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Control of Submersed Weeds by Grass Carp in Waterlily Production Ponds

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ABSTRACT

A 4 x 2 factorial randomized block experimental design was used to evaluate triploid grass carp (*Ctenopharyngodon idella* Val.) for submersed weed control in waterlily (*Nymphaea* spp.) production ponds. Two stocking levels (one carp per enclosure and two carp per enclosure) were evaluated and compared to that of hand harvesting and no control. The effect of weed growth and control on the growth of two waterlily types, hardy and subtropical, was also investigated. Waterlily plants in the untreated-control enclosures had significantly ($P= <0.05$) lower leaf area/plant and number of flowers than in any of the weed control treatments. Manual weed control (hand harvesting) allowed for the greatest amount of waterlily growth (leaf area) and was significantly different from the one-carp treatment but not from the two-carp treatment. The hand harvesting treatment resulted in lower weed biomass throughout the experiment; however, complete control was not achieved. In the one-carp and two-carp treatments, complete weed control was achieved in 60 and 40 weeks, respectively, after introduction of grass carp. Following complete weed elimination, grass carp in two of the enclosures damaged some waterlily plants, but overall, results indicated that with careful management, triploid grass carp can be used to control submersed aquatic weeds in waterlily production ponds.

Key words: *Ctenopharyngodon idella*, Eurasian watermilfoil, *Hydrilla verticillata*, *Nymphaea*, triploid grass carp.

INTRODUCTION

Excessive growth of undersirable aquatic plants in production ponds is a major problem in commerical waterlily nurseries. Shallow depth coupled with heavy fertilization provides a favorable environment of unwanted aquatic plants (weeds) in these ponds and hinders the growth of waterlily plants. Additionally, weeds are unattractive to customers and increase labor required in processing plants for sale which increases the cost of production.

Hand pulling (harvesting) and draining are the most common weed control methods implemented in commercial waterlily ponds. The high cost of labor, land and water

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has created a need to exploit possible alternative methods of weed control. Registered herbicides are expensive, may affect desirable species, and may require long post-entry times before personnel can work the ponds.

Among the biological control agents, triploid grass carp (*Ctenopharyngodon idella* Val.) have been highly publicized as an effective biocontrol agent of aquatic weeds in lakes and reservoirs (Sutton 1974, Wiley et al. 1974, Prabhavathy and Sreenivasan 1977, Martyn et al. 1986). The purpose of the present study was to investigate how the culture of one hardy and one tropical waterlily cultivar is affected by competing aquatic weeds and the potential of using triploid grass carp to control submersed aquatic weeds in waterlily production ponds.

MATERIALS AND METHODS

A 4 X 2 factorial randomized block experiment was used to evaluate four weed control methods and two waterlily cultivars. The experiment was conducted at a commercial waterlily production facility in Brookshire, Texas. Surface area of the pond was 975 m^2 (15.8 m x 61.7 m), and depth varied from 30 to 90 cm.

Sixteen enclosures (7 m x 7.5 m) were set-up in the pond (two rows of eight) with plastic netting (1.5 cm X 1.8 cm mesh size) for the walls. To prevent escape of the grass carp (Ellis 1974), the netting was extended 15 cm below the pond bottom and 70 cm above the water surface. The top 30 cm of the above-surface netting was inclined inward at a 45° angle. The netting was supported by 2.5-cm-diameter PVC pipe sections fixed to the bottom, one per each meter. U-shaped, 15-cm-long metal staples were used to anchor the netting to the bottom of the pond, and the netting was secured to the PVC pipes approximately every 50 cm with wire.

Weed control methods included an untreated control, manual harvesting (hand pulling), one grass carp per enclosure, and two grass carp per enclosure. The tropical waterlily hybrid, 'Robert Strawn', developed by crossing *Nymphaea elegance* Hook (pod parent) and an unknown pollen parent, and the hardy waterlily hybrid 'Attraction', (parents not described) were selected as the two experimental cultivars. Six waterlily plants (in two rows), of either the 'Robert Strawn' or 'Attraction' cultivar, were planted in each enclosure (2 m between plants and 3 m between rows). The eight enclosures in the drain-end were considered as one block and the remaining eight as the other block to accommodate for the difference in depth. All treatments (factor combinations) were assigned randomly within each block. Enclosures that received the manual harvest treatment were cleaned once every 8 weeks during colder months (November to March) and once every 4 weeks during the rest of the year. Three man-hours were necessary each time to remove weeds from each enclosure. Twelve triploid grass carp, obtained from Leon Hill's Fish Farm, Lonoke, Arkansas, were stocked according to the respective treatment on 2 Sep 1988. The average initial weight and length of fish were 145±7 g and 24±1 cm, respectively. Two stocked fish died during the first week and were replaced.

Leaf length and width of each waterlily plant in each enclosure were measured once every 4 weeks. Upper surface area was calculated for individual leaves (Y) and regressed separately against leaf width x length (X) for the two cultivars with intercept equal to zero. The equations for 'Attraction' and 'Robert Strawn' were $Y=0.797X$ and $Y=0.778X$, respectively. The slope of the regression equation was used to calculate upper surface leaf area of leaves from field measurements of length and width of each leaf. The surface areas of all leaves on a plant that were fully above the water surface were summed to obtain the total leaf area per plant.

The number of waterlily flowers produced per plant for the experimental period was recorded by counting the buds and flowers once every 2 weeks. Overcounting or undercounting of flowers was avoided by labelling all flowers and buds, 15 cm or more above the bottom, with plastic tags. The number of biweekly-recorded flowers per plant throughout the study was added separately for each plant. All daughter plants were removed and only the mother plant was allowed to grow to make comparisons on a per plant basis. Initially, and then monthly (once every 4 weeks), above ground plant biomass of aquatic weeds was determined from 10 randomly selected places in each enclosure. Submersed aquatic weeds were cut within a 0.1 m^2 (0.33 m X 0.33 m) sampling frame with shears. The cut weeds were washed thoroughly and the excess water was removed by circular swinging in a nylon bag. Weed samples were separated by species and the wet weight of each species was determined. Individual species weights in each sample were summed to get the total weight of each weed sample. Percent species composition was calculated from the proportional contribution to weight.

Monthly measurements on weed biomass, waterlily leaf areas and waterlily flower production data were analyzed as repeated measures factorial randomized block experiments. The Tukey's test ($P<0.05$) was used to compare the treatment factors. All data analyses were done using SAS (Statistical Analysis System 1989). There were significant interactions with time in biomass and leaf area due to the change in environmental conditions (ie., weather) over the course of the experiment. Thus, weed biomass and leaf area measurements were analyzed separately. There was a cultivar effect late in the growing season; however there was no cultivar x treatment or cultivar x time interaction.

RESULTS AND DISCUSSION

Differences in vegetative growth of the two waterlily cultivars were evident from the leaf area measurements. On 19 Aug 1989, 'Robert Strawn' cultivar had an average leaf area of 310 dm^2/plant compared to the average leaf area/plant of the 'Attraction' cultivar of 123 dm^2 (Table 1). Neither cultivar had leaves during the winter months (Jan - Apr). The competitive effect of weeds on waterlily plant growth also was evident in the latter part of the experiment. Waterlily plants growing in the untreated check treatment had significantly lower leaf area per plant than those in enclosures with all other treatments. These plants were fairly small and had an average leaf area of only 162

TABLE 1. PLANT LEAF AREA (dm^2) AS AFFECTED BY WEED CONTROL TREATMENT AND DATE[1].

Treatment	Leaf area (dm^2)/plant[2]														
	Date and weeks (no.) post-introduction of grass carp														
	Sep 17 (2)	Oct 15 (6)	Nov 2 (10)	Dec 10 (14)	Jan 7 (18)	Feb 4 (22)	Mar 4 (26)	Apr 1 (30)	Apr 29 (34)	May 27 (38)	June 24 (42)	July 22 (46)	Aug 19 (50)	Sep 16 (54)	Oct 14 (58)
Weed control															
Control	139[a]	146[a]	120[a]	56[a]	0	0	0	0	18[b]	60[c]	91[a]	122[c]	162[c]	162[c]	154[c]
Manual	140[a]	150[a]	113[ab]	49[ab]	0	0	0	0	23[a]	96[a]	140[a]	203[a]	289[a]	292[a]	310[a]
1-carp	134[a]	142[a]	108[b]	44[b]	0	0	0	0	21[a]	69[b]	103[a]	158[b]	205[b]	245[b]	247[b]
2-carp	139[a]	146[a]	105[b]	43[b]	0	0	0	0	22[a]	81[ab]	113[a]	189[a]	238[a]	269[a]	285[a]
Cultivars															
Hardy	75[b]	80[b]	43[b]	13[b]	0	0	0	0	17[b]	42[b]	75[b]	98[b]	123[b]	133[b]	140[b]
Tropical	200[a]	212[a]	180[a]	89[a]	0	0	0	0	25[a]	111[a]	148[a]	238[a]	309[a]	341[a]	357[a]

[1]Data are represented as a factorial design. Factor 1 = weed control treatment; factor 2 = waterlily cultivar. Data were collected for each treatment x cultivar x time throughout the experiment. There was a time interaction and, thus, the data were analyzed separately. There was a cultivar effect late in the season but there was not a cultivar x treatment interaction. Zero data points from Jan 7 - Apr 1 are indicative of the winter months when there were no leaves present.

[2]Means in the same column followed by the same letter are not significantly different according to Tukey's test ($P<0.05$).

dm^2 per plant on 19 Aug 1989 (Table 1). The average leaf area per plant in the manual harvest treatment, one-carp and two-carp treatments were 289 dm^2, 205 dm^2 and 238 dm^2, respectively (Table 1). The manual harvest treatment had the highest average leaf area per plant, which indicated that a continuous absence of competing weeds results in better growth. Waterlily plants in all experimental enclosures except the untreated check had leaves and flowers for longer periods than plants growing in other commercial production ponds at the nursery.

The 'Robert Strawn' cultivar produced more flowers than the 'Attraction' cultivar. 'Robert Strawn' had an average of six flowers per plant biweekly during the growing season while 'Attraction' averaged less than two flowers per plant. Average total number produced during the experimental period was 101 and 25 flowers per plant in 'Robert Strawn' and 'Attraction' cultivars, respectively. The difference in flower production was due in part to genetic differences in the two waterlily types; however, weed control methods also had a significant effect on flower production. Waterlily plants in the untreated check produced an average of 55 flowers per plant during the experimental period, and this was significantly lower than other treatments. The manual harvest and the two-carp treatments produced an average of 70 and 69 flowers per plant, respectively, during the experimental period. These were significantly higher than either the one-carp treatment or untreated check. The one-carp treatment produced an average of 63 flowers per plant which was significantly higher than that of the untreated check.

The pond selected for the study had several submersed aquatic weeds present (*Hydrilla verticillata* L. F. Royle, *Myriophyllum spicatum* L., *Ceratophyllum demersum* L., *Utricularia biflora* Lam., and *Najas flexilis* Rostkov and Schmidt), but no emergent species were found inside the enclosures. At the initiation of the experiment, hydrilla dominated the pond (92% of the vegetation). Eurasian watermilfoil consisted of approximately 5% of the population, and the rest was a mixture of coontail, bladderwort, southern naiad and pondweed (*Potamogeton crispus* L.). Weed species composition changed during the experiment and dominant species changed with different seasonal conditions. In November 1988, the percent composition of hydrilla was reduced to 30% and Eurasian watermilfoil and southern naiad increased to about equal proportions. With colder weather, southern naiad became dominant (50%), filamentous algae (e.g. *Cladophora* sp. and *Spirogira* sp.) made up about 30% and Eurasian watermilfoil was 20%. With warm weather, hydrilla increased again but Eurasian watermilfoil was dominant (60%) in those enclosures where weeds were still growing.

The effect of grass carp on submersed weed control was evident over time (Table 2). In November 1988, all weed control treatments had significantly lower weed biomass than the untreated check and the manual harvest treatment had the lowest weed biomass. During colder months, weed biomass in all weed-control treatments was very low, and there were no significant differences among them. In March 1989, the manual harvest, one-carp and two-carp treatments had significantly lower weed biomass than the untreated check. In early June, submersed weeds in the two-carp treatment were completely eliminated. In September, a significantly lower weed biomass occurred in the one-carp treatment than was present in the manual-control treatment. Eventually, the grass carp completely controlled all weeds in the one-carp treatment. Terrel and Fox (1975) reported that when grass carp are stocked for weed control the situation will almost certainly arise where fish eliminate all vegetation. The grass carp stocking densities used in this experiment (one-carp per enclosure =

TABLE 2. WEED BIOMASS (g FRESH WEIGHT/0.1m^2) PRESENT ON EACH SAMPLING DATE AND AVERAGED BY TREATMENT FACTOR[1].

Treatment	Weed biomass (g fresh weight/0.1m^1)[2]														
	Date and weeks (no.) post-introduction of grass carp														
	Oct 1 (4)	Oct 29 (8)	Nov 26 (12)	Dec 23 (16)	Jan 21 (20)	Feb 18 (24)	Mar 18 (28)	Apr 15 (32)	May 13 (36)	June 9 (40)	July 8 (44)	Aug 5 (48)	Sep 2 (52)	Sept 30 (56)	Oct 28 (60)
Weed control															
Control	272^{a}	278^{a}	255^{a}	229^{a}	100^{a}	82^{a}	115^{a}	138^{a}	203^{a}	234^{a}	248^{a}	256^{a}	263^{a}	267^{a}	629^{a}
Manual	162^{b}	161^{b}	156^{d}	129^{c}	79^{b}	77^{a}	23^{d}	38^{c}	47^{c}	58^{c}	70^{c}	74^{c}	77^{b}	77^{b}	76^{b}
1-carp	266^{a}	271^{a}	216^{b}	192^{b}	87^{ab}	78^{a}	87^{b}	95^{b}	108^{b}	116^{b}	122^{b}	93^{b}	60^{c}	24^{c}	0^{c}
2-carp	272^{a}	249^{a}	190^{c}	155^{b}	79^{b}	73^{a}	65^{c}	52^{c}	26^{d}	0^{d}	0^{d}	0^{d}	0^{c}	0^{d}	0^{c}
Cultivars															
Hardy	242^{a}	242^{a}	207^{a}	179^{a}	88^{a}	79^{a}	73^{a}	83^{a}	103^{a}	109^{a}	116^{a}	111^{a}	104^{a}	96^{a}	90^{a}
Tropi.	247^{a}	237^{a}	202^{a}	174^{a}	85^{a}	77^{a}	72^{a}	75^{b}	89^{b}	95^{b}	104^{b}	102^{b}	96^{b}	88^{b}	83^{b}

[1]Data are represented as a factorial design. Factor 1 = weed control treatment; factor 2 = waterlily cultivar. Data were collected for each treatment x cultivar x time throughout the experiment. There was a significant time interaction and, thus, the data were analyzed separately.
[2]Means in the same column within each treatment factor followed by the same letter are not significantly different ($P<0.05$) according to Tukey's test.

188 carp/ha; two-carp per enclosure = 376 carp/ha) were sufficient for the complete elimination of submersed weeds in 60 and 40 weeks, respectively.

Among the weed control methods used, manual harvesting resulted in a significantly lower weed biomass throughout the experiment, but complete control was not achieved (Table 2). Compared to the other methods, manual harvesting also resulted in greater waterlily plant growth (Table 1). However, this method is highly labor-intensive and more expensive than using grass carp. During this experiment, 3 man-hours per enclosure per month were employed to remove weeds. This extrapolates to 571 man-hours/ha per month with an estimated cost of $2,484/ha per month, considering $4.35 per man-hour (minimum wage). The grass carp used in this study were purchased for $3 per fish (including transporatation). Weed control with grass carp in waterlily ponds would theoretically cost $564/ha per year [1-carp per enclosure (188 carp/ha) controlled all weeds in 1 year], a savings of over $1,900/ha per year. The economic savings could be increased further depending on the longevity of the grass carp.

The differential water surface covered by the waterlily cultivars also showed a significant effect on weed biomass with time. In May 1989, the average weed biomass in enclosures with the 'Attraction' cultivar was significantly higher than 'Robert Strawn' cultivar (Table 2). 'Robert Strawn' produced a greater number of large leaves with a mean coverage of 33% of the water surface. The 'Attraction' cultivar had fewer large leaves and only covered 14% of the water surface.

Waterlily plants were not damaged by grass carp in enclosures in the presence of aquatic weeds. However, following weed elimination, 'Robert Strawn' plants in one of the four enclosures with two-carp were destroyed. Six plants were replanted in this enclosure. Two weeks after replanting, all plants were once again destroyed, and grass carp were observed eating remnants of waterlily leaves. The grass carp in the other three enclosures did not damage the waterlilies (one with 'Robert Strawn' cultivar and two with 'Attraction' cultivar). 'Attraction' plants in one of the four with the one-carp treatment also were eaten in October after complete control of weeds occurred in that enclosure. There was no evidence of any grass carp damage to waterlilies in any of the other enclosures. Van Dyke et al. (1984) reported that grass carp did not damage waterlilies in four Florida lakes; however, results from caged fish studies and open water studies are likley to be different.

All stocked grass carp survived until the end of the experiment. They grew from an average initial weight of 0.15 kg to 2.49 kg. Average weight of the fish in the one-carp and two-carp treatments was 2.87 kg and 2.05 kg, respectively.

The results of this experiment showed that weeds growing in competition with waterlily plants adversely affect the growth of waterlilies. The results also showed that competing submersed aquatic weeds can be successfully controlled using triploid grass carp in waterlily production ponds. It is possible that grass carp could damage waterlily plants in the absence of other vegetation; therefore, it might be necessary to remove or reduce the number of grass carp following weed reduction.

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