Evaluation of the nutrient status and forage quality of the hippo grass (Vossia cuspidata (Roxb.) Griff.) along Ismailia canal, Egypt

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ABSTRACT
The present study aims at investigating the potential of the hippo grass for sequestering inorganic and organic nutrients in its biomass, in addition to its forage quality along Ismailia Canal, Egypt. Eight sites including 6 polluted and 2 unpolluted were selected for a seasonal plant, water and sediment investigations. The nutrients and nutritional value of the plant tissues were estimated. The highest aboveground biomass was recorded during summer, while the lowest was in winter. The plant had the highest contents of Na, K, N and Mg during winter, while P and Ca during spring and autumn, respectively. Also, Na, K and P had the highest concentrations (176.7 mg kg\(^{-1}\), 206.9 mg kg\(^{-1}\) and 1.1%) in the belowground, while N, Ca and Mg (0.9, 1.6 and 0.5%) in the aboveground organs. The contents of the investigated elements (except Na) were comparable in polluted and unpolluted canals with no significant differences. The aboveground parts had the highest values of ether extract (1.1%) during summer, crude fibres (60.2%) during spring, and total proteins (5.6%) during winter. The belowground tissues had the highest values of metabolized, digestible and net energy (2.4, 2.0 and 1.0 Mcal kg\(^{-1}\)) during winter. In contrast, the aboveground shoots had the highest amounts of digestible crude protein (1.7%) during winter and gross energy during spring. The nutritional value of the hippo grass from unpolluted canals were greater than polluted ones for both above- and belowground parts. Hippo grass can sequester large amounts of nutrients. Consequently, this plant can be used in restoring eutrophic water through harvesting the aboveground biomass during the growing season. Besides, the aboveground shoots of the hippo grass could be used as a forage for dairy cattle, goat, beef cattle and sheep.

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1. Introduction

Aquatic macrophytes play a crucial role in nutrient uptake, storage and release in the aquatic ecosystem. They can absorb macro- and micro-elements and translocate them into different plant organs (Eid et al. 2012). Particularly, aquatic macrophytes, such as *Vossia* species, with high growth production can sequester extensive quantities of nutrients from their surroundings (Eid et al. 2010; Galal et al. 2019). Consequently, these plants can be used to mitigate nutrients from industrial, agricultural and domestic wastewater (Vymazal 2008). Nutrient recycling is an essential aquatic ecosystem function; therefore, nutrients dynamics should be investigated for managing these ecosystems that are used for wastewater treatment or biomass production (Calheiros et al. 2009). Moreover, the contribution of aquatic macrophytes in nutrient remediation is temporary, since they release nutrients again through microbial decomposition and leaching (Eid et al. 2012).

Depending on the capability of using aquatic macrophytes for monitoring water pollution, there are several ways to determine the relationships between the nutrient status of aquatic plants and the surrounding environment (Kröger et al. 2007). Some aquatic macrophytes have high nutrient use potential and can concentrate large amounts of these nutrients in their above- and below-ground tissues (Eid et al. 2020). The increased plant tissue nutrients is known as luxury uptake, which is a strategy by which plants assimilate excessive nutrient concentrations for normal metabolism (Cronk and Fennessy 2001).

Nutrient contents in aquatic environments have increased due to the intensive anthropogenic activities, which results in eutrophication and, thus, ecosystem degradation (Wu et al. 2021).

In Egypt, there is a shortage in green summer forage, which suppresses animal production; thus, it is necessary to improve local food resources for both humans and animals (Galal and Shehata 2013). *Vossia cuspidata* (Roxb.) Griff. (hippo grass) of the family Poaceae is an aquatic perennial grass, which grows laterally as well as vertically up to 3 m height. According to Raphael et al. (2016), the hippo grass is mainly found in the rainforest regions of the world including tropical Africa and Southeast Asia. It grows rooted along rivers with slow water flow and on the edges of lakes and streams (IUCN 2012). It can resist high pH, drought, waterlogging and loamy soils (Duke 1978). This species does not flower during its life in Egypt and reproduces vegetatively by rhizomes, which either spread horizontally on the canal banks or float on the water surface (Shehata 1996). Boulos (2009) reported dense growth and conspicuous populations of this plant along Nile banks, which were often submerged or floating. Moreover, the hippo grass can form floating mats and grass islands, in addition to its capability to grow with other floating macrophytes like water hyacinth to form intensive associations of floating wetland plants (IUCN 2012). According to Galal et al. (2017), soil pH, organic carbon and magnesium content, in addition to water chloride and magnesium were the most critical variables which are significantly correlated with the distribution of hippo grass.

Emergent macrophytes like the hippo grass can regulate aquatic ecosystem services through nutrient removal and water purification (Manolaki et al. 2020). They can sequester large amounts of nutrients in their biomass (Eid et al. 2020). The present study hypothesizes that the aquatic macrophytes can accumulate large quantities of nutrients in their biomass. Hence, they can be used for mitigating water eutrophication. Moreover, there are difficulties in the system of forage production worldwide, as a result of the competition with food crop production and the restriction of agricultural land (Bruinsma 2003). Thus, in developing countries, there is a necessity for searching and utilizing alternative feed resources. In this context, the present work aims at investigating the potential
of the hippo grass to sequester inorganic and organic nutrients in its biomass and also to evaluate the nutritional value of this plant and its sustainable use as animal forage.

2. Material and methods

2.1. Plant sampling and growth measurements

The hippo grass plant samples were collected seasonally through six sites at Ismailia canal, which branches from the River Nile and receives pollutants from several municipal industrial, and anthropogenic activities from the adjacent area. For comparison, two sites were selected on the River Nile, which is the common source for drinking water in Egypt. The two sites were chosen at South Cairo away from any anthropogenic activities (Ghazi et al. 2019). Four quadrats (0.5 × 0.5 m) were randomly selected at each site representing the growth of the hippo grass plants. All plant shoots (sprouts) from each quadrat were harvested and transferred to the laboratory in polyethylene bags. Shoots were washed with de-ionized water, air dried, and then oven-dried to constant weight at 65°C for estimating the aboveground biomass (g DW m⁻²).

2.2. Plant analysis

Three composite plant samples, from the aboveground shoots (leaves and stem) and belowground parts (roots and rhizome) of the hippo grass, were collected seasonally from each site. Collected samples were oven-dried, homogenized using a metal-free plastic mill and then sieved through 2 mm mesh size. One gram from each sample was digested in 20 ml of HNO₃:HClO₄:HF (1:1:2 V:V:V). Total nitrogen (N) was determined by Kjeldahl method, while P was assessed spectrophotometrically (CECIL CE 1021) using molybdenum blue method. In addition, Ca, Na, and K were determined using a flame photometer (CORNING M410), while Mg was measured using atomic absorption photometer (Shimadzu AA-6200). All the above-mentioned methods were gathered from Allen (1989).

The total protein content was estimated by multiplying a factor of 6.25 by the concentration of total nitrogen (Adesogon et al. 2000). Ash percentage was determined by ignition of 1 g dried sample at 550°C for 2 h in a muffle furnace to constant weight. Ether Extract (crude fat) was estimated by ether extraction, and crude fibre (CF) was assessed using the Soxhlet extraction method (Allen 1989). Carbohydrate as nitrogen-free extract (NFE) were calculated according to Le Houérou (1980) as follows:

\[
\text{NFE} \left(\% \text{ dry matter}\right) = 100 - (\text{TP} + \text{EE} + \text{CF} + \text{ash}) \quad (1)
\]

Given that TP = total protein, EE = ether extract and CF = crude fibre. Digestible crude protein (DCP) was determined according to Demarquilly and Weiss (1970) as follows:

\[
\text{DCP} \left(\% \text{ dry matter}\right) = 0.929 \times \text{TP} \left(\% \text{ dry matter}\right) - 3.52 \quad (2)
\]

Total digestible nutrients (TDN) was determined according to Naga and El-Shazly (1971):

\[
\text{TDN} \left(\% \text{ dry matter}\right) = 0.623 \times (100 + 1.25 \times \text{EE}) - \text{PCP} \times 0.72 \quad (3)
\]

where PCP = percentage of crude protein. Digestible energy (DE) was assessed following NRC (1984):
DE (Mcal kg\(^{-1}\)) = 0.0504 TP (%) + 0.077 EE (%) + 0.02 CF (%) 
+ 0.000377 (NFE)\(^2\) (%) + 0.011 (NFE) (%) - 0.152. \(\text{(4)}\)

Metabolized energy (ME) was calculated as (Garrett 1980; Le Houérou 1980):

\[
\text{ME} = 0.82 \text{ DE} \quad \text{(5)}
\]

Net energy (NE) = 0.50 ME \(\text{(6)}\)

Moreover, gross energy (GE) was estimated following the equation (National Research Council: NRC 1984):

\[
\text{GE (Kcal 100 g} - 1) = 5.72 \text{ TP} (%) + 4.03 \text{ NFE} (%) + 4.79 \text{ CF} (%) 
+ 9.5 \text{ EE} (%) \quad \text{(7)}
\]

2.3. Water and sediments analyses

One litre surface water were sampled from each site (three composite samples) for chemical analysis. The dissolved nutrients were estimated using the standard methods of Allen (1989). The Kjeldahl method was used to determine the total nitrogen (N), while the molybdenum blue method using a spectrophotometer (CECIL CE 1021) was used to estimate P, and a flame photometer (CORNING M410) was used to determine Na and K. Chlorides were estimated by titration against AgNO\(_3\) solution using 5% potassium chromate as an indicator, while bicarbonates were determined by titration against 0.01 N HCl. Sulphates were assessed turbidimetrically at 500 nm as barium sulphate. On the other side, sediment samples were taken from each site (three composite samples) using a stainless steel crab. Samples were dried and sieved through 2 mm sieve. Sediment-water extracts (1:5 w/v) were prepared for the estimation of pH, EC, N, P, K, Na, Cl, HCO\(_3\), and SO\(_4\) as water analysis (Allen 1989).

2.4. Data analysis

The differences between polluted and unpolluted watercourses in the sediment and water variables were assessed using a paired-sample t-test. In addition, the significant seasonal variations of nutrient elements between the above- and below-ground organs were estimated using one-way analysis of variance (ANOVA) after testing the data for homogeneity of variance and normality according to SPSS software (SPSS 2012).

3. Results

3.1. Water and sediments properties

The chemical properties of water and sediment exhibited significant differences in water pH, EC, N, P, and K; and sediment pH, EC, HCO\(_3\), SO\(_4\), N, Na and K, between the polluted canal and unpolluted Nile (Table 1). It was found that most of the investigated variables were concentrated in the sediment rather than in water.
3.2. Biomass estimation

Significant seasonal variation in the biomass of the hippo grass populations was recognized (Figure 1). The highest biomass (829.1 g m\(^{-2}\)) was recorded during summer; then gradually reduced until it reached its lowest value (594.2 g m\(^{-2}\)) during winter; after that, it started to increase. On average, the biomass of the hippo grass in the unpolluted was significantly higher than in the polluted canals. However, no significant difference between plant biomass of unpolluted and polluted summer, autumn and spring populations.

3.3. Inorganic nutrients

The above- and belowground tissues of the hippo grass exhibited significant seasonal variation in their inorganic nutrients (Table 2). Winter season contributed the highest contents of plant Na and K (176.7 and 206.9 mg kg\(^{-1}\)) in its root, while total N and Mg (9.0 and 5.2 g kg\(^{-1}\)) in the shoot. The highest P (11.1 g kg\(^{-1}\)) was attained in the belowground tissues during spring, while the highest Ca (15.8 g kg\(^{-1}\)) was recorded in the aboveground parts during autumn. On the other hand, the lowest values of N, Ca and P (4.4, 7.6 and 2.7 g kg\(^{-1}\)) were recorded in the belowground parts during summer, winter and autumn, respectively.

On the average, the investigated elements, except shoot Na, had no significant differences between plants from unpolluted and polluted canals (Table 3). It was found that root Na in the unpolluted Nile (172.9 mg kg\(^{-1}\)) was higher than in the polluted ones (162.8 mg kg\(^{-1}\)) in contrast with the shoot Na, which was higher in the polluted (167.6 mg kg\(^{-1}\)) than unpolluted (166.3 mg kg\(^{-1}\)) canals. Moreover, the contents of total N, P, Ca and Mg were comparable in above- and belowground parts on the one hand, and polluted and unpolluted canals, on the other hand.

3.4. Organic constituents

The analysis of organic nutrients in the above- and belowground tissues of the hippo grass revealed significant seasonal variation in all investigated nutrients (Table 4). The aboveground parts contributed to the highest percentage of ether extract (1.1%) during summer, crude fibres (60.2%) during spring, and total proteins (5.6%) during winter, while the lowest ash content (8.2%) during winter, and carbohydrates (25.7%) during

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Table 1. Variation in the water and sediment characteristics (mean ± standard deviation) of *Vossia cuspidata* in polluted and unpolluted canals.

| Variable | Water          | Sediment       |
|----------|----------------|----------------|
|          | Unpolluted     | Polluted       | t-value | Unpolluted     | Polluted       | t-value |
| PH       | 6.3 ± 0.4      | 7.6 ± 0.4      | 2.5*    | 7.0 ± 0.2      | 5.1 ± 0.4      | 2.6*    |
| EC       | 265.5 ± 10.2   | 452.0 ± 9.6    | 3.4*    | 392.7 ± 2.9    | 486.4 ± 8.8    | 2.8*    |
| Nutrients| mg l\(^{-1}\)  | mg kg\(^{-1}\) |         |                |                |         |
| HCO\(_3\) | 400.0 ± 7.6    | 415.2 ± 13.3   | 0.8     | 248.9 ± 28.7   | 396.5 ± 32.1   | 2.5*    |
| Cl       | 82.4 ± 8.7     | 100.0 ± 5.8    | 1.7     | 156.5 ± 22.1   | 231.2 ± 24.3   | 1.3     |
| SO\(_4\) | 50.1 ± 3.3     | 51.1 ± 3.4     | 1.2     | 251.3 ± 9.8    | 350.0 ± 82.1   | 3.3*    |
| Total N  | 191.1 ± 25.4   | 413.2 ± 12.2   | 5.7**   | 1340.4 ± 121.2 | 2230.3 ± 321.2 | 3.1*    |
| P        | 51.1 ± 4.6     | 92.1 ± 10.9    | 2.6*    | 81.8 ± 10.1    | 94.9 ± 21.1    | 0.9     |
| Na       | 214.1 ± 12.6   | 233.3 ± 21.3   | 0.8     | 142.7 ± 6.2    | 213.5 ± 6.7    | 2.6*    |
| K        | 15.7 ± 9.8     | 19.7 ± 2.4     | 2.7*    | 124.6 ± 6.9    | 143.8 ± 10.8   | 2.8*    |

*: P < 0.05, **: P < 0.01.
spring. On the other hand, the belowground parts had the highest contents of ash (12.2%) during autumn and carbohydrates (52.5%) during winter, while the lowest of ether extract (0.2%) during autumn, crude fibres (33.7%) during winter, and total proteins (2.8%) during summer.

In the belowground tissues, the crude fibre and carbohydrates content showed significant differences between the unpolluted and polluted canals (Figure 2). At the same time, in the aboveground parts, the investigated organic nutrients were not significantly different. The hippo grass root showed an increase of crude fibres from 35.7% to 41.2% in the polluted plants, while carbohydrates were reduced (49.6 – 45.1%). In addition, the shoot organic nutrients showed a reduction of ether extract, total proteins and carbohydrates, but increase in crude fibres and ash contents under pollution stress.

3.5. Nutritional value

The nutritional value of the hippo grass indicated significant variations in the digestible crude proteins (DCP), total dissolved nutrients (TDN) and gross energy (GE) among the different seasons (Table 5). The belowground tissues attained the highest content of digestible energy (DE), metabolized energy (ME) and net energy (NE) (2.4, 2.0 and 1.0 Mcal kg⁻¹) during winter, while the lowest DCP (0.6%) during spring, ME (1.6 Mcal kg⁻¹) during summer and GE (389.6 Mcal kg⁻¹) during autumn. On the other hand, the aboveground shoots of hippo grass had the highest values of DCP (1.7%) during winter and GE (422.8 Mcal kg⁻¹) during spring, while the lowest of DE and NE (1.9 and 0.8 Mcal kg⁻¹) during spring and TDN (58.7%) during winter.

On average, the nutritional values of the hippo grass from unpolluted canals were greater than polluted ones for both above- and belowground parts (Table 6). The belowground tissues exhibited significant differences between unpolluted and polluted canals in DE, ME and NE; however, the aboveground parts showed no significant differences in all investigated variables.
4. Discussion

The water and sediment chemical analysis exhibited significant differences in water pH, EC, N, P, and K; and sediment pH, EC, HCO3, SO4, N, Na and K, between the polluted canal and the unpolluted Nile. The high concentrations of nutrients in the polluted canal are due to the industrial, domestic and agricultural drainage from the inhabitants, and
factories in the neighbourhood (Eid et al. 2010). Moreover, most of the investigated variables were concentrated in the sediment more than water. According to Schulz et al. (2003), sediments act as semi-permanent nutrient sinks, so become main sources of nutrients for the wetlands, however nutrient input to water occurs via leaching from sediments.

The biomass assessment is of great interest for studying dry matter flow and plant functions (Farahat et al. 2012). Seasonal variation in the biomass of hippo grass populations was recognized with the maximum in summer (829.1 g m⁻²) and the minimum during winter (594.2 g m⁻²). A more or less similar trend was recorded by El-Kady (2002) and Eid et al. (2012) on Phragmites australis (Cav.) Trin. Ex Steudel, Galal and Shehata (2013) on Desmostachya bipinnata (L.) Stapf, Shaltout et al. (2010) on Echinochloa stagnina (C. Mast.) Solms and Shaltout et al. (2013) on Cynodon dactylon (L.) Pers. and Panicum repens L. Whereas, the biomass (g m⁻²) of hippo grass was lower than that of

![Figure 2. Organic nutrient of the below- (a) and above-ground (b) tissues of Vossia cuspidata collected from polluted and unpolluted canals. T-values are provided.](image-url)
D. bipinnata (1499.2; Galal and Shehata 2013), Arundo donax (8400.0; Galal and Shehata 2016; 7700.0; Eid et al. 2016) and P. australis (921.7; El-Kady 2002), but higher than that of E. stagnina (803.6; Shaltout et al. 2010). Furthermore, the biomass of the hippo grass in the unpolluted Nile was significantly higher than that in the polluted canal associated with higher salinity. Soetaert et al. (2004) found that the above- and belowground biomasses are lower in more saline habitats. In addition, Sánchez et al. (2015) reported a significant reduction in the biomass of giant reed under salinity stresses. The decline in biomass of the hippo grass in the polluted water may be one of the common effects of heavy metal stress on plants (Galal and Farahat 2015; Galal and Shehata 2016).

In wetlands, aquatic plants play an essential role in nutrients cycling due to absorption, storage, and resorption processes, whereas, plants with efficient and high annual production can remove large amounts of nutrient elements from their surroundings and sequester them in biomass (Eid et al. 2010). The above- and belowground tissues of the hippo grass exhibited significant seasonal variation in their inorganic nutrients. According to Klaus et al. (2011), nutrients concentration of grasses varied according to the growing season and plant size. The nutrient contents in the tissues of the hippo grass exceeded those of D. bipinnata (Galal and Shehata 2013; Shaltout et al. 2016); P. australis (El-Kady 2002); and C. dactylon and P. repens (Shaltout et al., 2014); but lower than those of A. donax (Galal and Shehata 2016; Eid et al. 2016). Moreover, Na, K and P had higher concentrations in the belowground, while N, Ca and Mg in the aboveground organs. These results coincided with the findings of Ruiz and Velasco (2010), Eid et al. (2012) on T. domingensis and Eid (2012) on P. australis, but contrasted with the study of Galal and Shehata (2016) on A. donax.

### Table 5. Seasonal variation in the nutritional value (Mean ± SD) of Vossia cuspidata grown in polluted canal. DCP: digestible crude protein, TDN: total digestible nutrients, DE: digestible energy, ME: metabolized energy, NE: net energy and GE: gross energy. Maximum and minimum values are underlined.

| Season | Nutritive value |   |   |   |   |
|--------|----------------|---|---|---|---|
|        |        | DCP | TDN | DE | ME | NE | GE |
|        | %    | %   | Mcal kg⁻¹ | %  | %  | Mcal kg⁻¹ | Mcal kg⁻¹ |
| Spring | R     | 0.6 ± 0.2abc | 60.3 ± 0.5bcd | 2.2 ± 0.3 | 1.8 ± 0.1 | 0.9 ± 0.1 | 411.5 ± 10.4bc |
| S      | 0.7 ± 0.2bcd | 59.5 ± 0.9abc | 1.9 ± 0.1 | 0.8 ± 0.1 | 0.7 ± 0.1 | 422.8 ± 20.2c |
| Summer | R     | 0.9 ± 0.4a   | 61.1 ± 0.5d  | 2.0 ± 0.2 | 1.7 ± 0.1 | 0.8 ± 0.1 | 415.7 ± 7.7bc |
| S      | 0.8 ± 0.7ab  | 60.9 ± 0.5c  | 2.0 ± 0.1 | 1.7 ± 0.1 | 0.9 ± 0.1 | 408.1 ± 1.6abc |
| Autumn | R     | 0.7 ± 0.2abc  | 59.9 ± 0.5abd | 2.2 ± 0.4 | 1.8 ± 0.4 | 0.9 ± 0.2 | 389.6 ± 4.9a  |
| S      | 0.7 ± 0.3abc  | 59.8 ± 0.7abd | 2.0 ± 0.1 | 1.7 ± 0.1 | 0.8 ± 0.1 | 405.9 ± 6.14abc |
| Winter | R     | 0.9 ± 0.7cd   | 59.1 ± 0.6a  | 2.4 ± 0.1 | 2.0 ± 0.1 | 1.0 ± 0.1 | 402.9 ± 7.2ab  |
| S      | 1.7 ± 1.1d   | 58.7 ± 0.9ab  | 2.2 ± 1.3  | 1.8 ± 1.2 | 0.9 ± 1.0 | 417.3 ± 13.0abc |
| F-value|      | 3.1*          | 3.6**       | 1.5 | 1.5 | 2.4* |

Means with different letters are significantly different according to Duncan test. *: P < 0.05, **: P < 0.01.

### Table 6. Nutritional value (Mean ± standard deviation) of the different organs of Vossia cuspidata grown in polluted and unpolluted canals.

| Nutritive value | Root | Shoot | t-value |
|----------------|------|-------|---------|
|                | P    | U     |         |
| DCP (%)        | 0.8 ± 0.2 | 0.5 ± 0.2 | 1.2 |
| TDN (%)        | 60.1 ± 0.8 | 60.1 ± 0.5 | 0.1 |
| DE Mcal kg⁻¹   | 2.2 ± 0.1 | 2.4 ± 0.2 | 4.8* |
| ME             | 1.8 ± 0.1 | 1.9 ± 0.1 | 4.8* |
| NE             | 0.9 ± 0.1 | 1.0 ± 0.1 | 4.8* |
| GE             | 404.4 ± 10.9 | 406.9 ± 53.9 | 0.7 |

| Nutritive value | P    | U     | t-value |
|----------------|------|-------|---------|
|                | P    | U     |         |
| DCP (%)        | 0.4 ± 0.1 | 0.9 ± 1.1 | 0.7 |
| TDN (%)        | 59.7 ± 0.9 | 60.5 ± 1.1 | 0.6 |
| DE Mcal kg⁻¹   | 2.1 ± 0.2 | 2.2 ± 0.1 | 0.9 |
| ME             | 1.7 ± 0.1 | 1.8 ± 0.1 | 0.9 |
| NE             | 0.8 ± 0.1 | 0.9 ± 0.1 | 0.9 |
| GE             | 412.5 ± 7.9 | 413.5 ± 25.4 | 0.5 |
Generally, the accumulation of nutrients in a plant tissue depends mainly on the concentrations of N and P in the tissue and its biomass (Maddison et al. 2009). The highest concentration of N was recorded during winter associated with the lowest plant biomass. Irfan (2014) stated that an excessive increase of N concentrations only enhance the nitrogen storage in plant tissues and negatively affect the biomass. According to Bignal et al. (2008), elevated tissue-N may harmful to plant growth. In addition, Petrucio and Esteves (2000) reported that N and P concentrations exceeding 20 mg l\(^{-1}\) and 2 mg l\(^{-1}\), respectively, are determinants for growth rate and productivity of aquatic macrophytes. Most of the investigated elements had no significant differences between below- and above-ground parts coinciding with Eid et al. (2012) on *T. domingensis*; and Eid (2012) on *P. australis*. The plant shoot attained its maximum nutrient concentrations early at the growing season during winter and declined during summer and autumn, and this confirm that the biomass was the main factor in assessing the amount of nutrients standing stock (Eid et al. 2012; Vymazal 2020). According to Boudet and Riviere (1968), the Na, K, Ca, Mg and P contents of the hippo grass meet the required level for animals maintenance. In addition, the aboveground tissues had Na, K, Ca and P contents that exceed the maximum tolerable level (NRC 1984). In addition, the concentrations of inorganic nutrients is lower than those of the normal forage in the rangeland of the western Mediterranean coas (El-Kady 2002).

The nutrient dynamics investigation of the hippo grass indicated that most nutrients were reduced in the aboveground and increased in belowground parts at the end of the vegetation period, which shows downward translocation. According to Vitousek (1982), nutrients were translocated from shoots toward the rhizomes and roots at the end of autumn and winter, where the belowground parts take nutrients from senescing tissues for reuse. Meanwhile, the belowground pools provide necessary amounts of nutrients for the growth of young stems in early spring, during which a reverse translocation occurred again (i.e. from rhizomes to shoots). The nutrient translocation potential from an organ to another enables plants to resist nutrient fluctuations and thus, be strongly competitor in habitats with fluctuating nutrients (Garbey et al. 2004). To be used effectively in removing nutrients and restoring the eutrophic water, the aboveground parts of the hippo grass should be harvested before senescence and the translocation of the nutrients to the belowground parts (Eid et al. 2020). Besides, for maximum nutrient removal, the aboveground parts should be harvested at the highest plant biomass associated with the highest nutrients accumulation. Accordingly, the ideal time for harvesting the hippo grass for maximum nutrients removal was spring with high nutrients content as well as plant biomass.

The belowground parts showed an increase of crude fibres, while total proteins and carbohydrates were reduced, in the polluted plants. The reduction in the contents of proteins and carbohydrates in the polluted canal may be attributed to photosynthetic inhibition or stimulation of the respiration rate (John et al. 2009). In addition, the total proteins were slightly reduced in the above- and below-ground tissues under pollution stress. The reduction in protein content may be caused under heavy metal stress (Costa and Spitz 1997) by enhancing protein degradation through the increased protease activity (Palma et al. 2002).

As fodder availability and access is becoming limited (NEMA 1998), the response of farmers has been to keep fewer heads of cattle (Tabuti 2009). According to Heneidy (2002), crude protein and crude fibres are indicators for the nutritional quality of animal forages. In the grazeable parts of the hippo grass, the percentage of crude protein is lower than the minimum value (6-12% of forage DM) required for maintaining animals, while
the crude fibre content was relatively high. In addition, the average annual protein content in the tissues of hippo grass did not exceed the maintenance requirement, as well as the value of *Trifolium alexandrinum* (16.2% Chauhan et al. 1980) and *P. australis* (6.7% El-Kady 2002). Moreover, the protein contents reached its lower value during summer in the polluted watercourse consistent with Singh and Andon (2009), where they found that the decrease in protein concentration may be due to the increase in pollution levels and toxic metals. Furthermore, the lipid content of the aboveground parts of the hippo grass lie within the range of some rough fodders, but lower than those of *Pistia stratiotes* (Dakhil 2016) and *T. alexandrinum* (Chauhan et al. 1980). The same trend was observed for the total carbohydrates and crude fibre, which did not exceed the values of *T. alexandrinum* and *P. australis* (Chauhan et al. 1980, El-Kady 2002).

The total digestible nutrients (TDN) are an appropriate estimate of the food energy for animals only after deduction of the digestion losses (El-Beheiry 2009). The mean value of TDN of the aboveground parts of hippo grass meets the diet requirements of sheep (61.7%; NRC 1975) and breeding cattle (50.0%; NRC 1984). Moreover, the digestible energy of the hippo grass was lower than required (2.7 Mcal kg⁻¹) by sheep (NRC 1985). In addition, the mean annual value of metabolized energy of the aboveground shoots was 1.8 Mcal kg⁻¹, which approximated the requirement of breeding cattle and sheep (NRC 1985, 1984). It seems that the nutritive values of the aboveground shoots of the hippo grass lie within the scale of nutritive value of beef cattle (NRC 1984), goat (NRC 1981), dairy cattle (NRC 1978) and sheep (NRC 1975). However, the relatively low protein content of the aboveground parts of the hippo grass supports this plant to be used as a rough fodder (Boudet and Riviere 1968). According to Ibewiro et al. (2000), tropical grasses may limit the growth and production of cattle milk and meat, because some of these grasses have relatively low minerals and crude protein contents compared to browse species. Additionally, drought is a limiting factor for the growth of tropical grasses, which results in a decreasing their quality and quantity (Paterson et al. 1998).

**Conclusion**

The maximum nutrient contents in the hippo grass shoot were attained at the beginning of the growing season during winter and declined throughout the growing season during summer and autumn, and this means that biomass was the common factor in estimating the quantity of accumulated nutrients. The hippo grass can sequester large amounts of nutrients compared with other similar grasses. The contribution of this plant to nutrient remediation is often temporary due to nutrients resorption through leaching at its senescence. Therefore, for using the hippo grass for nutrient removal, in polluted water bodies, the plant should be harvested when it had the maximum nutrient amounts or at the maximum plant biomass. Accordingly, the ideal time for harvesting the hippo grass for maximum nutrients removal was spring with high nutrients content as well as plant biomass. In addition, the aboveground shoots of this plant could be used as a forage for sheep, goat, dairy cattle and beef cattle. It is worth to note that the ideal times to exploit the aboveground shoot of the hippo grass as forages are winter and spring in the polluted canals taking into consideration the accumulation potential of this plant for heavy metals.

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The authors declare that they have no conflict interest.
Availability of data and materials

Not applicable

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