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PERFORMANCE AND COSTS OF GRASS CARP IN CONTROLLING AQUATIC WEEDS COMPARED TO MECHANICAL CONTROL IN SOME EGYPTIAN CANALS (CASE STUDY)

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ABSTRACT: *During the recent years, biological weed control in Egypt has faced questioning for its ability to submerged weeds control; and its application does not reduce the costs of canals maintenance. Therefore, the study aims to verify the performance and costs of grass carp in controlling submerged aquatic weeds and compared to mechanical control in some earthen and lined canals in Aswan governorate. Six earthen and lined canals with a high rate of submerged aquatic weeds growth were selected in the irrigation administration of Aswan governorate. The results of the study showed that the biological control of submerged weeds by grass carp led to decrease the percentage of submerged weeds infestation in the canals that subjected to biological control compared to the similar canals that subjected to mechanical control. Grass carp prefer to feed on submerged aquatic weeds types in the studied canals as follows: Vallisneria spiralis, followed by Ceratophyllum demersum and finally Myriophyllum spicatum. The value of the condition factor for grass carp was above 1, indicated good condition of the fish growth. Water quality was good and valid for grass carp growth. The average decreasing in the costs per kilometer for the canals and reaches that subjected to biological weed control was 7880 LE, with a decreasing percentage of 38% compared to mechanical control. It is recommended to control submerged aquatic weeds using grass carp in suitable Egyptian canals through applying an integrated management program. The program is combination of mechanical removal process of weed a one-time before stocking fish, then, stocking rates of 100 kg/ha.*

KEYWORDS: performance, grass carp, biological weed control, mechanical weed control, costs**,** Egyptian canals.

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INTRODUCTION

Aquatic weeds in canals can cause many problems. The presence of aquatic weeds with high density in the canals leads to bottlenecks in cross sections, which lead to unfair water distribution (Reda and Nasr 2006). Dense submerged weed growth reduce the discharge capacity of the canals (Abdel Salam, 2015). Whereas, emergent and floating weeds increase the rate of water loss by evapotranspiration (Ali and Khedr 2018). In Egypt, Aquatic weeds are controlled by three methods, which are mechanical, manual and biological. Although mechanical weed control in canals is the most widely used for rapid removal of aquatic weeds, may lead to aggressive dredging the cross sections of canal became deeper and wider. Therefore, it directly affects the water distribution and their velocity and the rate of aquatic weed growth which negatively effects on hydraulic efficiency and required maintenance works (Awad, 1998; Abdel Salam, 2015). Manual control was applied in canals of bed width less than 2 m in Manual Channel Maintenance Project to clean and maintain small Egyptian canals by using developed manual tools during the period from 1995 to 2002. This method is reliable because it cleans the canal without any damage for the cross section (El Samman and Abou El Ella 2009). In 2015, the periodic manual weed maintenance on Desonas Canal in Beheira Governorate reduced the aquatic weed infestation with a percentage reach to 64% (Ali, 2020). Since 1990, the biological weed control using grass carp was adopted in Egyptian irrigation networks as an alternative approach for chemical method, the aquatic submerged weeds were controlled biologically in some canals and Aswan Reservoir (Bakry *et al.*, 2004; Ali and El-Samman 2018).

Grass carp growth is a function of age, size and abiotic factors such as stocking density, quantity and quality of weed present from preferred and non-preferred types, the conditions are appropriate for grass carp growth and feeding (e.g. temperature, oxygen, pH and water level). Biological weed control is effective if submerged weeds removed before fish stocking and prior to the beginning of the rapid growth of weeds, until the fish are able to manage or reduce the weeds. Therefore, Pipalova (2006) mentioned that the initial plant density is as important as grass carp stocking density.

Stocking density of grass carp in lakes is less than waterways due to the percentage of coastal areas (the preferred feeding areas for carp fish) in lakes water is less than that of waterways, this reported by (Pipalova 2006). Adámek *et. al.,* (2003) reported that the total length of grass carp stocking in Czech Republic should be larger than 12 inches to avoid

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predation by fish, birds and otter. Grass carp stocking in the Egyptian waterways ranging between 4 - 8 inches to controlling aquatic weed and avoid predation by fish only (Abou El Ella and El Samman 2013).

Grass carp have specific preferences of aquatic submerged weed. It control certain species of them better than others, this fish prefer to feed first on succulent submerged weeds when smaller in size (Hanlon *et. al.*, 2000). When the fish gained size larger than 500 g they feed on the fibrous weeds (Filizadeh *et. al.,* 2004). *Myriophyllum spicatum* known as spiked water milfoil. It is a submerged aquatic plant, grows in the beginning of spring from broken off stems in still or slow-moving water. It is considered to be a highly invasive species (Gross, *et. al.,* 2003; CABI, 2018). Grass carp is preferred this plant sometimes or controlled as mentioned by Filizadeh *et al.*, 2004 and Silva, *et. al.*, 2014. *Ceratophyllum demersum*, known as coontail, it is a submerged weed and grows in slow-moving water. It is classed a harmful weed and as an unwanted organism which has caused problems with hydroelectric power plants in New Zealand (Global Invasive Species database 2006). Filizadeh *et. al.*, (2004) reported that the plant is classified from the plants sometimes preferred or controlled after succulent weed. *Vallisneria spiralis* known as tape grass. This species is an effective invader due to its efficient dispersal (Wasowicz, *et. al.*, 2014). The plant is classified from the plants consumed preferentially or controlled by Grass carp.

The relationship between length-weight and condition factor is one of the performance indicators to evaluate the relationship among fish growth, aquatic organisms, water productivity, and the level of fish health (Belal, 2007; Richter and Rypel 2008; Muchlisin, *et. al.,* 2010; Prabha and Kusum 2017). Water temperature for food consumption by the grass carp is 20 to 28°C (Krupauer, 1989; Belal, 2007). Grass carp feeding can be reduced by increased salinity, low water temperature, and low dissolved oxygen <4 ppm, and fish stop feeding if DO falls below 2 ppm (Pipalova 2006; Sutton and Vandiver, 2006; Colle 2009). Sutton and Vandiver, (2006) reported that grass carp can tolerate salinities reach to 10 parts per thousand, however, they will not feed when salinity are higher than 6 parts per thousand.

Mcfadyen, (2000) reported that successful biological control sufficient to have impact on the target species, very cost-effective and achieve a net economic benefit. Moazzem, *et. al.,* (2020) found that the net economic benefit from feeding grass carp on water grass was obtained and may reduce the production cost. Also, it may enhance the socio-economic condition for the poor people and total fish production of the country. The research's in Europe various countries showed that the efficiency of the fish for weed control is high, that costs are low (Van Zon, 1997). In Egypt, the Egyptian-Dutch project (1976 - 1983) has shown that a stocked grass carp not only provides effective weed control, but it also increases the protein production in Egyptian waterways substantially (Van Zon, 1984). In the analysis of previous studies of the Channel Maintenance Research Institute (Ali and El-Samman, 2018) proved that the applying biological weed control in Suez canal (1987 - 1996), West Al-Nubaria drain (1999) and the reach between High Dam and Aswan Reservoir (1999 -2016) reduced the costs of maintenance by about 64%, 46% and 43% compared to mechanical control, respectively.

The problem, during the recent years, biological weed control in Egypt has faced questioning for its ability to submerged weeds control; and its application does not reduce the costs of canals maintenance. On the other hand, although mechanical weed control in canals is the most widely used for rapid removal of aquatic weeds, the implementation of uncontrolled maintenance programs and aggressive dredging for the cross sections of canal became deeper and wider. This negatively effects on hydraulic efficiency and increases the required maintenance work and cost of the Egyptian canals. Therefore, 6 earthen and lined canals with a high rate of submerged aquatic weeds growth were selected in the irrigation administration of Aswan governorate for the present study.

This study aims to: 1) Verify the performance of grass carp in controlling submerged weeds, through (i) Estimating infestation percentages in the canals subjected to biological control compared to similar canals that subjected to mechanical weeds control. (ii) Measuring the growth rate of grass carp under different conditions. (iii) The effect of introducing grass carp on water quality properties of the canals water. 2) Estimate the direct economic return of applying biological control in the earthen and lined canals compared to similar canals that applied mechanical control, and also, the indirect economic return from applying biological control.

MATERIAL AND METHODS

Study area

In the irrigation administration in Aswan, Seven earthen and lined canals were selected for this study during the period from February 2019 to October 2019, as shown in Figure (1). Six earthen canals, 5 of them (Kassel canal, Al-Silsila canal, Al-Dukka canal, Al-Tuwaisa canal and Bilana canal) were selected for biological control application, while the sixth canal (Toshka and Abu Simble) was selected for mechanical control application. The seventh is lined canal (Al-Naqra canal), 3 reaches (from pump station 1 to pump station 2, from station 2 to station 3 and from station 3 to station 4) were selected for biological control application, while, the fourth reach from station 4 to station 5 in the same canal were selected for mechanical control application.

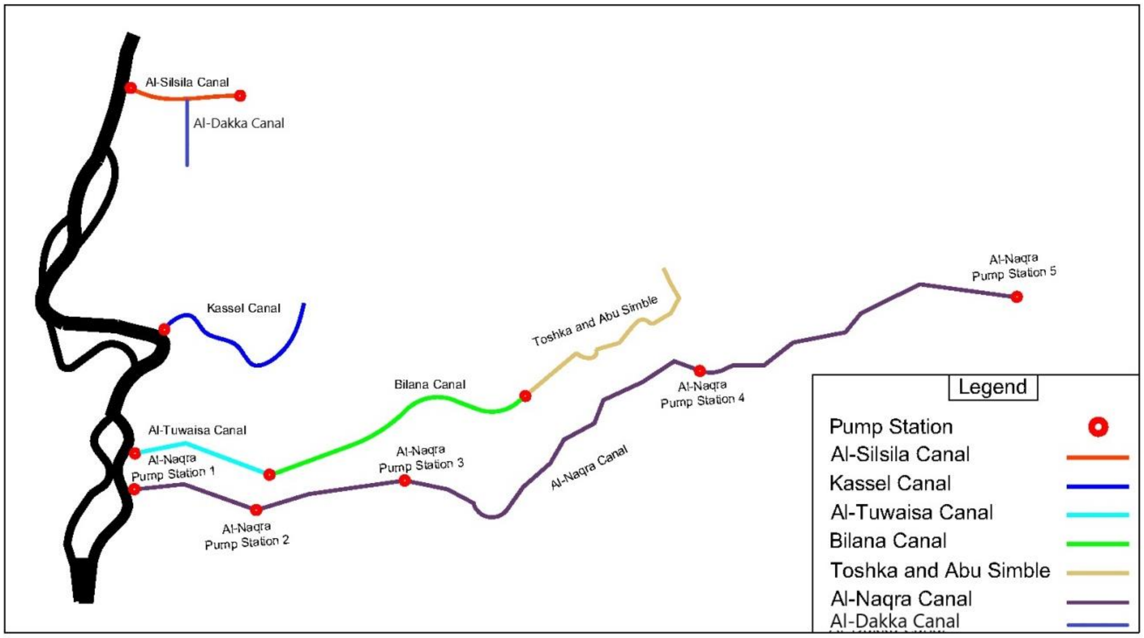

Figure 1: Map shows the selected canals and reaches to apply the biological and mechanical weed control in the irrigation administration of Aswan governorate during 2019.

Application of biological and mechanical control in the studies canals

The biological and mechanical control was conducted during the period from February 2019 to October 2019 according to the following steps:

- One to two weeks before stocking grass carp fingerlings in the canals and reaches, the submerged weed were mechanically removed. This is the start the experiment with similar conditions of used infestations. Moreover, weed removal before grass carp stocking would allow some open water areas for fish growth and increase dissolved oxygen water (NIWA, 2014).
- A barrier was installed from chains on nozzles at the inlet of the sub-canal located on the canals and reaches that subjected to biological control. The spaces between the chains narrower than the stocked grass carp's body width to prevent escaping the fish and allowing unrestricted movement of water, as described by (Hofstra and Rowe 2008).

- The stocking density of grass carp in canals and reaches was calculated based on the total waterway area, not the infested area, as described by (Schramm and Brice 1998; Abou El Ella and El Samman, 2013).
- The stocking density was 100 kg/ha with a weight ranged between 10 - 13 grams (An approximate rate of one fish m^2). The fingerlings were stocked about 800 thousand fingerlings and were distributed on canals and reaches as shown in Table (1).
- Mechanical control was carried out by two methods, the first method of weeds removed using two tractors and a chain carrying hooks. The second method of weed removing was using a hydraulic excavator.
- During the study, the number of mechanical weed removal processes in canals subjected to biological control was less than the number of weed removal processes in the canals subjected to mechanical control only.

Table 1: Stocking density of grass carp fingerlings numbers a rate of (100 kg/ha) in the canals and reaches that subjected to biological weed control in Aswan Governorate during 2019.

Canal/reach	Length of the canal /reach (m)	Average of water surface width (m)	Total area (m^2)	Numbers of fish fingerlings stocked (10^3)
Al-Silsila Canal	3400	24	81600	85
Al-Dukka Canal	1300	24	31200	35
Kassel Canal	5200	24	124800	125
Al-Tuwaisa Canal	2500	20	50000	50
Bilana Canal	9500	20	190000	190
Al-Naqra Canal **(reach from station 1 to station 2)**	3500	17	59500	60
Al-Naqra Canal **(reach from station 2 to station 3)**	3200	17	54400	55
Al-Naqra Canal **(reach from station 3 to station 4)**	11750	17	199750	200
Total of fingerlings stocked				**800**

Estimation of infestation weeds percentages and determination their types

Survey was conducted on the cross sections of the studied canals using Echo Sounder every 200 meters to monitor the percentage of submerged weed infestation. 26 sections in Kassel canal, 11 sections in Al-Silsila canal, 6 sections in Al-Tuwaisa canal, 19 sections in Bilana canal, 12 sections in Toshka and Abu Simble canal, 5 sections of reach from station 1 to station 2 in Al-Naqra canal, 8 sections of reach from station 2 to station 3 in Al-Naqra canal, 50 sections of reach from station 3 to station 4 in Al-Naqra canal, 37 sections of reach from station 4 to station 5 in Al-Naqra canal. This survey was repeated five times during February, April, June, August and October 2019. To estimate the infestation percentage of submerged weeds, the area of submerged weed infestation was calculated of the surveyed cross-sections attributed to the total water area of these sections. Site investigation and visual observations were performed for the determination of submerged weeds types during the five field visits.

Measure the growth rate of grass carp

100 grass carp fish samples were caught from each canal that subjected to biological control on 5 periods every two months (at a rate of 20 fish per period) during February, April, June, August and October 2019. Weight and length of grass carp samples were measured to calculate weight gain (WG), length gain (LG), Average daily weight gain (ADWG), Average Daily length gain (ADLG), according to (Carlos, 1988) as follows:
Weight gain (WG) was calculated from the following equation:

$$WG = \text{final Weight (g)} - \text{initial Weight (g)}.$$

Length gain (LG) was calculated from the following equation:

$$LG = \text{final Weight (g)} - \text{initial Weight (g)}.$$

Average Daily weight gain (ADWG) was calculated from the following equation:

$$ADWG = \frac{final\ weight\ rate(g) - initial\ weight\ rate(g)}{time\ period\ (day)}\ x\ 100.$$

Average Daily length gain (ADLG) was calculated from the following equation:

$$ADLG = \frac{final\ length\ rate(cm) - initial\ length\ rate(cm)}{time\ period\ (day)}\ x\ 100.$$

The Fulton (K) condition factor was analyzed according to (Okgerman, 2005) equation given: $K = WL^{-3} \times 100$. Where: K is a Fulton condition factor, W is the weight of fish (g), L is the total length of fish (cm), -3 is a correction factor for the length coefficient leading to number one. Fish are considered to be in good growth when the condition fish is ≥ 1 g/cm^3. Fish were dissected, and the food content from the intestine was collected to verify the fish feeding on the submerged weed types.

Sampling and laboratory analysis of water

Water samples were collected from locations in the studied reaches and canals on three time periods during February, June and October 2019. Water samples were collected from midstream water about 30 cm beneath water surface by water sampler and saved in cleaned polyethylene bottles. All water samples were filtered using whatman No. 42 filter paper. Preliminary treatment and preservation methods for various water parameters were applied according to (APHA, 2017). Water samples were analyzed in the laboratories of the National Water Research Center (NWRC). pH samples were measured using a combined

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electrode connected to a pH meter, Dissolved oxygen (DO) was measured using a combined electrode connected to a (DO) meter and Electrical conduction (EC) was determined by digital electrical conductivity meter. Ammonium (NH_4^+), Nitrate (NO_3^-) and Phosphate (PO_4^{3-}) were determined spectrophotometrically as described by (APHA, 2017).

The economic return of applying biological control

Proofing that implementing appropriate application of biological control reduces the aquatic weed maintenance cost is one of the main objectives of the present study. Therefore, the direct and the indirect economic return of applying biological control have been estimated. The direct economic return was estimated by comparing the costs of applying biological weed control with the costs of applying mechanical weed control in the similar canals and reaches. In the earthen canals, the average maintenance costs per kilometer in the five canals, Kassel canal, Al-Silsila canal, Al-Dukka canal, Al-Tuwaisa canal and Bilana canal (biological weed control) were compared with average maintenance costs per kilometer for Toshka and Abu Simbel canal (mechanical weed control) for the year 2019. In the lined Al-Naqra canal, the average maintenance costs per kilometer for 3 reaches (from station 1 to station 2, from station 2 to station 3 and from station 3 to station 4) that subjected to biological weed control were compared with average maintenance costs per kilometer of the fourth reach from station 4 to station 5, that subjected to mechanical weed control in the same canal through the year 2019. Also, the reduction in the number of weeds removal processes in the studied canals and reaches in year 2019, was compared to the average number of weeds removal in the same canals and reaches in previous years (for the period from 2014 to 2018). The indirect economic return was estimated as the increase in animal protein for fish produced at the end of the study, in addition to other returns.

RESULTS AND DISCUSSION

Weed infestation percentages in canals and their types

The weed infestation percentages in canals subjected to biological and mechanical control were estimated during 5 periods as shown in Table (2). The results of the cross sections measurements showed the infestation percentages of submerged weeds in the five earthen canals (Kassel, Al-Silsila, Al-Dukka, Al-Tuwaisa and Bilana) was lower than the infestation percentages of Toshka and Abu Simble canal. Also, the infestation percentages of submerged weeds in the three reaches of lined Al-Naqra canal (from station 1 to station 2, from station 2 to station 3 and from station 3 to station 4) were lower than the infestation percentages in the fourth reach (from station 4 to station 5). This is evidence that, the

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biological weed control in the earthen and lined canals was better than mechanical weed control. This largely due to the applying the correct criteria for biological weed control, this agrees with (Ali and El Samman, 2018). Sites investigation and visual observations during the field visits were preformed, three plants related to aquatic submerged weed were observed with different degrees of spreading. *Myriophyllum spicatum* is the highest spread value, followed by *Ceratophyllum demersum*, then *Vallisneria spiralis*.

Table 2: Weed infestation percentages in the canals and reaches subjected to biological and mechanical weed control in Aswan Governorate during the period (Feb. – Oct. 2019)

Canal/ reach	Control type	Reach distance (Km.)		Average of total infestation of submerged weeds %				
		From (Km)	To (Km)	Feb-19	Apr-19	Jun-19	Aug-19	Oct-19
Al-Silsila Canal	Biological	0.000	3.400	6.0±0.35	6.6±0.23	12.0±0.45	8.5±0.26	5.8±0.28
Al-Dukka Canal	Biological	0.000	1.300	6.5±0.29	4.7±0.19	7.2±0.33	5.6±0.19	3.3±0.18
Kassel Canal	Biological	0.000	5.200	3.5±0.19	2.8±0.07	2.0±0.11	1.5±0.06	0.5±0.04
Al-Tuwaisa Canal	Biological	0.000	2.500	3.8±0.21	4.1±0.32	7.6±0.22	4.5±0.23	3.0±0.17
Bilana Canal	Biological	0.000	9.500	5.8±0.32	6.5±0.19	13.0±0.47	8.2±0.33	4.7±0.31
Toshka and Abu Simble Canal	Mechanical	0.000	7.500	9.0±0.42	19.7±0.22	17.6±0.38	16.8±0.27	19.2±0.52
Al-Naqra Canal (station 1 to station 2)	Biological	0.000	3.500	4.0±0.17	3.5±0.29	2.5±0.09	1.8±0.08	1.2±0.06
Al-Naqra Canal (station 2 to station 3)	Biological	3.500	6.700	1.0±0.08	1.8±0.07	2.6±0.07	1.9±0.14	0.8±0.05
Al-Naqra Canal (station 3 to station 4)	Biological	6.700	18.450	7.0±0.36	4.5±0.23	4.2±0.25	2.1±0.08	1.8±0.07
Al-Naqra Canal (station 4 to station 5)	Mechanical	18.450	37.000	2.0±0.11	1.9±0.06	2.1±0.14	3.2±0.21	4.1±0.25

Preferences of submerged weed types by grass carp

Visual observations were conducted for the submerged weeds types spread in the canals. In addition to, submerged weeds types were examined inside the intestines of fish during the follow up growth rate of fish during different age's stages. Very low infestation rates of *Vallisneria spiralis* were spotted, it is a succulent weed; and also, it is one of the preferred species was found inside the intestines of grass carp. Moderately low infestation rates of *Ceratophyllum demersum* was spotted, it is less preferred for the grass carp fish than the previous one. This agree with (Belal, 2007) reported that treatment with 1 fish for m^{-2} grass carp (the same of stocked rate in the current study) did not completely eliminate *Ceratophyllum demersum*. Also, (Dochink, *et. al.*, 2020) reported that the aquatic weed (mostly *Ceratophyllum demersum* L.) was successfully reduced in ponds stocked with two-year-old grass carp. When the fish gained more weight, they was observed feed on all weeds including *Myriophyllum spicatum* (this specie has coarse-leaved), this agree with (Hanlon *et. al.*, 2000; Filizadeh *et. al.*, 2004). Therefore, the three plants were classified in terms of preference for grass carp for feeding them: *Vallisneria spiralis*, followed by

Ceratophyllum demersum and finally *Myriophyllum spicatum*, this prefer behavior of grass carp agrees with (Catarion, *et. al.*, 1997; Silva, *et. al.*, 2014).

Stocking density, growth rates and condition factor of grass carp

The stocking density of grass carp of 100 kg/ha (Table 1) was led to eliminate most aquatic weeds in the canals under study as shown in Table (2). In some studies, Hanlon, *et. al.*, (2000) and Pipalova, (2002) reported that the high stocking rates (higher than the current study) was used to compensate for any mortality due to the presence of any carnivorous fish in the canals. While, in this study carnivores fish in the canals were not detected. Another studies, used larger grass carp to stock waterways at much lower rates than that used in this study, because the goal was not to eliminate all aquatic weeds (Shirman and Smith, 1983). The results in Table (3) showed that when grass carp feed on submerged aquatic weed, the net weight of grass carp was gained (WG) from 781 - 913 g/240 day. These results are similar to the results (Majhi, 2005) who mentioned that grass carp when fed on submerged weeds attaining about 1.0 – 1.2 kg in a year. The average daily weight gain (ADWG) of grass carp ranged from 3.26 - 3.81 g/day about 106 grams per month, this rates of growth were similar to findings (Belal, 2007). The average of length gain (LG) ranged from 30.4 - 32.6 cm/240 day, while, the average daily length gain (ADLG) ranged from 0.126 - 0.136 cm/day about 4 cm (1.5 inches) per month. The value of the condition factor of grass carp was ranged from 1.27 - 1.40 (>1) in all canals and reaches under the study as shown in the table (3), meant that the fish is good condition and feed on submerged weed in this canals, and the possibility for predators are very low, this agree with (Paiboon and Kriangsak, 2015).

Table 3: The weight gain and length and condition factor of grass carp in the canals and reaches of Aswan Governorate during the period (Feb. – Oct. 2019)

Canal/ reach	No. of fish	IW (g)	FW (g)	WG (g)	ADWG (g/day)	IL (cm)	FL (cm)	LG (cm)	ADLG (cm/day)	K (g/cm^3)
Al-Silsila Canal	100	12.5±1.2	926±15.5	913.5±12.5	3.81±0.02	9.7±0.09	42.3±0.21	32.6±0.22	0.136±0.007	1.28±0.07
Al-Dukka Canal	100	13.5±1.3	795±17.1	781.5±13.2	3.26±0.03	9.8±0.08	40.8±0.22	31.0±0.18	0.129±0.008	1.33±0.08
Kassel Canal	100	11.5±0.9	815±13.8	803.5±11.2	3.35±0.04	9.6±0.11	40.0±0.19	30.4±0.21	0.126±0.006	1.32±0.09
Al-Tuwaisa Canal	100	13.1±1.4	865±16.2	851.9±13.9	3.55±0.06	9.8±0.10	40.9±0.22	31.1±0.23	0.129±0.003	1.35±0.07
Bilana Canal	100	10.9±1.1	820±17.1	809.1±15.7	3.37±0.02	9.6±0.08	41.4±0.31	31.8±0.25	0.133±0.006	1.27±0.06
Al-Naqra Canal (station 1 to station 2)	100	12.4±1.2	895±15.5	882.6±13.4	3.67±0.03	9.7±0.01	40.6±0.23	30.9±0.19	0.128±0.007	1.40±0.07
Al-Naqra Canal (station 2 to station 3)	100	12.9±1.3	865±16.8	852.1±14.9	3.55±0.04	9.8±0.12	40.5±0.25	30.7±0.21	0.128±0.008	1.33±0.06
Al-Naqra Canal (station 3 to station 4)	100	11.2±0.9	835±14.9	823.8±12.8	3.43±0.05	9.6±0.08	41.2±0.27	31.6±0.23	0.132±0.005	1.33±0.07

IW: initial weight, FW: final wright, WG: weight gain, ADWG: Average daily weight gain, SGR: specific growth rate, IL: initial length, FL: final length, LG: length gain, ADLG: Average daily length gain, , K: Condition factor.

Water quality in the canals

The mean and the standard deviation values with regard to various physico-chemical properties of water quality in canals and reaches during the study period, (Table 4) showed that the average water temperature from 20.7 to 27.1°C, this temperature achieves a high feeding rate by grass carp, this agree with (Krupauer, 1989; Belal, 2007). The average dissolved oxygen (DO) concentration ranged between 5.22 – 5.91 mgL^{-1} (> 4 mgL^{-1}), these concentrations are suitable for feeding grass carp on submerged aquatic weeds, this results agrees with (Pipalova 2006, Sutton and Vandiver, 2006; Colle, 2009). The pH level after stocked grass carp during the study period was stable and tended to slightly alkaline, no noticeable change occurred, and it ranged between 7.36 – 7.98. The average nutrients concentration in all canals and reaches ranged between 0.01 – 0.13, 0.76 – 1.58 and 0.18 – 0.39 mgL^{-1} for NH_4, NO^{3-}, and PO_4^{3-} respectively. These lower concentrations of the nutrients do not affect the growth and efficiency of grass carp in feeding the submerged aquatic weeds. Although excretions of grass carp into water can lead to the release of nutrients and cause an acceleration of eutrophication process in water, but water velocity in the studied canals can limit the eutrophication process in water. In general, the ranges of water quality parameters recorded during the study period were suitable for growth carp fish and feeding on submerged aquatic weeds which are supported by many other authors (Chowdhury and Hasan, 2015; Uddin *et. al.,* 2016; Moazzem, *et. al.,* 2020).

Table 4: Mean (± SD) values of physico-chemical properties of water quality in canals and reaches of Aswan Governorate during the stocking fish period (Feb. – Oct. 2019)

Canals name	Date	No. of sample	Temp. (Cº)	DO (mgL^{-1})	pH	EC (dSm^{-1})	NH_4 (mgL^{-1})	NO_3^- (mgL^{-1})	PO_4^{3-} (mgL^{-1})
Al-Silsila Canal	Feb-19	12	21.4±0.05	5.22±0.06	7.68±0.03	0.352±0.04	0.02±0.01	1.12±0.09	0.24±0.05
	Jun-19	12	26.1±0.08	5.63±0.05	7.36±0.04	0.324±0.02	0.04±0.02	1.25±0.10	0.28±0.06
	Oct-19	12	24.4±0.06	5.74±0.05	7.64±0.02	0.347±0.03	0.05±0.01	1.38±0.09	0.29±0.03
Al-Dukka Canal	Feb-19	12	21.8±0.06	5.75±0.03	7.75±0.02	0.349±0.04	0.04±0.02	1.14±0.07	0.28±0.05
	Jun-19	12	26.2±0.09	5.75±0.04	7.63±0.03	0.354±0.05	0.05±0.01	1.28±0.11	0.33±0.02
	Oct-19	12	24.4±0.08	5.81±0.07	7.71±0.03	0.352±0.08	0.07±0.01	1.53±0.12	0.34±0.04
Kassel Canal	Feb-19	12	21.8±0.04	5.60±0.06	7.74±0.03	0.269±0.02	0.03±0.01	1.34±0.15	0.24±0.03
	Jun-19	12	26.9±0.07	5.91±0.08	7.57±0.02	0.282±0.01	0.06±0.02	1.48±0.14	0.29±0.04
	Oct-19	12	24.4±0.06	5.74±0.05	7.68±0.01	0.281±0.03	0.09±0.01	1.53±0.08	0.35±0.03
Al-Tuwaisa Canal	Feb-19	12	21.6±0.05	5.64±0.04	7.82±0.02	0.262±0.04	0.01±0.01	0.95±0.13	0.24±0.05
	Jun-19	12	26.1±0.09	5.80±0.08	7.64±0.03	0.266±0.02	0.06±0.01	1.18±0.12	0.30±0.03
	Oct-19	12	24.2±0.07	5.45±0.05	7.71±0.05	0.267±0.03	0.09±0.02	1.44±0.10	0.34±0.04
Bilana Canal	Feb-19	12	21.8±0.06	5.45±0.04	7.76±0.03	0.273±0.04	0.01±0.03	0.87±0.08	0.23±0.03
	Jun-19	12	27.0±0.09	5.62±0.07	7.63±0.04	0.267±0.06	0.08±0.02	1.22±0.15	0.34±0.04
	Oct-19	12	24.8±0.07	5.70±0.07	7.71±0.05	0.277±0.04	0.09±0.04	1.27±0.03	0.35±0.06
Toshka and Abu Simble Canal	Feb-19	12	21.5±0.06	5.52±0.06	7.77±0.01	0.296±0.02	0.01±0.04	1.37±0.06	0.21±0.05
	Jun-19	12	26.5±0.09	5.73±0.05	7.68±0.01	0.294±0.04	0.06±0.05	1.46±0.07	0.28±0.06
	Oct-19	12	24.7±0.04	5.47±0.03	7.74±0.03	0.289±0.01	0.09±0.07	1.58±0.08	0.38±0.08
Al-Naqra Canal (station 1 to station 2)	Feb-19	12	20.7±0.07	5.33±0.06	7.74±0.02	0.269±0.03	0.06±0.05	0.86±0.06	0.18±0.03
	Jun-19	12	26.2±0.08	5.44±0.06	7.63±0.04	0.268±0.02	0.08±0.03	0.96±0.08	0.23±0.02
	Oct-19	12	24.9±0.07	5.31±0.07	7.71±0.03	0.268±0.04	0.11±0.02	1.18±0.12	0.36±0.04
Al-Naqra Canal (station 2 to station 3)	Feb-19	12	21.1±0.04	5.61±0.08	7.75±0.01	0.270±0.04	0.04±0.01	1.21±0.09	0.25±0.07
	Jun-19	12	27.1±0.08	5.91±0.07	7.69±0.02	0.282±0.02	0.06±0.02	1.34±0.14	0.27±0.06
	Oct-19	12	24.7±0.06	5.82±0.07	7.73±0.02	0.263±0.03	0.08±0.03	1.27±0.08	0.32±0.05
Al-Naqra Canal (station 3 to station 4)	Feb-19	12	21.3±0.05	5.50±0.08	7.73±0.03	0.271±0.04	0.07±0.04	0.76±0.07	0.33±0.06
	Jun-19	12	26.8±0.09	5.32±0.07	7.61±0.04	0.278±0.02	0.09±0.05	0.99±0.11	0.35±0.07
	Oct-19	12	24.6±0.07	5.44±0.05	7.68±0.02	0.282±0.03	0.10±0.01	1.16±0.12	0.39±0.04
Al-Naqra Canal	Feb-19	12	21.4±0.06	5.55±0.04	7.82±0.03	0.284±0.02	0.08±0.01	1.32±0.09	0.21±0.06

(station 4 to station 5)	Jun-19	12	26.5±0.09	5.30±0.08	7.68±0.02	0.278±0.01	0.09±0.03	1.44±0.08	0.25±0.07
	Oct-19	12	24.3±0.06	5.54±0.05	7.79±0.04	0.285±0.02	0.13±0.04	1.57±0.07	0.29±0.03

The direct economic return of applying biological control

The results in Table (5) shows that a decrease in the average cost of maintenance per kilometer of earthen canals for Al-Silsila Canal, Al-Dukka Canal, Kassel Canal, Al-Tuwaisa Canal, and Bilana Canal that subjected to biological weed control compared to Toshka and Abu Simbel canal that subjected to mechanical weed control was estimated about 12350, 12235, 16042, 3520, and 3520 LE, represent about 59.2%, 58.7%, 76.9%, 16.9%, and 16.9% respectively.

Table 5: Weed control costs in earthen canals (Aswan Governorate) subjected to biological control compared to similar earthen canal subjected to mechanical control during year 2019

Canal/ reach	Weed control method	Canal/reach length (km.)	Maintenance costs: Biological control costs (10^3 LE)	Maintenance costs: Mechanical control costs (10^3 LE)		Total control costs (10^3 LE)	Average cost per km (10^3 LE)	Percentage decreasing in the costs per Km. (%)
			Grass carp	Tractors	Hydraulic excavator			
Al-Silsila Canal	Biological	3.400	17.000	11.900	0	28.900	8.500	59.2
Al-Dukka Canal	Biological	1.300	7.000	4.200	0	11.200	8.615	58.7
Kassel Canal	Biological	5.200	25.000	0	0	25.000	4.808	76.9
Al-Tuwaisa Canal	Biological	2.500	10.000	8.950	24.375	43.325	17.330	16.9
Bilana Canal	Biological	9.500	38.000	34.010	92.625	164.635	17.330	16.9
Toshka and Abu Simble Canal	Mechanical	6.500	0	72.150	63.375	135.525	20.850	-

Source of data: Engineering Water Resources and Irrigation in Al-Naqra, Al-Tuwaisa, Kom Ombo and Al-Silsila in Aswan.

The results in Table (6) shows that a decrease in the average cost of maintenance per kilometer in the lined Al-Naqra canal for three reaches (from station 1 to station 2, from station 2 to station 3, and from station 3 to station 4) that subjected to biological weed control compared to fourth reach from Station 4 to Station 5 that subjected to mechanical weed control was estimated by 6533, 6730, and 7429 LE, representing about 31.9, 32.9, and 36.3% respectively.

Table 6: Weed control costs of lined reaches in Al-Naqra canal (Aswan Governorate) subjected to biological control compared to reach subjected to mechanical control in the same canal during year 2019

Canal/ reach	Weed control method	Canal/reach length (km.)	Biological control costs (10^3 LE)	Mechanical control costs (10^3 LE)		Total control costs (10^3 LE)	Average cost per km (10^3 LE)	Percentage decreasing in the costs per Km. (%)
			Grass carp	Tractors	Hydraulic excavator			
Al-Naqra Canal (station 1 to station 2)	Biological	3.500	12.000	0	36.670	48.670	13.906	31.9
Al-Naqra Canal (station 2 to station 3)	Biological	3.200	11.000	0	32.870	43.870	13.709	32.9
Al-Naqra Canal (station 3 to station 4)	Biological	11.750	40.000	35.242	77.620	152.862	13.010	36.3
Al-Naqra Canal (station 4 to station 5)	Mechanical	18.550	0	136.530	242.617	379.147	20.439	-

Source of data: Engineering Water Resources and Irrigation in Al-Naqra, Al-Tuwaisa, Kom Ombo and Al-Silsila in Aswan.

In general, the results of Tables (5) and (6) show that the average decreasing in the costs per kilometer in the canals and reaches that subjected to biological weed control was 7880 LE, with a decreasing percentage of 38%. The application of biological weed control has saved about 315.2 thousand LE in the canals and reaches under study (40 kilometers). It was clear that there is economic feasibility for biological weed control using grass carp to reduce the costs of maintenance in the earthen canals and the lined Al Naqra Canal, these agree with both (Van Zon, 1997; Greenfield *et al.*, 2004, Ali and Al-Samman, 2018; Moazzem, *et. al.*, 2020).

The results in Table (7) indicated that there was a significant decrease in the weed removal processes number from 1 to 5 times removal with a decreasing percentage from 50% to 100% in the canals and reaches that subjected to biological weed control in the year 2019, compared to the average weed removal numbers for the same canals and reaches during the period from 2014 to 2018. While there has been no change in the weed removal numbers for both Toshka and Abu Simbel canal, and reach from Station 4 to Station 5 in the Al-Naqra canal that subjected to mechanical weed control during the year 2019 compared to the average removing numbers during the period from 2014 to 2018 for the same canals.

Table 7: A comparison between the number of weed removal processes in the studied canals and reaches (Aswan Governorate) in 2019 with the average of previous years (2014-2018)

Canal/ reach	Weed control method	Canal/reach length	The average number of weeds removal processes (2014-2018)	Number of weeds removal processes 2019	Decreasing in number of removing	Percentage decreasing in number of removing
Al-Silsila Canal	Biological	3.400	7	2	5	71
Al-Dukka Canal	Biological	1.300	7	7	5	71
Kassel Canal	Biological	5.200	5	0	5	100
Al-Tuwaisa Canal	Biological	2.500	4	2	2	50
Bilana Canal	Biological	9.500	6	2	4	67
Toshka and Abu Simble Canal	Mechanical	7.500	8	8	0	0
Al-Naqra Canal (station 1 to station 2)	Biological	3.500	2	1	1	50
Al-Naqra Canal (station 2 to station 3)	Biological	3.200	2	1	1	50
Al-Naqra Canal (station 3 to station 4)	Biological	11.750	6	3	3	50
Al-Naqra Canal (station 4 to station 5)	Mechanical	18.550	6	6	0	0

Source of data: Engineering Water Resources and Irrigation in Al-Naqra, Al-Tuwaisa, Kom Ombo, and Al-Silsila in Aswan.

The indirect economic return of applying biological control

The indirect economic benefit resulting from the application of biological weed control by means of grass carp is represented in the following points:

- Converting unwanted weeds to fish protein, this agree with (Van Zon, 1984), 800 thousand fingerlings were placed in the canals understudy, assuming a loss rate estimated by 50%, and average one fingerling weight reach to 850 gm/240 day. Therefore, the amount of fish produced at the end of the study is estimated by 340 tons of carp fish and assuming, the price of a kilogram is about 10 LE, therefore, the indirect economic return converting weeds to protein is about 3.4 million LE.
- Using biological weed control is preserving canals reaches from cross-sections widening and this decrease the financial cost of rehabilitation. While, mechanical weed control causing the over widening of the canals cross-section, this agree with (Abdel Salam, 2015). In addition, weed removal provide an additional amount of water to reaching the ends, which will be used to increase the cultivated land and increase agricultural productivity.
- When applying biological weed control, that prevent the traffic and environmental problems arising from placing the residuals of weed on canal banks. While, using mechanical weed control leads to placing the residuals on canal banks. In addition, it may effect on cultivation part of the agricultural lands on both sides of the canals.

CONCLUSION AND RECOMMENDATIONS

The current study showed that:

- The biological weed control by means of grass carp in Egyptian canals has shown success, and it is considered an environmentally safe solution to reduce the spread of submerged weeds. And economically contributed to reduce maintenance costs.
- The infestation percentages of submerged weeds in the canals that applied the biological weed control were lowers than that of the canals which applied mechanical weed control only in the same study period.
- The biological weed control by grass carp is cheap method to control submerged aquatic weeds compared to mechanical control.
- The average cost reduction per kilometer of the canals and reaches that applied biological weed control was about 38% compared to the cost of mechanical weed control.
- Monitoring of aquatic weed control using grass carp within one year revealed that it gave good results, and it is expected that with the continuous application for several years it will give better results.
- Converting unwanted weeds to valuable fish protein is an additional benefit of using grass carp. This could improve the socio-economic status of the fishermen and farmers around canals, as well as for the all over Egypt in general, these agree with (Moazzem, et. al., 2020).

From the results of the study, it is recommended that:

- Control submerged aquatic weeds using grass carp through applying an integrated management program. The program is combination of mechanical removal process of weed one-time before stocking fish, then, stocking rates of 100 kg/ha. This method is considered a reliable method of canal maintenance, and the cheapest to control submerged aquatic weeds in Egyptian canals.
- Irrigation administrations in Egypt adopt the use of biological control of submerged weeds in suitable irrigation canals. As the use of mechanical control was show rapid results, but its cost is high and has negative effects on the canals cross-section, this leads to the increase in the required maintenance work.

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