. Water temperatures during each application period were monitored every hour for 72 hours.

Application rates were selected based on results from previous studies (Netherland et al. 2000, Skogerboe and Getsinger 2002). Because diquat acts quickly (Langeland and Warner 1986, Poovey and Getsinger 2002), treatments were applied using a static exposure of eight hours. Low rates of endothall require a longer contact time, therefore, a 24-hour dissipation half-life was simulated for the endothall treatments (Netherland et al. 1991). Half the water was drained from each treatment mesocosm and replaced with clean lake water 24 hours after treatment (HAT). This process was then repeated at 48 and 72 HAT.

Plant biomass, turion numbers, and visual ratings were used to evaluate herbicide effects. Biomass and turion data were collected 29 June 1999. Shoot and root biomass was harvested from three containers in each of the three treatment tanks. Shoots were harvested by clipping the plants at the sediment surface and roots were recovered by washing the sediment through a sieve. All biomass was oven dried at 70C for 48 h and weighed. Turion production was determined by dividing each treatment tank into quarters and counting the number of turions floating or lying on the bottom in each quarter.

TABLE 1. SPRING TREATMENTS OF DIQUAT AND ENDOTHALL IN AN OUTDOOR MESOCOSM STUDY FOR CURLYLEAF PONDWEED CONTROL.

Treatment	Application date	Application rate (mg ai L^{-1})	Target water temperature (C)	Plant height (cm)
Diquat	3 March 1999	2	15	12
	7 April 1999	1	20	25
	5 May 1999	1	25	50
Endothall	3 March 1999	2	15	12
	7 April 1999	1	20	25
	5 May 1999	1	25	50

Shoot biomass, root biomass and turion data were square root transformed to stabilize variance then subjected to a one-way analysis of variance (ANOVA) to compare temperature effects. If effects were significant, means were separated using the Student-Newman-Keuls (S-N-K) method at $p \leq 0.05$.

Visual ratings were conducted 1, 2, 3, 6, and 12 weeks after treatment (WAT). Ratings ranged from 1 to 5; 1 equaled no visible sign of living plant tissue above the sediment surface and 5 equaled healthy lush tissue as indicated by the untreated reference. The last treatment in May was not rated 12 WAT because plants had started senescence which prompted the end of the study.

RESULTS AND DISCUSSION

Water temperatures averaged 16C for the March treatments despite some fluctuation between day- and nighttime temperatures; the minimum water temperature was 11C while the maximum was 20C. Temperatures averaged 21C for the April treatments with a minimum temperature of 19C and a maximum temperature of 23C. Temperatures averaged 23C with a minimum temperature of 18C and a maximum of 27C for treatments conducted in May.

Visually, curlyleaf pondweed treated with diquat at 16C showed slight injury initially; however, plants were similar to the reference by 12 WAT (Figure 1). Although herbicide effects were more pronounced with the 21C than the 16C diquat treatments, plants showed signs of appreciable recovery by 6 WAT. Treatments conducted when water temperatures were 23C were most effective in sustaining plant injury. At 1 WAT, there was no shoot biomass observed from these treatments; by 2 and 3 WAT, however, some plant regrowth was noted with small shoots lying on the sediment surface. At the end of the study, these shoots were green and healthy when harvested, in contrast with plant shoots from the 16C and 21C treatments, which were decayed.

All diquat treatments at the end of the study were effective in reducing shoot and root biomass (Figure 2). Shoot biomass decreased by 60% compared to the reference, with no statistical differences between water temperatures. The 16C and 23C treatments were most effective in reducing biomass of roots and rhizomes. These treatments reduced biomass by more than 70% compared to the reference.

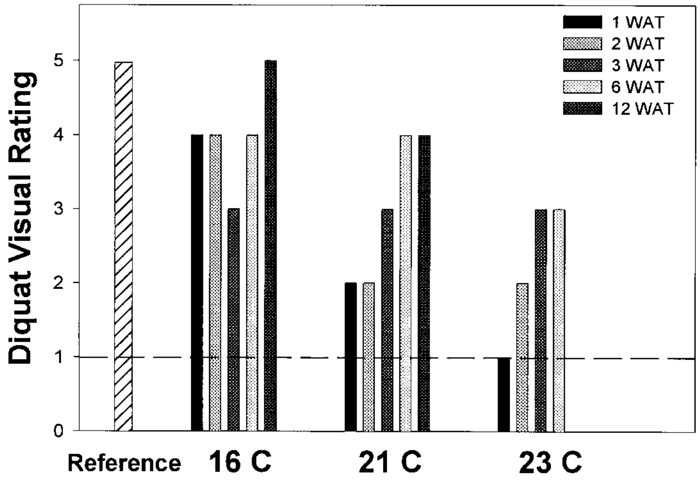

Figure 1. Visual ratings of curlyleaf pondweed after diquat applications in cool water temperatures. Rates for the 16C treatments were 2 mg ai L^{-1}. Rates for the 21C and 23C treatments were 1 mg ai L^{-1}. Plant shoots were rated from 1 (dead) to 5 (healthy).

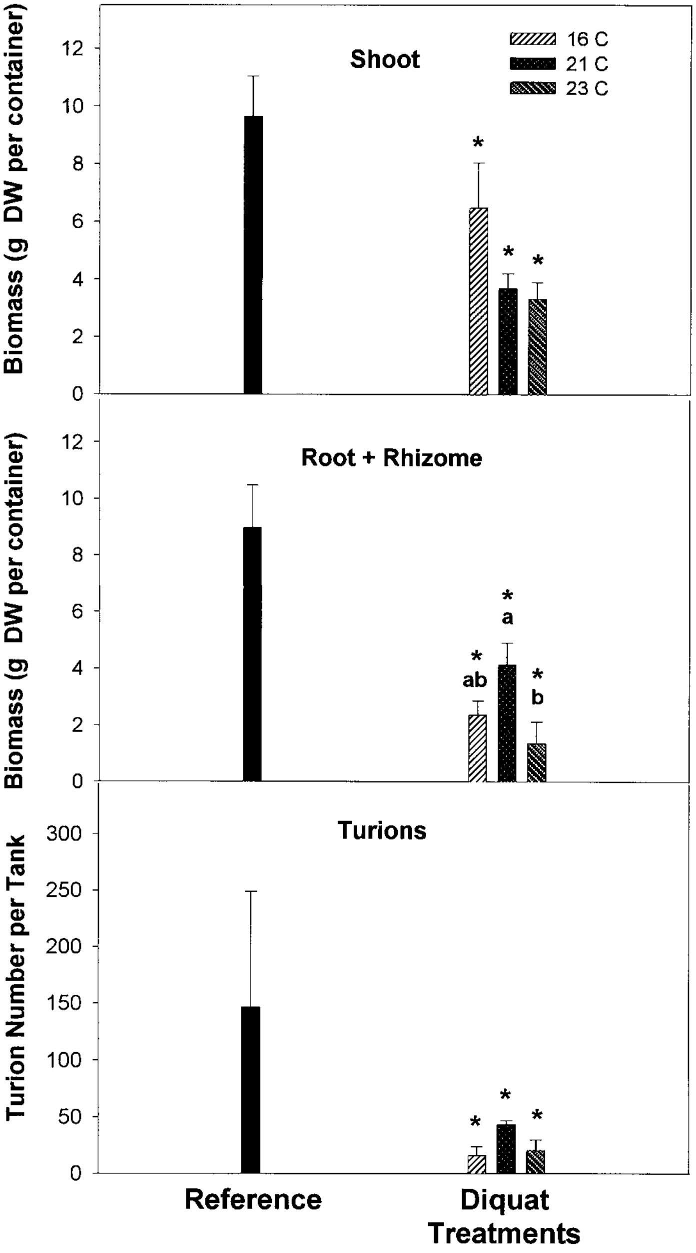

Figure 2. Shoot biomass, root biomass, and turion production of curlyleaf pondweed after diquat applications in cool water temperatures. Rates for the 16C treatments were 2 mg ai L^{-1}. Rates for the 21C and 23C treatments were 1 mg ai L^{-1}. Means are expressed ±1 SE (n = 9 for shoot and root biomass, n = 3 for turions). Asterisks denote significant differences between each treatment and the reference; letters denote significant differences among water temperatures (S-N-K method, $p \leq 0.05$).

Turion numbers decreased by more than 85% compared to the reference, with no significant differences between water temperatures (Figure 2). Most turions from treated plants were thin black structures about 0.25 to 0.5 cm in length that formed at the junction of branching nodes. They floated easily when detached from the plant. By the end of the study, many had sunk to the bottom of the tanks and sprouted; turion sprouting soon after detachment is not unusual (Rogers and Breen 1980). Plants grown from these small turions may be less likely to survive another herbicide treatment than plants grown from reference turions (Spencer et al. 1989). Turions from the reference were similar to those previously reported (Wehrmeister and Stuckey 1992): large brown dormant apices consisting of numerous lobes that formed at the ends of stems or branches.

Comparable reduction of curlyleaf pondweed shoot biomass and turion numbers was achieved in a greenhouse study using lower rates and longer exposure times of diquat (Netherland et al. 2000). In another greenhouse study, 2 mg ai L^{-1} diquat decreased coontail (*Ceratophyllum demersum* L.) shoot biomass by 90% using 24- and 48-hour exposure times with water temperatures ranging from 15 to 21C (Hofstra et al. 2001). Perhaps longer exposure times would have improved results in this study. For example, diquat residue analyses from the 16C treatments revealed that water concentrations were a little below target rate (1.4 ± 0.25 mg ai L^{-1}) just 1 hour after treatment (HAT). By 8 HAT, concentrations were substantially less than the target rate (0.5 ± 0.06 mg ai L^{-1}); nonetheless, probably enough diquat was in the water column to significantly injure curlyleaf pondweed (Poovey and Getsinger 2002).

Visual ratings of curlyleaf pondweed treated with endothall when water temperatures were 16C indicated that plants were injured 1 WAT. No live plant shoots were observed 6 WAT (Figure 3); however, small shoots were observed by 12 WAT. Similarly, treatments at 21C destroyed plant shoot biomass 1 WAT, with no biomass remaining above the sediment 2 WAT; however, sparse regrowth was observed 12 WAT. No plant shoots were visible immediately after the 23C treatments, but small shoots were observed by 2 and 3 WAT. These shoots remained green and healthy until the end of the study.

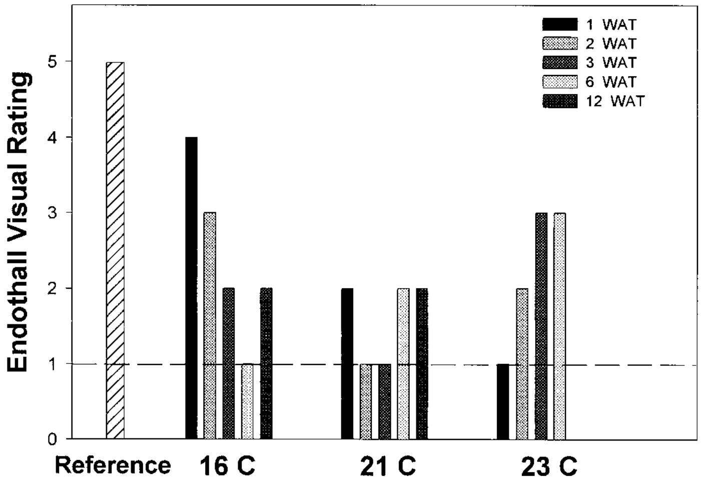

Figure 3. Visual ratings of curlyleaf pondweed after endothall applications in cool water temperatures. Rates for the 16C treatments were 2 mg ai L^{-1}. Rates for the 21C and 23C treatments were 1 mg ai L^{-1}. Plant shoots were rated from 1 (dead) to 5 (healthy).

All endothall treatments were effective in suppressing plant biomass compared to the reference (Figure 4). Both the 16C and 21C treatments reduced shoot biomass by 90% compared to the 23C treatment, which reduced shoot biomass by 60%. Biomass from the roots and rhizomes decreased by >90% for the 16C compared to 60% for the 23C treatment (Figure 4). In another mesocosm study conducted at the LAERF, a 1 mg ai L^{-1} endothall application during early May reduced curlyleaf pondweed shoot biomass by <90%

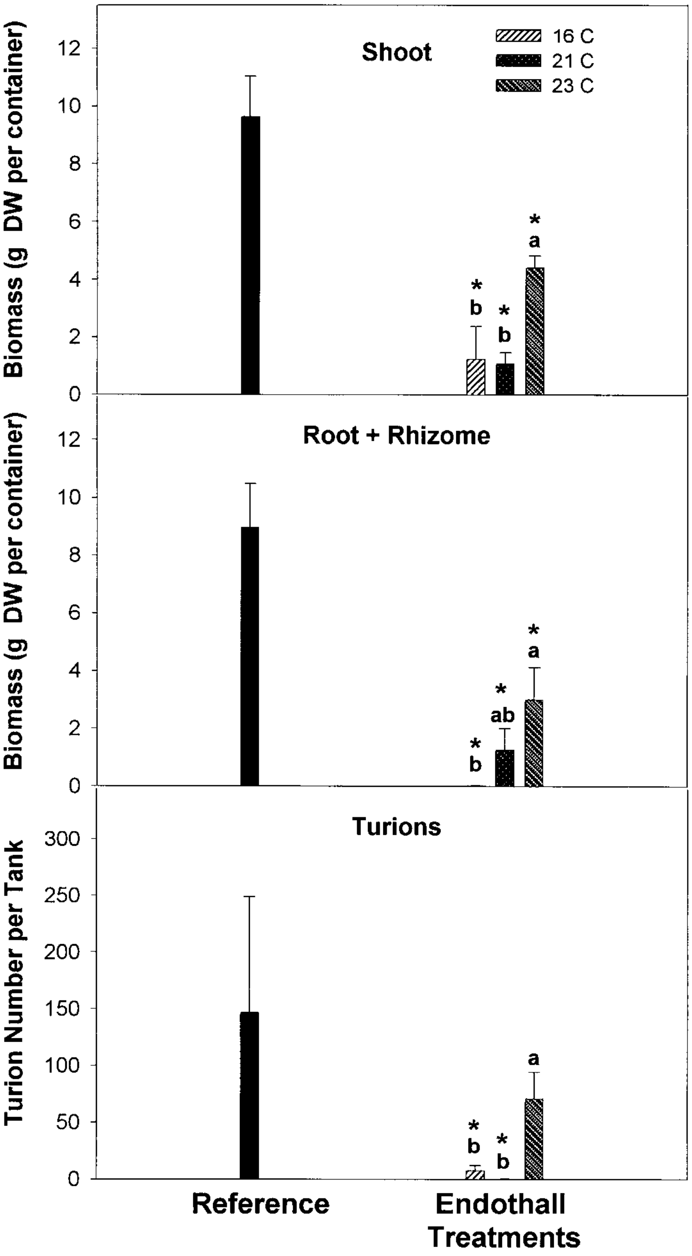

Figure 4. Shoot biomass, root biomass, and turion production of curlyleaf pondweed after endothall applications in cool water temperatures. Rates for the 16C treatments were 2 mg ai L^{-1}. Rates for the 21C and 23C treatments were 1 mg ai L^{-1}. Means are expressed ±1 SE (n = 9 for shoot and root biomass, n = 3 for turions). Asterisks denote significant differences between each treatment and the reference; letters denote significant differences among water temperatures (S-N-K method, $p \leq 0.05$).

(Skogerboe and Getsinger 2002). Netherland et al. (1991) demonstrated that endothall treatments that reduce plant biomass by >85% will not exhibit regrowth for at least four weeks. Endothall applied at 5 mg ai L^{-1} to a Wisconsin pond (0.31 ha) in late May 1973 suppressed curlyleaf pondweed for two years following treatment (Serns 1977). No plant regrowth was observed in October 1973. Curlyleaf pondweed comprised <5% of the plant population in October 1974 and <15% in October 1975.

Turions harvested from treated plants were like those previously described from the diquat treatments. Turion numbers were significantly less than the reference for the 16C and 21C treatments, but not the 23C treatment (Figure 4). Turion production was reduced by >90% for the cooler temperature treatments. Similar results were obtained when endothall was applied to a LAERF pond (0.9 mg ai L^{-1} for 16-hour exposure) when water temperatures were 18C and 25C (Netherland et al. 2000). There was a 90% reduction in turions when water temperatures were 18C compared to a 55% reduction when temperatures were 25C.

A hard stem-like structure was also harvested from reference and from both diquat and endothall treated plants. These "hard stems" were rigid, brittle plant structures about 2.5 to 5 cm in length, protruding from the sediment surface attached to rhizomes, or broken off and lying on the sediment surface. They were green in the middle when broken, and produced new plant growth when placed in an incubator at 25C and a day length of 14 hours. Plant generation from "hard stems" could be another survival mechanism for curlyleaf pondweed. Although different from the "underground stems" described by Kunii (1989), hard stems may also maintain plant populations at specific sites as part of the plant's vegetative reproduction strategy.

Diquat and endothall applications in cool water temperatures could potentially provide long-term control for curlyleaf pondweed. Label rates of diquat with a relatively short exposure time were sufficient to significantly decrease turion numbers; however, visual ratings suggested that treatments when water temperatures are ≥20C might be more efficacious in reducing shoot biomass. Low rates of endothall with a 24-half life provided excellent control when applied in water with temperatures ≤20C; however, as temperatures warmed, plants became more resilient to herbicide treatment.

Field recommendations for using these herbicides in cool water temperatures will depend on plant management objectives. Results of this study indicate that spring applications of diquat could be used in areas with short exposure times (due to wind and wave action) to reduce curlyleaf pondweed shoot biomass and, thereby, limit turion production. These applications would also limit plant regrowth from roots and rhizomes. Endothall could be used in more quiescent areas for large block or whole lake applications to curtail growth when plants are young, interrupting turion formation as well as limiting regrowth from hard stems and rhizomes.

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