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Original Research

Nutrient Remediation Potential and Forage Quality of the Emergent Jointed Flatsedge (*Cyperus articulatus* L.) Grown in Eutrophic Waterbodies

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Abstract

This research examined the seasonal fluctuations in the nutrient remediation capability of the jointed flatsedge in eutrophic waterbodies through biomass harvesting and estimation of its potential use as animal feed. Samples of plants, water, and sediment were gathered seasonally from six polluted and three unpolluted sites. Fall had the highest biomass (3341.6 g/m^2) and summer had the lowest (283.8 g/m^2) in polluted waterbody with an average of 1.17 kg/m^2 lower than in the unpolluted Nile (1.39 kg/m^2). The aboveground parts had their highest contents of K, N, and Ca (174.4, 11.3, and 12.4 mg/kg, respectively) during fall, and Na, P, and Mg during spring, while belowground parts had their highest Na content (165.9 mg/kg) in winter, and Ca and P (13.3 and 5.4 mg/kg) in spring. Summer contributed to the highest contents of crude fibers and protein contents (58.4 and 9.8%) in aboveground shoots, while spring had their highest value (31.1 and 7.3%) in the belowground organs. Moreover, fall months had the highest efficiency in removing Na, K, N, Ca, and P (0.94, 0.59, 34.75, 37.77, and 17.77 g/m^2) by shoot tissues. Therefore, jointed flatsedge has the efficiency to remediate nutrients from eutrophic waterbodies by harvesting aboveground biomass, especially in the fall.

Keywords: emergent macrophyte, nutrients, harvesting, forage quality, piripiri, eutrophication

Introduction

Due to increased anthropogenic activities and socioeconomic expansion, nutrient concentrations in aquatic habitats have increased, which has resulted in ecosystem degradation [1, 2]. Without being adequately cleaned, domestic water, agricultural runoff, and municipal wastewater are frequently dumped into surface waterbodies like lakes, rivers, and canals [3]. The accumulation of excess nutrients from wastewater on the bottoms of waterbodies can lead to eutrophication [4], a major problem for human health and other aquatic biota [5]. However, these nutrients can also be recycled back

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into the surrounding water, and increase eutrophication [6]. In addition, rising rates of water pollution due to nutrients like phosphorus (P) and nitrogen (N) are causing eutrophication [7, 8], which leads to excessive growth of algae in surface water that deteriorates water quality [9]. Moreover, the rapid deterioration of aquatic vegetation in waterbodies around the world due to eutrophication and other factors has changed the waterbodies from clear water states dominated by aquatic plants to turbid water states dominated by algae, degrading the aquatic ecosystems [10].

The use of a workable and sustainable water and sediment treatment technology is necessary to prevent the eutrophication of surface waterbodies [3]. Nutrients from wastewater are currently removed using a variety of treatment methods, including physical, chemical, and biological processes [11]. Because of its efficient, economical, and environmentally friendly approach, phytoremediation is one of these treatment strategies that shows promise for removing nutrients from wastewater [12]. Phytoremediation is a unique plant-based technology that replaces traditional methods of purifying contaminated water by using aquatic macrophytes as a tool to remove toxins from wastewater [13]. It is customary to harvest above-ground biomass in order to create low nutrient conditions for the restoration and management of waterbodies [7]. Harvesting plants at the beginning of blooming, when biomass production and nutrient concentrations are highest, will result in the best possible nutrient removal [14]. Because harvesting eliminates nutrients, especially N and P, that would otherwise be partially released following plant death at the end of the growing season, it can improve water purification [15].

An affordable, green, and organic approach to managing contaminated waterbodies is through the use of emergent aquatic macrophytes to clean up wastewater [5, 16]. By storing nutrients in plant tissues and making it easier for them to be removed, emerging macrophytes aid in the removal of nutrients [17, 18]. In addition to absorbing contaminants and heavy metals from the water, they also purify it by absorbing N, P, and other nutrients [19, 20]. The perennial rhizomatous marshland plant *Cyperus articulatus* L. (Cyperaceae), sometimes referred to as "jointed flatsedge" or "piripiri", has the potential to be a phytoremediator for nutrients and other contaminants [21]. It is a common emergent macrophyte in Egypt, occurring in the Nile Valley, the Nile Delta, and along the Mediterranean coast [22]. It lives in shallow waterbodies such as ponds, ditches, rivers, marshes, lakes, and the sides of canals, where it produces vast reed marshes on temporarily unflooded soils [23]. This jointed flatsedge was shown to have direct agronomic uses as a heavy metal accumulator and as a fodder crop [24].

Aquatic macrophytes play a significant economic role in the areas of animal nutrition, sources of natural products, and improving water quality [25]. Apart from acting as the base of the aquatic food chain, they are well-known for being a good source of food and fodder for humans, farm animals, and aquatic herbivores [26]. They are also utilized as fertilizer, such as mulch, compost manure, green manure, ash, etc., for the production of agricultural crops [27]. Macrophytes are used for these objectives because of their great nutritional value resulting from the abundance of biochemical elements such as moisture, proteins, fiber, lipids, ash, etc. [28]. Therefore, in order to assess the food potential and estimate the forage quality of macrophytes, it is crucial to understand their chemical composition [28]. Aquatic plants present an intriguing substitute for traditional food sources due to their rapid growth and high nutritional content [29].

The current study is one of a series on the potential of emergent macrophytes to restore contamination and eutrophication and recycle harvested biomass in Egyptian waterbodies [4, 23, 30-38]. The current study intends to investigate the seasonal fluctuations in the nutrient remediation capability of the different tissues of *Cyperus articulatus* in eutrophic waterbodies through biomass harvesting and estimation of its potential use as animal feed. In this regard, the forage quality as well as the inorganic and organic nutrients of the above- and below-ground parts were examined. Such research can aid in the management of water quality and the restoration of eutrophic waterbodies in addition to offering useful new knowledge of sustainable feed and nutrient remediation techniques.

Experimental Procedures

Sampling Design and Growth Measurements

In order to assess the study plant's potential for nutrient remediation, fresh wild plant samples of the jointed flatsedge were collected seasonally, from winter 2016 to fall 2017, through six polluted sites evenly distributed on the Ismailia Canal (30° 06′ 84.90″ N and 31° 17′ 05.36″ E), which receive sewage, agricultural, and industrial wastes from the surrounding areas. In addition, three reference sites were chosen in the spring and fall of 2017 along the Nile River (29° 51′ 08.31″ N and 31° 17′ 34.72″ E), which serves as Egypt's main supply of drinking water (Fig. 1). During every season, sampling was done instantly at each location using five quadrats (0.5x0.5 m) that represented the population of jointed flatsedges (n=120 in polluted watercourses and 30 in unpolluted ones). All plant shoots in each quadrat were counted to calculate the shoot density as shoot/m^2. Then, five randomly selected shoots from each quadrat were taken as a sub-sample and brought in polyethylene bags to the lab. After thoroughly cleaning all plant materials twice with tap water to get rid of any debris, they were again cleaned with deionized water. To obtain the dry weight data per shoot, plant shoots were oven-dried at 65°C until they reached a consistent weight. The average dry weight (g/shoot) was then multiplied by the

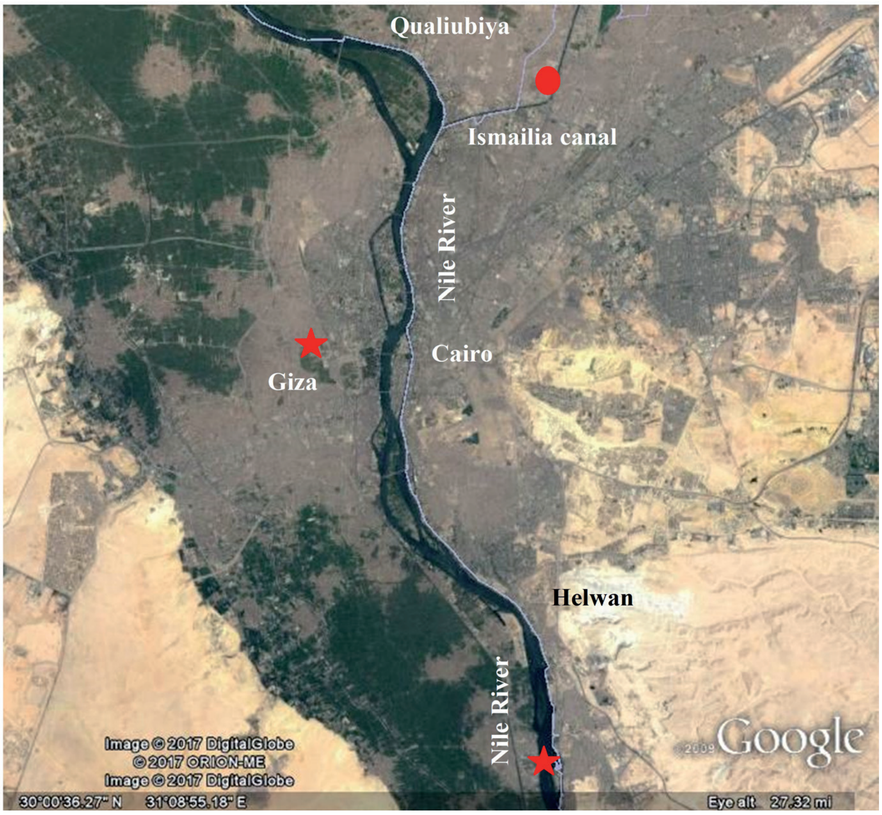

Fig. 1. Location map showing the polluted site (●) receiving sewage, agricultural, and industrial wastes from the surrounding areas, and the unpolluted site (★) of the study area. 30° 00′ 36.27″ N and 31° 08′ 5.18″ E. Source: Google earth 19 April 2017.

shoot density (shoot/m^2) to determine the dry biomass (g DW/m^2).

Plant Analysis

Three composite samples from the jointed flatsedge plants' aboveground shoots (stem and leaves), as well as their belowground rhizomes and roots, were collected seasonally from each site for plant examination. Samples that had been oven-dried were ground into a homogeneous form using a metal-free plastic mill and then sieved with a mesh size of 2 mm.

Inorganic Nutrients

One gram of powdered material was digested in 20 ml of HNO_3:$HClO_4$:HF (1:1:2 v:v:v) triacid combination. The Kjeldahl method was used to test total nitrogen (N), which includes the total Kjeldahl N (total organic nitrogen + ammonium), in addition to nitrate and nitrite; a spectrophotometer (CECIL CE 1021) was used to examine P; a flame photometer (CORNING M410) was used to evaluate Ca, Na, and K; and an atomic absorption photometer (Shimadzu AA-6200) was used to measure Mg. Allen [39] provided an outline for each of these plant analysis processes. In addition, the nutrient standing stock (g DM/m^2) of the aboveground portions was estimated by multiplying the shoot biomass by its nutrient concentrations.

Organic Nutrients

A gram of the dry sample was heated in a muffle furnace for two hours at 550°C, or until the weight remained constant, in order to assess the percentage of ash content. The plant was extracted using ether to determine the crude fat content (EE), and the Soxhlet extraction method was used to evaluate the crude fiber (CF) content (Allen 1989). Following Adesogon et al. [40], the total protein (TP) content was determined using by multiplying the total nitrogen by 100/16, or 6.25. The formula mentioned by Le Houérou [41] was used to calculate the amount of carbohydrates (NFE):

$$\text{NFE (in \% dry matter)} = \text{NFE (in \% dry matter)} = 100 - (\text{TP} + \text{CF} + \text{crude fat} + \text{ash}) \quad (1)$$

Forage Quality

All the calculations of forage quality are mentioned in Galal et al. [4].

The digestible crude protein (DCP) was estimated by the formula:

$$\text{DCP (in \% dry matter)} = 0.929\ \text{TP (in \% dry matter)} - 3.52 \quad (2)$$

The total digestible nutrients (TDN) were calculated using the formula:

$$TDN \text{ (in \% dry matter)} = 0.623\ (100 + 1.25\ EE) - 0.72TP \quad (3)$$

The digestible energy (DE) was evaluated following the formula:

$$DE\ (Mcal/kg) = 0.0504\ TP\ (\%) + 0.077\ EE\ (\%) + 0.02\ CF\ (\%) + 0.000377\ (NFE)2\ (\%) + 0.011\ (NFE)\ (\%) - 0.152 \quad (4)$$

The metabolized energy (ME) was calculated as:

$$ME = 0.82DE \quad (5)$$

The net energy

$$(NE) = 0.82\ ME \quad (6)$$

The gross energy (GE) was calculated following the formula:

$$GE\ (Kcal/100\ g) = 5.72\ TP\ (\%) + 9.5\ EE\ (\%) + 4.79\ CF\ (\%) + 4.03\ NFE\ (\%) \quad (7)$$

Sediment Sampling and Analysis

Using stainless steel crab, sediment samples (three composite samples) were taken from each site, air-dried, and then passed through a 2 mm sieve. Using a pH meter Model 9107 BN (ORION type) and a conductivity meter 60 Sensor Operating Instruction Corning, sediment-water extracts of 1:5 w/v were made in order to measure the sediment's pH and electrical conductivity (EC), respectively. The conventional techniques outlined by Allen [39] were employed to estimate the dissolved nutrients. The Kjeldahl method was used to measure the total nitrogen (N); a flame photometer (CORNING M410) was used to measure Na and K; and a spectrophotometer (CECIL CE 1021) was used to apply the molybdenum blue method to measure P. Additionally, chlorides were estimated by employing 5% potassium chromate as an indicator and performing a straight titration against a silver nitrate solution, while carbonates and bicarbonates were determined by titration against 0.01N HCl, and sulfates were estimated as barium sulfate turbidimetrically at 500 nm.

Data Analysis

The differences in the sediment and plant variables between the polluted and unpolluted waterbodies were evaluated using a Paired-sample t-test. In addition, a one-way analysis of variance (ANOVA) was performed to evaluate the significance of seasonal fluctuations in the nutritional content of the various organs of the jointed flatsedge plants after assessing the data for normality and homogeneity of variance. When differences are significant, a post-hoc test (Duncan's test) was used following the SPSS software [42].

Results and Discussion

Water and Sediment Properties

The kind and contamination severity caused by wastewater discharge may be reflected in the bottom sediment composition of waterbodies [3]. The chemical analysis of the sediments revealed substantial

Table 1. Chemical characteristics (Mean±standard deviation) of the sediment of the studied polluted and unpolluted waterbodies.

Variable		Sediment		t-value
		Unpolluted	Polluted	
PH		7.3±0.4	5.4±0.8	2.6*
EC	(µS/cm)	372.7±32.7	476.4±24.6	2.8*
CO_3^{-2}	mg/kg	254.2±2.2	392.0±5.8	3.1*
HCO_3^-		241.9±21.7	396.5±13.1	3.4*
SO_4^{-2}		251.3±9.8	350.0±8.1	3.6*
N^{-3}		132.4±12.3	221.3±12.8	4.7**
P^{-3}		81.8±2.1	92.9±6.1	2.6*
Na^+		142.7±6.2	213.5±6.7	2.8*
K^+		124.6±6.9	143.8±10.8	4.2**
Cl^-		156.2±11.2	221.3±12.2	4.6**

Note: *: P<0.05, **: P<0.01.

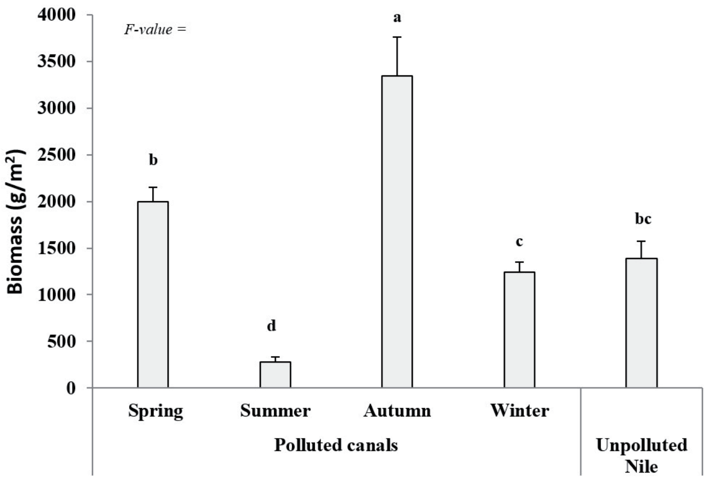

Fig. 2. Seasonal variation in the dry biomass of the aboveground organs of Cyperus articulatus collected from polluted and unpolluted waterbodies. Means with the same letters are not significant.

Table 2. Inorganic nutrient concentrations (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs of Cyperus articulatus collected from polluted (P) and unpolluted (U) waterbodies.

Inorganic element		BG organs		t-value	AG organs		t-value
		P	U		P	U	
Na	(mg/kg)	153.7±12.1	150.4±6.2	0.8	154.9±7.3	160.1±7.1	1.2
K	(mg/kg)	156.8±11.4	188.5±8.6	2.5*	151.1±23.6	192.8±4.9	3.2*
Total N	(mg/g)	12.8±2.5	13.4±2.2	1.1	10.6±1.2	13.1±2.3	2.7*
Ca	(mg/g)	12.2±1.2	13.4±2.3	0.9	11.2±1.5	14.1±2.8	1.1
P	(mg/g)	4.5±0.9	5.2±0.9	0.4	4.9±1.0	6.1±1.1	0.7
Mg	(mg/g)	3.0±0.5	2.1±0.1	0.6	3.5±1.4	2.1±0.1	0.7

differences in all measured variables between polluted and unpolluted waterbodies (Table 1). The unpolluted waterbody's sediment was slightly alkaline (7.3) with lower salinity (372.7 µS/cm), whereas the polluted canal's sediment was acidic (pH 5.1) with higher salinity (EC 476.4 µS/cm). The polluted sediment has notably higher concentrations of the anions and cations under study than the unpolluted Nile's sediment. These findings are consistent with the findings of Ghazi et al. [21] and Galal et al. [35, 36], who found that the sediment from polluted waterbodies contained more heavy metals and nutrients than the sediment from the unpolluted River Nile. Furthermore, compared to the unpolluted Nile's sediment, the polluted sediment contained noticeably larger contents of the anions and cations under investigation. According to Ali et al. [5], industrial, municipal, and agricultural drainage from nearby companies and human settlements is to blame for the excessive quantities of nutrients found in the polluted waterbodies. Additionally, fertilization and irrigation are two agricultural practices near the contaminated waterbody that may greatly raise the amount of inorganic elements and, consequently, the nutrients in the water [2].

Plant Biomass

The assessment of biomass holds significant value in the investigation of dry matter movement and plant functioning [11]. The jointed flatsedge's dry biomass showed notable seasonal variation and, on average, there is a noteworthy distinction between plants collected from polluted and unpolluted waterbodies (Fig. 2). Fall had the highest biomass (3341.6 g/m^2) and summer had the lowest (283.8 g/m^2) in the polluted waterbody. This high value contributes to the plant's survival as it avoids competition for light and nutrients with other emergent species with growth peaks in summer, like *Phragmites australis* [33], *C. alopecuroides* [35], *Vossia cuspidata* [34, 36], and *Arundo donax* [32]. Additionally, the plant biomass in the unpolluted Nile (1387.5 g/m^2) did not differ substantially from the values (1998.3 and 1245.3 g/m^2) recorded in the polluted canal during spring and winter, respectively. In the polluted waterbody, the average plant biomass was 1.17 kg/m^2, which is less than the 1.73 and 5.00 kg/m^2 for the same species [4]; 3.00 and 3.10 kg/m^2 for *C. alternifolius*; 2.60 and 5.00-8.00 kg/m^2 for *C. papyrus* [38]; but greater than the 0.51 kg/m^2 reported for *Ludwigia stolonifera*, *C. alopecuroides*, and *V. cuspidata*, respectively [4, 37], and 0.6 kg/m^2 for

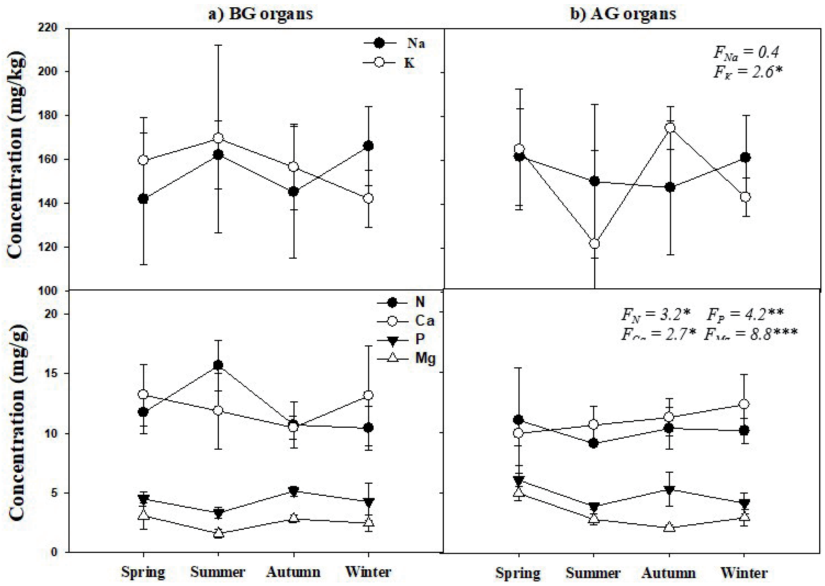

Fig. 3. Seasonal variation in the nutrient concentrations of the a) belowground (BG) and b) aboveground (AG) organs of Cyperus articulatus collected from polluted canals. Vertical bars represent the standard deviation. *: P<0.05, **: P<0.01, ***: P<0.001.

C. alternifolius [35]. Moreover, the polluted waterbody's plant biomass was lower than the unpolluted Nile's (1.39 kg/m^2). The increased amounts of heavy metals, which negatively impact plant growth, and the higher salinity of the polluted sediment may be the cause of the decreased biomass in the polluted waterbody [6].

Inorganic Nutrients

Aquatic plants have a remarkable seasonal variation in their nutrients' absorbing potential depending on the sediment and water chemistry [18]. These plants also demonstrate seasonal growth that varies based on their nutritional requirements [33]. With the exception of Na, which is the main cause of salinity toxicity in plants, the jointed flatsedge's above- and below-ground tissues showed notable seasonal variations in their inorganic nutrient levels (Fig. 3). This finding is consistent with the findings of Galal et al. [38], who determined that the primary causes of variance in are plant size and growth season. However, the insignificant seasonal variation in Na may suggest that this plant has a lower Na accumulation capacity and, hence, a better control mechanism of its distribution and transport in the plant tissues. It is well-recognized that plants require N, P, and K more than other macronutrients [43]. Fall brought the largest concentrations of K, N, and Ca (174.4, 11.3, and 12.4 mg/kg, respectively) to the aboveground sections,

Table 3. Seasonal variation in the organic nutrient contents (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs of Cyperus articulatus grown in polluted waterbodies. EE: ether extract, CF: crude fiber, TP: total protein, NFE: nitrogen free extract (soluble carbohydrate). Maximum and minimum values are underlined.

Season		Organic nutrient (%)				
		EE	CF	Ash	TP	NFE
Spring	BG	0.4±0.1c	31.1±1.5bc	9.7±0.6bc	6.9±2.7b	51.4±0.9c
	AG	0.6±0.3bc	49.6±7.7ab	7.7±1.1e	5.7±0.1c	35.3±9.5de
Summer	BG	0.6±0.1bc	8.2±13.3e	10.9±0.4a	7.3±1.1b	70.7±12.4b
	AG	0.8±0.1a	58.4±12.1a	7.8±0.8e	9.8±1.3a	27.3±11.5e
Fall	BG	0.6±0.1bc	8.1±13.4e	10.5±1.1ab	6.7±1.2bc	74.1±14.7a
	AG	0.7±0.1bc	12.3±20.5d	9.2±1.6bc	6.5±1.1bc	71.3±21.7ab
Winter	BG	0.8±0.2ab	27.1±6.2c	9.0±1.6cd	6.5±1.3bc	56.6±3.7c
	AG	1.0±0.3a	45.5±5.7ab	8.0±0.4de	6.4±0.6bc	39.1±6.1d
F-value		4.4**	8.6***	8.5***	3.8**	7.1***

Note: Means with the same letters are not significant according to Duncan's test. **: P<0.01, ***: P<0.001.

Table 4. Average organic nutrient concentrations (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs of Cyperus articulatus collected from polluted (P) and unpolluted (U) waterbodies.

Organic nutrient (%)	BG organs		t-value	AG organs		t-value
	P	U		P	U	
EE	0.6±0.1	1.1±0.1	3.1*	0.8±0.2	1.1±0.1	1.4
CF	18.6±12.3	32.4±5.7	6.4**	41.5±20.2	52.5±12.1	6.2**
Ash	10.0±0.8	9.1±0.1	1.1	8.2±0.7	8.9±1.0	0.7
TP	7.6±1.5	9.1±0.8	2.7*	6.4±0.5	6.4±05	0.1
NFE	63.2±10.9	48.5±4.8	5.3**	43.3±19.3	31.1±12.6	3.3*

Note: *: P<0.05, **: P<0.01.

whereas spring brought the highest contents of Na, P, and Mg (161.4, 6.2, and 5.4 mg/kg). Alternatively, the belowground tissues had the largest concentration of Na (165.9 mg/kg) in the winter, the highest concentration of Ca and P (13.3 and 5.4 mg/kg) in the spring, and the highest concentration of K and N (169.4 and 16.4 mg/kg) in the summer. Vymazal [44] states that the plant tissues accumulated their highest concentrations of nutrients at the start of the growth season, and their lowest quantities after maturation and senescence.

The jointed flatsedge plants from polluted and unpolluted waterbodies did not differ significantly in any of the examined inorganic components, with the exception of shoot K and N and root K (Table 2). The unpolluted Nile's root and shoot K concentrations (188.5 and 192.8 mg/kg, respectively) were found to be substantially greater than those in the polluted waterbody (156.8 and 151.1 mg/kg). In a similar vein, the shoot N (13.1 mg/g) in the unpolluted waterbody was noticeably greater than that of the polluted waterbody (10.6 mg/g). Furthermore, both polluted and unpolluted watercourses, as well as plant shoots and roots, had comparable amounts of P, Ca, and Mg. These results are in line with those of Galal et al. [38] and Ghazi et al. [21], who stated that the high water or sediment nutrient amounts in polluted or unpolluted waterbodies may not raise nutrient content in plant tissues, but it may enhance aboveground biomass.

Nutrients Standing Stock

The nutrient standing stock for a given species can be determined with the aid of chemical composition and biomass data, which are necessary for aquatic ecosystem nutrient budget calculations [33]. Multiplying an organ's biomass by the element concentration yields the nutrient standing stock, also known as plant nutrient content [45]. The inorganic nutrient contents in the jointed flatsedge plant shoots were found to be significantly varied seasonally, as validated by ANOVA I statistical

Table 5. Seasonal variation in the forage quality (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs Cyperus articulatus grown in polluted waterbodies. 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			
Spring	BG	3.3±1.0b	57.4±0.9cd	2.4±0.1bc	2.0±0.03bc	1.1±0.1ab	402.3±1.9bc
	AG	2.9±2.5bc	57.8±2.2cd	2.1±0.2c	1.7±0.1cd	0.9±0.1b	424.4±9.8a
Summer	BG	<u>5.6±1.2a</u>	55.7±0.9d	3.2±0.5a	2.7±0.4a	1.3±0.2a	385.0±9.1cd
	AG	<u>1.8±0.1f</u>	<u>58.8±0.1a</u>	<u>2.0±0.1c</u>	<u>1.6±0.1d</u>	<u>0.8±0.1b</u>	<u>430.2±11.9a</u>
Fall	BG	2.7±1.1cd	57.9±0.9cd	3.3±0.6a	2.7±0.5a	1.4±0.3a	<u>381.3±7.9d</u>
	AG	2.5±1.1de	58.2±0.8bc	<u>3.4±0.9a</u>	<u>2.8±0.7a</u>	<u>1.5±0.4a</u>	389.8±9.8cd
Winter	BG	2.5±1.1de	58.2±0.9bc	2.6±0.1b	2.1±0.1b	1.1±0.1ab	402.6±9.8bc
	AG	2.4±0.6e	58.5±0.6ab	2.2±0.1c	1.8±0.1cd	0.9±0.1b	421.3±4.1ab
F-value		4.1**	7.9***	4.3**	5.2**	5.3**	13.6***

Note: Means with the same letters are not significant according to Duncan's test. **: P<0.01, ***: P<0.001.

Table 6. Average nutritive value (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs of Cyperus articlatus grown in polluted (P) and unpolluted (U) waterbodies. 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.

Nutritive value		BG organs		t-value	AG organs		t-value
		P	U		P	U	
DCP	%	3.5±1.4	4.8±07	1.2	2.4±0.5	2.4±0.5	0.1
TDN	%	57.3±1.1	56.7±0.5	0.4	58.3±0.5	58.6±0.5	0.3
DE	Mcal/kg	2.9±0.4	2.5±0.2	0.8	2.4±0.6	2.1±0.2	0.7
ME	Mcal/kg	2.4±0.4	2.1±0.1	0.4	2.0±0.5	1.7±0.1	0.7
NE	Mcal/kg	1.2±0.2	1.1±0.1	0.2	1.0±0.2	0.8±0.1	0.4
GE	Mcal/kg	392.8±11.2	412.3±51.9	1.3	416.4±18.2	423.8±112.2	0.1

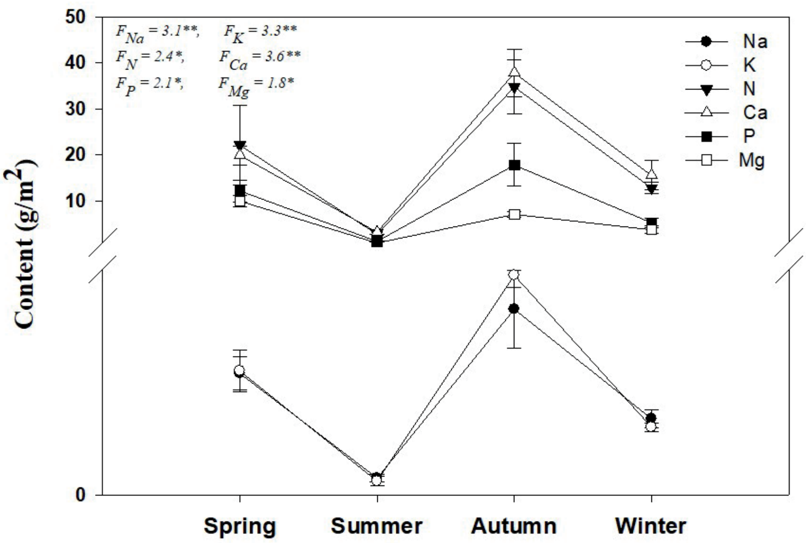

Fig. 4. Seasonal variation in the nutrients standing stock (g/m2) of the aboveground tissues of Cyperus articulatus collected from a polluted waterbody. Vertical bars represent standard deviation.

analysis (Fig. 4). Our research showed that the best time to harvest jointed flatsedge for the greatest removal of (0.94, 0.59, 34.75, 37.77, and 17.77 g/m^2, respectively) from eutrophic waterbodies is in the fall, and the best time to remove Mg (9.94 g/m^2) is in the spring. This finding is consistent with that of Galal et al. [36-38], who linked the highest plant biomass to the maximum accumulation of nutrients (particularly N and P). Besides, restoring aquatic ecosystems that are heavily N and P-loaded can benefit from the removal of nutrients by biomass harvesting [46]. However, summer had the lowest potential to remove nutrients from polluted waterbodies, where their nutrient contents were lowest.

The jointed flatsedge shoots possessed the capability to restore nutrients from contaminated waterbodies in a manner: Ca (19.08) > N (18.08) > P (9.06) > Mg (5.38) > K (0.28) > Na (0.27), which is like that of *C. alopecuroides* [38], but dissimilar from N > K > Ca > Na > Mg > P that of *P. australis* [33]. In addition, the annual average of N and P contents exceeded 11.89 and 3.76 g/m^2 for *C. alopecuroides* [38], but lower than 74.5 and 7.3 g/m^2 for *P. australis* [33]. The nutrient contents that the jointed flatsedge extracts support its potential use in aboveground biomass collection, particularly in the fall to remediate nutrients from eutrophic water bodies. Furthermore, the seasonal sequence of the shoot removal efficiency for all nutrient elements (except Mg) was as follows: fall > spring > winter > summer, whereas for magnesium, it was as follows: spring > fall > winter > summer. For wetland restoration, aquatic plants should be harvested during the growing season, when the biomass and nutrient levels in the plant tissues are at their peak [47]. Harvesting aquatic plants also needs to take into account the fact that these plants mitigate light and nutrients, which prevents algal blooms from forming in eutrophic waterbodies [47]. As a result, harvesting large stands of aquatic biomass will accelerate algal growth and eventually lead to phytoplankton dominance [1].

Organic Nutrients

Significant seasonal fluctuation was found in all examined organic nutrients in the jointed flatsedge's above- and below-ground tissues were recognized (Table 3). In accordance with the recommendation of Geurts et al. [14], which states that plants should be harvested when the protein content is highest for high forage quality, the jointed flatsedge should be harvested in the summer for use as fodder, where their aboveground parts had the highest protein content (9.8%) and could produce fiber-rich fodder (CF = 58.4%). However, during the summer, the belowground organs had the greatest amounts of ash and total proteins (10.9 and 9.8%), while the spring and fall had the lowest amounts of ether extract and crude fibers (0.4 and 8.1%), respectively. The Egyptian clover (*Trifolium alexandrinum* L.), a common grazing herb, had a CF content of 21.5% [38]. The protein content meets the minimal protein level (6-12%) needed for animal feed [48], and is consistent with the rough fodder's protein level (2.7-13.4%) reported by Galal et al. [37]. In line with Galal et al. [36], polluted plant tissues demonstrated a decrease in crude fibers and total proteins, which could be caused by suppression of photosynthetic activity or stimulation of the rate of respiration. Moreover, the content of crude fats, or ether extract, is between 0.5 and 3.1%, which lies within the scale of some rough fodder [37]. Furthermore, the average amount of total carbohydrates (63.2%) in the polluted waterbody was higher than 45.7% for *C. esculentus* [49], 43.4% for *T. alexandrinum* [38], and 57.6% and 57.4% for *Imperata cylindrica* and *D. bipinnata*, respectively [36], but less than the 73.6% recorded by Galal et al. [37] on *L. stolinefera*. Furthermore, they surpassed the range of some rough fodder material (27.8 and 51.9%) described by Shaltout et al. [48].

Statistically, there were significant changes in the estimated organic nutrients, with the exception of ash content in the belowground tissues, and EE, ash content, and TP in the aboveground tissues, between polluted and unpolluted waterbodies (Table 4). The belowground tissues in the polluted canal demonstrated a large rise for NFE from 48.5 to 63.2, but a significant decrease for EE, CF, and TP from 1.1 to 0.6%, 34.3 to 20.0%, and 9.1 to 7.6%, respectively. Nonetheless, under pollution stress, the aboveground tissues showed a considerable rise in NFE from 31.1 to 43.3% and a significant drop in CF from 52.5 to 41.5%. This conclusion is consistent with Galal et al. [37], who observed increased carbohydrate content under salinity stress in polluted waterbodies, which benefits plants in maintaining water balance through turgor pressure maintenance and osmotic stress resistance.

Forage Quality

Significant seasonal fluctuations were found in all estimated nutritional elements of the jointed flatsedge above- and below-ground organs (Table 5). The TDN of the jointed flatsedge's above- and below-ground portions surpassed 57.0%, satisfying the breeding cattle's dietary needs of 50.0% [21]. Besides, the ME (1.6-2.8 Mcal/kg) approximated the requirements for breeding cattle and sheep, while the mean value of DE (2.1-3.4 Mcal/kg) saved the amount (2.7 Mcal/kg) needed by sheep [48]. The jointed flatsedge's forage quality did not significantly differ between polluted and unpolluted waterbodies; as a result, both waterbodies' above- and below-ground forage quality meet the NRC standards for beef cattle, dairy cattle, goat, and sheep [4]. Comparable outcomes were noted by Farahat et al. [50] for *V. cuspidata* and Galal et al. [38] for *C. alopecuroides*.

On average, there were no significant changes between polluted and unpolluted waterbodies in the forage quality of the jointed flatsedge's above- and below-ground portions (Table 6). The contents of TDN, DE, ME, and NE in the belowground tissues in the polluted canal (57.3%, 2.9, 2.4, and 2.1 Mcal/kg) were higher than in the unpolluted Nile (56.7%, 2.5, 2.1, and 1.1 Mcal/kg). Nonetheless, in the aboveground shoots, the TDN and GE values (58.6% and 423.8 Mcal/kg) in the unpolluted were greater than those in the polluted (58.3 and 416.4 Mcal/kg) waterbodies. It is imperative to acknowledge the possibility that this species may accumulate heavy metal contaminants inside its tissues [23]. For this reason, caution should be exercised while gathering jointed flatsedge plants for animal feed from polluted waterbodies.

Conclusions

The aboveground biomass of the jointed flatsedge was maximum during fall, and minimum during summer. The aboveground parts had their highest contents of K, N, and Ca during fall, and the highest Na, P, and Mg during spring, while the belowground tissues had their highest Na content in the winter, Ca and P in the spring, and K and N in the summer. Additionally, the aboveground tissues exhibited the maximum nutrient standing stock (g/m^2) of Na, K, N, Ca, and P throughout the fall months, whereas the spring exhibited the highest Mg content. Therefore, by harvesting aboveground biomass, especially in the fall months, the jointed flatsedge has the efficiency to remediate nutrients from eutrophic waterbodies. Additionally, in order to recycle the materials that were harvested, the above- and below-ground parts of the plants from both polluted and unpolluted waterbodies had the forage quality for beef cattle, dairy cattle, goats, and sheep, but care should be taken when harvesting plants from polluted waterbodies because of their potential to accumulate heavy metal pollutants in their tissues.

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Conflict of Interest

All the authors confirm that there are no conflicts of interest.

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