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Controlling aquatic weeds in a Saudi drainage canal using grass carp (*Ctenopharyngodon idella* Val.)

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Abstract

Aquatic weeds have a negative effect on agriculture by blocking water drainage system. This is especially true in hot climate countries, like Saudi Arabia, where aquatic weeds grew quickly. For this reason, a field experiment was conducted as follows: grass carp *(Ctenopharyngodon idella* Val.) fingerlings (average weight 3.3±0.3 g) were randomly stocked in 12 sections (50 m L x 5 m W x 1.5 m D) of a drainage canal at a rate of 0, 1, 3 and 5 fish m^{-2} in triplicate. Starting from upstream, the drainage canal was divided into 12 sections using 13 metal frames covered from both sides with 0.5-inch plastic mesh screens. The canal was infested with 850 km^{-2} of *Phragmites australis* Cav. (5.1±0.6 kg m^{-2}), 100 km^{-2} of *Ceratophyllum demersum* L. (2.39±0.22 kg m^{-2}) and filamentous algae *Cladophora globulina* Kützing (0.35 kg $section^{-1}$). Fish grew on aquatic weeds for a period of one year. The results indicated that the grass carp completely eliminated filamentous algae within 5 months. The number of *Phragmites australis* m^{-2} was significantly reduced in all treatment groups as compared to the control group. Sections containing 3 and 5 fish m^{-2} were yielding similar results and significantly higher than those containing 1 fish m^{-2}. Average daily growth rates were 3.47, 5 and 6.25 g day^{-1} for treatments with 1, 3 and 5 fish m^{-2}, respectively. Removal of aquatic macrophytes by grass carp affected water quality parameters by increasing levels of dissolved oxygen, carbon dioxide, turbidity, chlorophyll *a* (phytoplankton), conductivity and total dissolved solids in the down-stream water samples, as compared to that of up-stream.

Key words: Grass carp, stocking density, growth parameters, *Phragmites australis, Ceratophyllum demersum*, aquatic weed control, drainage canal.

Introduction

In warm climates, it is known that aquatic weeds grow at a much faster rate than in a cold climate. Therefore, aquatic weeds in irrigation and drainage systems of some hot climate countries, such as Saudi Arabia, grow heavily and cause serious problems to agriculture. Aquatic weeds [1, 2] 1) hamper the drainage water flow by their excessive growth which increases silting, 2) cause a considerable amount of water loss through evaporation, 3) a gradual increase in water salinity causes salinization of irrigated land when the drainage water is reused for irrigation, 4) provide a suitable habitat for a vector of various human and animal diseases. Additionally, aquatic weeds increase salinity in the soil of the cultivated area due to malfunctioning of the drainage system [3].

In Saudi Arabia, an exhausting and expensive mechanical control of aquatic weeds in the drainage canals (1300 km long of different sizes) is highly inefficient. Chemical control (algaecides and herbicides), however, is not an alternative method to mechanical weed control. This is because drainage water is reused for agriculture irrigation after mixing fresh well water at a certain level. As a result, a proper biological control method is highly preferred under these conditions.

Drainage canals in the Eastern Province of Saudi Arabia have 77 different species of aquatic weeds. *Phyla nodiflora*, *Ceratophyllum demersum* L., *Bacopa monnieri*, wigeongrass *Ruppia maritime* and *Phragmites australis* Cav. are found in the canals [4]. *C. demersum* and *P. australis* have the widest spread in the canals and the most detrimental effect on the drainage process, while *Phyla nodiflora*, *B. monnieri* and *R. maritime* are present in non-significant numbers [4].

Because of its efficiency in controlling aquatic weeds, grass carp (*C. idella* Val.) has been introduced to more than 50 countries around the world [5, 6]. Grass carp successfully completed weed control in the Kara Kum Canal in Russia [7]. It has been investigated for many years as a control agent for nuisance aquatic plants. Grass carp eats hundreds of aquatic plant species [8]. In general, grass carp selects softer plants over more fibrous or woody ones when smaller in size and/or at lower water temperatures [9] but eats more fibrous or woody aquatic plants, such as cattail, *Typha latifolia* L. and *Phragmites communis* Trin., at size larger than 500 g and at high water temperature [10]. Daily food consumption of grass carp is increased at high water temperatures and reduced at low water temperatures [10]. Grass carp is known to eat more than 1000 g kg^{-1} of the body weight of aquatic weeds per day. The utilization of aquatic weeds, however, is poor as only 500 g kg^{-1} is digested of the plants ingested [6]. This results in releasing large amounts non-digested nutrients into the water.

Grass carp does not reproduce in tropical areas, the natural reproduction only occurs in large rivers with precise requirements of turbulence, current velocity and flow [11]. The environmental requirements for spawning include proper temperature, photoperiod, diet and social interactions for gametogenesis [7]. This is in addition to some internal factors mainly involving the hypothalamus–hypophysis–gonad axis. The only way to produce fry for fish farming is by artificial reproduction [12].

The goals of this study were to 1) study the possibility of introducing grass carp to the Saudi Arabia agriculture drainage system, (2) estimate the optimum stocking density of grass carp that would reduce the number of the most fibrous and/or least palatable aquatic weeds *P. australis* and *C. demersum* in drainage canal to the minimun, (3) study the effect of introducing grass carp on water quality parameters of the drainage water, and (4) measure the growth rate of grass carp under the experimental conditions.

Materials and Methods

Status of the drainage canal before the experiment: This study was conducted in a semi principle drainage canal called D_{-1-5} which is part of the Al-Hassa, Eastern Province Agriculture Drainage System. The canal is 5 m wide, 3 km long, and an average water depth is 1.5 m. According to the Irrigation Department, Irrigation and Drainage Authority, Ministry of Agriculture and Fisheries Resources, water current varied according to the seasons and ranged 0.24-0.28 m s^{-1}. The canal was completely covered with *P. australis* and *C. demersum*. Filamentous algae *Cladophora globulina* Kützing were seen on the bottom and the sides of the canal. Additionally, it had two fish species that were artificially introduced, namely Nile tilapia *Oreochromis niloticus* L. and *Aphanius dispar* T. [13].

The canal preparation: Using mechanical and manual equipment, part of the canal was divided into twelve sections (50 m long each) using iron frames covered with a plastic screen and gravels on the bottom. Manufacturing and the installation of the frames were done by the Department of Maintenance, Irrigation and Drainage Authority, Ministry of Agriculture and Water, Saudi Arabia. The frame was 8 m long x 3 m wide with 39 vertical iron cylinder bars (2 cm diameter) welded to the frame at 18 cm apart. The frame was covered on both sides with steel enforced plastic screen 1.25 cm mesh. A crane was used to cut into the canal sides to install the frames and cover the bottom with gravel. The screens were cleaned manually 6 days a week to prevent daily clogging.

Fish imports, isolation and stocking: 5000 grass carp (*Ctenophoraygodon idella*) fingerlings, average weight around 3 g each, were imported from the Egyptian Aquatic Resources Authority, Ministry of Agriculture. Fish were gradually adapted to the university wet laboratory (water temperature and water quality) conditions. They were treated with 160-ppm formalin for four hours for two days to get rid of the microorganisms and the external parasites that came with the fish. Fish were fed commercial tilapia feed (35 g kg^{-1} protein) at a rate of 5 g kg^{-1} of their body weight and kept in the wet laboratory for four weeks in a flow through system to check for any disease symptoms before transferring them to the drainage canals. Then fish were randomly stocked into the 12 sections of the canal at rates of 0, 1, 3 and 5 fish m^{-2} in triplicates in October 1999.

Sampling methods: Aquatic weeds were monitored as follows: 1) The number m^{-2} of *Phragmities australis*, as it is the most difficult aquatic weed to control, was determined by dropping 0.5 m^2 quadrant (1.255 cm diameter PVC pipes) in 20 random locations in each section of the drainage canal once every two months starting in June. 2) The percentage of surface area (the length multiplied by the average width in metres) in every section was calculated as follows: % = [(Total water surface area containing *C. demersum*)/(Total water surface area)]x 100. 3) Filamentous algae, *C. globulina*, *P. nudiflura, B. monnieri* and *R. maritime,* were monitored by visual observation in all sections, as they are found in small amount. Grass carp were sampled at the end of the 1st year and after the experiment. Four people and large enough seine were used to collect fish samples from the first section of the canal.

Methods of analysis: Samples of *P. australis* and *C. demersum* were collected from the canal, cleaned and analyzed for moisture, organic matter and total ash [10]. The average weight (g) and height (cm) of *P. australis* and *C. demersum* (weight only) m^{-2} of water surface area were determined.

Water quality samples from up-stream and down-stream of the canal were analyzed once every two months starting in June. A sub-sample of *P. australis* and *C. demersum* was dried in an air-blowing drying oven for 72 h at 60°C to measure moisture percentage and put in a muffle furnace at 600°C for 16 hours to measure the ash content [14].

Water parameters were measured by the following tools and methods: dissolved oxygen (DO) using PSI DO meter, carbon dioxide using a CO_2 meter RIC model 503, total dissolved solids using the evaporation method [16], conductivity using conductivity meter Model 4070 Jenway, turbidity using 2020-Turbidity Meter La Motte 1799, chlorophyll using method of Lorenzen [15] and Hatch Chemical Co. Model DR2010 water analysis kit and ammonia and phosphate using the methods of Boyd [16].

All data were analyzed using the SAS ANOVA procedure [17] one-way analysis of variance (ANOVA), and Duncan's multiple range test was used to compare treatment means [18]. Statements of significant differences were based on $P<0.05$.

Results

Overall, no disease symptoms were recorded in the experimental fish. Also no dead fish were found in the canal throughout the experimental duration. This was probably due to heavy growth of aquatic weeds while grass carp were small.

The mean and the standard deviation values with regard to various water quality parameters in up-stream and down-stream are presented in Table 1. The water temperature varied within a narrow range of 27±3°C. TDS, dissolved oxygen DO, CO_2, pH, conductivity, salinity, chlorophyll *a* and turbidity were higher in down-stream as compared to up-stream samples. On the other hand, pH readings were reduced ($P<0.05$).

Filamentous algae, *C. globulina,* were the first to be eliminated, after five months of grass carp stocking. *P. nudiflura*, *B. monnieri* and *R. maritime* were eliminated from all sections, except the control treatments after eight months of stocking grass carp. Additionally, fish eliminated *C. demersum* and *P. australis* in treatments of 3 and 5 fish m^{-2}, except in treatment with 1 fish m^{-2} grass carp did not completely eliminate those weeds. *C. demersum* was found to have an average weight of 2.393 kg m^{-2} of water surface area and contained 972.8 g kg^{-1} moisture, 844.1 g kg^{-1} organic matter and 166.9 g kg^{-1} total ash. Grass carp consumed *P. australis* with an average weight of the whole plant at 150.45 g, average height 198.3 cm and contained 750 g kg^{-1} moisture, 107.1 g kg^{-1} total ash and 892.9 g kg^{-1} organic matter (Table 2).

Table 1. Average ± SD values [1] of monthly water quality parameters during the last six months of the 1st year of the experimental duration taken from up-stream and down-stream.

Water quality parameter	Average of water quality parameter	
	Up-stream	Down-stream
Total Dissolved Solids (TDS), mg L^{-1}	$3320^b \pm 20$	$3390^a \pm 23$
Dissolved Oxygen (DO), mg L^{-1}	$7.3^b \pm 0.2$	$7.7^a \pm 0.1$
Carbon Dioxide (CO_2), mg L^{-1}	$3.3^b \pm 0.1$	$4.0^a \pm 0.2$
pH	$8.15^a \pm 0.19$	$7.92^b \pm 0.22$
Conductivity, µS cm^{-1}	$6260^b \pm 130$	$6500^a \pm 110$
Turbidity, ntu [2]	$22^a \pm 1^b$	$28^a \pm 1^a$
Salinity, g L^{-1}	$3.4^b \pm 0.2$	$3.6^a \pm 0.2$
Chlorophyll *a,* mg L^{-1}	0.538^a	0.733^b

[1] Values in the same row with different superscripts are significantly different (P<0.05); [2] Nephelometric Turbidity Unit.

Table 2. Moisture and ash content and average weight and height of *Phragmites australis* and *Ceratophyllum demersum*.

	Phragmites australis [1]	*Ceratophyllum demersum*
Moisture, g kg^{-1}	750	972.8
Total ash g kg^{-1}	107.1	166.9
Average weight	150.45 g $plant^{-1}$	2.393 kg m^{-2}
Average height, cm	198.3	---------

[1] Proximate analyses of *P. australis* [32] starting from three weeks of age to 24 weeks ranged as follows: DM 948.9-926.1 g kg^{-1}, Ash 154.5-123.3 g kg^{-1}, CP189.8-68.3 g kg^{-1}, CF 265.8-380.2 g kg^{-1}, Ether extract 32.7-24.1 g kg^{-1}, NFE 357.5-404.1 g kg^{-1}, NDF 641.6-876.9 g kg^{-1}, ADF 403.6-468.1 g kg^{-1}, Lignin 47.2-141.9 g kg^{-1}, P 2.4-1.1 g kg^{-1}, Ca 0.68-0.9, Cu 7.0-3.66 ppm and GE 3.88-3.21 kcal g^{-1}.

The number of *P. australis* m^{-2} in the drainage canal water surface area is shown in Table 3. There was a gradual reduction of *P. australis* number m^{-2} in the drainage canal water surface area over time for each treatment (1, 3, 5 grass carp m^{-2}) except for the control group (0 grass carp m^{-2}) where there was no change over time. The number of *P. australis* was significantly (P<0.05) reduced as the stocking density of grass carp increased during June, August and October 2000. During the following December 2000, the number of weeds m^{-2} in treatments of 3 and 5 grass carp m^{-2}, however, was similar and significantly lower than in the treatment containing 0 and 1 fish m^{-2}. Additionally, treatment with 1 grass carp m^{-2} had significantly lower number of weeds than the control treatment containing zero grass carp m^{-2}.

The percentage of *C. demersum* surface area (Table 4) was significantly affected by grass carp stocking rate. This weed was eliminated from sections with 3 and 5 grass carp m^{-2} after six and 9 months of the starting of the experiment, respectively.

Table 3. Monthly average number ± SD of aquatic weed *Phragmites australis* for experimental treatments stocked with different No. of grass carp m^{-2}.

Treatment	No. of plants m^{-2}				
No. fish m^{-2}	December	June	August	October	December
0	33±1.3	$35^a \pm 1.7$	$35^a \pm 0.8$	$32.00^a \pm 2.3$	$35.00^a \pm 1.4$
1	32±1.7	$23^b \pm 3.3$	$7.5^b \pm 3.2$	$4.90^b \pm 1.2$	$2.30^b \pm 0.4$
3	33±1.9	$19^c \pm 2.5$	$3.8^c \pm 0.6$	$2.50^c \pm 1.1$	$0.15^c \pm 0.1$
5	34±2.2	$14^d \pm 1.4$	$2.6^d \pm 0.3$	$0.34^d \pm 0.2$	$0.11^c \pm 0.0$

Values in the same column with different superscripts are significantly different (P<0.05).

The experimental fish growth rates are indicated in Table 5. Growth rates were inversely correlated with stocking density. In other words, fish growth rates were highest at the lowest stocking density.

Table 4. Average percentages±*SD* [1] of the water surface areas containing *Ceratophyllem demersum* for each of the experimental treatments stocked with different No. of grass carp/m^2.

Treatment	% of surface area				
No. fish m^{-2}	December	June	August	October	December
0	$4.3^a \pm 0.3$	$4.4^a \pm 0.3$	$4.3^a \pm 0.2$	$4.5^a \pm 0.2$	$4.3^a \pm 0.2$
1	$4.6^a \pm 0.2$	$4.1^a \pm 0.4$	$3.9^b \pm 0.2$	$3.1^c \pm 0.4$	$1.3^d \pm 0.1$
3	$4.6^a \pm 0.4$	$2.3^b \pm 0.3$	$0.9^c \pm 0.1$	$0.0^d \pm 0.0$	$0.0^d \pm 0.0$
5	$4.4^a \pm 02$	$1.5^b \pm 0.1$	$0.0^c \pm 0.0$	$0.0^c \pm 0.0$	$0.0^c \pm 0.0$

Values in the same row with different superscripts are significantly different (P<0.05). [1] Calculated by the formula: % = [(Total water surface area containing *C. demersum*)/(Total water surface area)]x 100.

Table 5. Grass carp growth parameter values [1] for two years.

Treatment No. fish m^{-2}	Average initial weight kg	Average one year weight kg	Average one year length cm	Average daily weight g^{-1} day^{-1}
1	0.00340	1.50^c	44^b	4.11
3	0.00320	1.10^b	40^a	3.01^b
5	0.00340	0.95^a	38^a	2.60^a
Pooled SE[2]	0.00048	0.06	1.6	1.1

[1] Pooled standard error of means $= \frac{SD}{\sqrt{n}}$ [2] Means in each column followed by different letters differed at 0.05 probability level.

Discussion

Water quality: Removal of aquatic macrophytes from a system (lakes) by grass carp may stimulate phytoplankton production [19, 20], increases DO level, reduces pH and increases ammonia [11], orthophosphate [21] and water turbidity [22]. Phytoplankton production is stimulated by nutrients release in the water column. Nutrients release is described as follows: 1) grass carp digest 500 g kg^{-1} of the feed they ingest and deposit the other 500 g kg^{-1} as fecal materials, 2) these materials are decomposed by microorganisms causing nutrients release, 3) grass carp release metabolic nutrients (NH_3, CO_2 ,etc.), and 4) damaged aquatic weeds by fish feeding activity causes nutrients to be released to the water system. The increased DO level and the reduction in pH is a result of the stimulation of phytoplankton production. Another similar study, however, did not find any stimulation of phytoplankton production [22]. This was explained by the increase in water turbidity due to grass carp feeding activity which causes shading effect and prevents phytoplankton enrichment [22]. All the above studies were done in lakes with minimal water movements.

The results showed that the removal of aquatic macrophytes by grass carp caused phytoplankton enrichment by moderately increasing levels of carbon dioxide, turbidity, chlorophyll *a* (phytoplankton), conductivity and TDS in the canal downstream water samples as compared to that of up-stream (Table 1). It is possible that water currents (0.24-0.28 m s^{-1}) played a role in keeping changes in water turbidity at a modest level and therefore increase in water turbidity was smaller than in the previous study [22].

One of the goals of this study was to eliminate all aquatic weeds (*R. martinima*, *C. demersum, P. australis*) that impede water movement. Our study indicated that 3 fish m^{-2} is the lowest stocking density which achieves this goal within one year. In an earlier study, aquatic weeds that were eaten reluctantly or not at all by grass carp included *R. martinima*, *C. demersum* and *P. communis* [8]. The same fish in the present study readily ate those plants. This was probably due to the following conditions: 1) Water temperature was high (27±3°C) under our tropical condition. It was within the optimum range for grass carp 28°C [9]. This increases grass carp palatability for aquatic weeds [23]. 2) Fish grew in size from 3 to 950 g during the one year experimental duration. It is well known that as grass carp grow in size, plant selectivity is reduced. Grass carp weighing 500 g ate *P. communis* and cattail *T. latifolia* less than 1 m high. This work was done in the former USSR at lower water temperatures [24]. On the other hand, at higher water temperatures, grass carp readily ate these plants over one metre high [7]. Our study was done at much higher water temperatures than the above studies. Therefore, our fish ate *P. australis* regardless of their heights (some of the *Phragmites* were 4 m high) as water temperatures were close to the preferred temperature by grass carp 28°C [9] and the fish reached over 500 g in weight. 3) Utilization of high stocking density of grass carp. Stocking density must be high if the body of water contains plants that are eaten reluctantly [23]. 4) It is possible that the strains of the above aquatic plants were more palatable than those from different locations as in the previous studies. It was indicated that the palatability of the same plant from different locations may differ depending on chemical contents [25].

Stocking density and growth rates: The results of the present study indicated that grass carp stocking density of three fish (3 g average wt) m^{-2} was the minimum rate to eliminate aquatic weeds in the drainage canal. Other studies used higher or lower rates than that of the present study [26]. High stocking rate (10 fish m^{-2}, average fish weight 30 g) was used to make up for any mortality due to the presence of large carnivorous fishes in the drainage canal that they used [27, 28]. In the present study, however, the drainage canal did not have any large carnivorous fishes that could cause fish mortality. Other studies used larger grass carp (≥200 g) to stock waterways at much lower rates than that of our study. The goal of these studies was to eliminate smaller amounts of *Hydrilla* spp., which is very palatable to grass carp. Additionally, there was no concern about mortality. Data from the literature [5] showed that most studies on aquatic weed control used much lower stocking density than that of the present study. They used much larger size fish than that of our study and their goal was not to eliminate all aquatic weeds. There is no available information about appropriate stocking densities to achieve continuous elimination of aquatic weeds. Manipulating grass carp stocking densities in a long-term study and simulation model is the way to achieve this goal [29].

Average daily growth rates of grass carp ranged between 3.47 and 6.25 g day^{-1} (Table 4). The rates of growth from this study were similar to other findings [30]. However, other studies [5] have indicated much higher growth rates (1.0, 14.7, 10.4 g day^{-1} respectively) than that of this study. These variations in the daily growth rates are related to growing season, food quality and quantity [31], environmental factors (water temperature and water quality) and fish stocking density [5].

Conclusions

Conclusions are that grass carp adapted well to the new environment, and a stocking rate of 3 fish m^{-2} is the least stocking density to achieve the goal of aquatic weed control in one year under our experimental conditions. Water quality parameters would change moderately. Grass carp feeding activity may have enhanced phytoplankton production.

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References

[1]Khattab, A. F., Gharably, Z. and Dubbens, F. A.A. 1981. The grass carp, a future alternative for control of aquatic weeds in the Arab Republic of Egypt. Proc. 4th Afro-Asian Reg. Conf. ICID, Lagos, Nigeria, **2**:215–226.

[2]Dougherty, T. C. and Hall, A. W. 1995. Environmental Impact Assessment of Irrigation and Drainage Projects. 53 FAO Irrigation and Drainage Paper. Publications Division, Food and Agriculture Organization of the United Nations, Rome, Italy.

[3]Fernandez, O. A., Irigoyen, J. H., Sabbatini, M. R. and Brevedan, R. E. 1987. Aquatic plant management in drainage canals of southern Argentina. J. Aquat. Plant Manag. **25**:65-67.

[4]Shaltout, K. and El-Halawany, E. 1993. Vegetation analysis of the irrigation and drainage canals in the Eastern Saudi Arabia. Journal of the University of Kuwait (Sci.) **20**:261-273.

[5]Shirman J. V. and Smith, C. R. 1983. Synopsis of biological data on grass carp *Ctenophoraygodon idella* (Cuvier and Valenciennes, 1844). FAO Fisheries Synopsis **135**:86.

[6]Sutton, D. L. and Vandiver Jr., V. V. 2000. Grass Carp: A Fish for Biological Management of Hydrilla and Other Aquatic Weeds in Florida. Bulletin 867, Department of Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, University of Florida.

[7]Aliev, D. S. 1976. The role of phytophagous fish in the reconstruction of commercial ichthyofauna and biological melioration of water reservoirs.

[8] Opuszynski, K. and Shireman, J. V. 1995. Herbivorous fishes culture and use for weed management. CRC Press, Inc., Boca Raton, Florida, pp. 223.

[9]Diaz, F., Espina, S., Rodriguez, C. and Soto, F. 1998. Preferred temperature of grass carp *Ctenophoraygodon idella* (Valenciennes), and brema carp, *Megalobrema amblycephala* (Yih), (Pisces, Cyprinidae) in horizontal and vertical gradients. Aquacul. Res. **29**:643-648.

[10]Cassani, J. R. and Caton, W. E. 1983. Feeding behavior of yearling and older hybrid grass carp. J. Fish Biol. **22**:35.

[11]Stanley, J. G., Miley, W. W. II and Sutton, D. L. 1978. Reproductive requirements and likelihood for naturalization of escaped grass carp in the United States. Trans. Amer. Fish. Soc. **107**:119-120.

[12]Bromage, N., Porter, M. and Randall, C. 2001. The environmental regulation of maturation in farmed finfish with special reference to the role of photoperiod and melatonin. Aquaculture **197**:63–98.

[13]Siddiqui, A. Q. and Adam, A. A. 1990. Ecological study of small lakes and the main drainage canal in Hofuf to see the possibility of using drainage water for aquaculture (in Arabic with English summary). Department of General Research Grants Program, King Abdul Aziz for Science and Technology, Riyadh, Saudi Arabia.

[14]AOAC (Association of Official Analytical Chemists) 1990. Official Methods of Analysis. 13th edn, AOAC, Washington.
[15]Lorenzen, C. D. 1967. Determination of chlorophyll and phaepigment: Spectrophotometric Equations. Limnol. Ocean. **12**:343-346.
[16]Boyd, C. E. 1980 Water Quality in Warm Water Fish Ponds. Graft Master Printers, Inc., Opelika, Alabama, USA.
[17]Statistical Analysis System 1995. SAS/STAT User's Guide, version 6.10. SAS Institute Inc., Cary, North Carolina, USA.
[18]Snedecor, G. W. and Cochran, W. G. 1981. Statistical Methods. 7th edn, The Iowa State University Press, Ames, Iowa, pp. 233-236.
[19]Wiley, M. J., Gorden, R. W., Waite, S. W. and Powless, T. 1984. The relationship between aquatic macrophytes and sports fish production in Illinois ponds: A simple model. N. Am. J. Fish. Manage. **4**:111.
[20]Canfield, D. E. Jr., Langeland, K. A., Maceina, M. J., Hellen, W., Shireman, J. V. and Jones, J. R. 1983. Trophic state classifications of lakes with aquatic macrophytes. Can. J. Fish. Aq. Sci. **40**:1713-1718.
[21]Hestand, R. S. and Carter, C. C. 1978. Comparative effects of grass carp and selected herbicides on macrophyte and phytoplankton communities. J. Aquat. Plant Manag. **16**:43-50.
[22]Leslie, Jr., A. J., Nall, L. E. and Van Dyke, J. M. 1983. Effects of vegetation control by grass carp on selected water quality variables in four Florida lakes. Trans. Am. Fish. Soc. **112**:777-787.
[23]Zonneveld, N. and Van Zon, H. 1985. The biology and culture of grass carp (*Ctenopharyngodon idella* Val.) with special reference to their utilization for weed control. Rec. Adv. Aquacult. **2**:120.
[24]Stronganove, D. J. 1963. The food selectivity of the grass carp. In Problems of the Fisheries Exploitation of Plant Eating Fishes in the Water Bodies of the USSR. Akademia Nuk Turkmenistan, 181 p.
[25]Bonar, S. A., Bolding, B. and Divens, M. 2002. Effects of triploid grass carp on aquatic plants, water quality, and public satisfaction in Washington State. N. Am. J. Fish. Man. **22**:96-105.
[26]Pipalova, I. 2002. Initial impact of low stocking density of grass carp on aquatic macrophytes Aquat. Bot.**73**(1):9-18.
[27]Gharably, Z., Khattab, A. F. and Dubbers, F. A. 1982. Experience with grass carp for control of aquatic weeds in the irrigation canal and deains in Egypt. Proceeding of the 2nd EWRS Symposium on Herbivorous Fish, Novi Sad, pp. 17-26.
[28]Hanlon, S. G., Hoyer, M. V., Cichra, C. E. and Canfield Jr., D. E. 2000. Evaluation of macrophyte control in 38 Florida lakes using triploid grass carp. Journal of Aquatic Plant Management **38**:48-54.
[29]Santha, C. R., Grant, W. G., Neil, W. H. and Strawn, R. K. 1991. Biological control of aquatic vegetation using grass carp: Simulation of alternative strategies. Ecolo. Model. **59**:229-245.
[30]Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Trans. Amer. Fish. Soc. **107**:135-145.
[31]Shirman, J. V., Colle, D. E. and Maceina, M. J. 1980. Grass carp growth rates in Lake Wales, Florida. Aquaculture **19**:379-382.
[32]Al-Shaheen, M. T. 2000. Utilization of Reed *Phragmites australis* in Fattening Rations of Sheep. Master thesis, Department of Animal Sciences, College of Agriculture and Food Sciences, King Faisal University, Al-Hassa, Saudi Arabia.