

NUTRIENT MITIGATION AND POSSIBLE RECYCLING STRATEGIES OF THE HARVESTED BIOMASS OF WILD MINT (*MENTHA LONGIFOLIA* L.) IN NUTRIENT-RICH ENVIRONMENTS, EGYPT

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Abstract. This research was conducted to examine the seasonal fluctuations in the ability to remediate nutrients of *Mentha longifolia* in eutrophic waterbodies through biomass harvesting and estimating its potential use as animal feed. Samples of plants, water, and sediment were collected seasonally from six eutrophic and three freshwater sites. In the eutrophic waterbody, the highest fresh and dry biomass (47.9 and 22.4 g/m², respectively) was recorded in summer, while the lowest (23.6 and 9.5 g/m²) was recorded in autumn. The aboveground parts had the highest concentrations of Na, K, and Ca (212.3, 327.2, and 16.7 mg/kg) during autumn, while the highest N concentration (24.4 mg/kg) was recorded during summer. The roots in the eutrophic waterbody had substantially higher concentrations of Na, N, Ca, P, and Mg (183.8, 11.1, 11.4, 7.4, and 1.9 mg/kg) compared to those in the roots of the freshwater Nile (165.2, 3.6, 13.4, 5.6, and 0.8 mg/kg). The wild mint's aboveground tissues removed the highest amounts of Na, K, Ca, P, and Mg (4.5, 6.4, 363.0, 152.4, and 47.1 g/m²) during spring, while the highest N removal (437.7 g/m²) occurred during summer. The total digestible nutrients (TDN) of the wild mint above- and below-ground portions exceeds 50.0% of the breeding cattle's dietary needs. Moreover, the metabolized energy (ME: 1.6–2.2 Mcal/kg) was close to the requirements for breeding cattle and sheep. The best time to harvest wild mint to remediate Na, K, Ca, P, and Mg from eutrophic wetlands is spring, while summer is optimal for removing N and using the biomass as fodder.

Keywords: *eutrophic water, emergent plants, horsemint, animal fodder, seasonal potential, organic nutrients*

Introduction

The delicate balance of aquatic environments is severely threatened by the extensive release of various nutrients and pollutants into these settings as a result of growing anthropogenic activities in recent decades (Galal et al., 2024). Additionally, increased nutrient concentrations in aquatic habitats due to human activities and socioeconomic expansion have led to ecosystem degradation (Huang et al., 2020). Eutrophication can result from wastewater-derived surplus nutrients, particularly N and P, accumulating at the bottoms of waterbodies (Chen and Costa, 2023; Galal et al., 2023). Pesticides, fertilizers, industrial chemicals, agricultural drainage, and other pollutants can lead to environmental degradation (Lovejoy, 2014; McNeely, 2021; Kevin, 2023). Aquatic ecosystems are rapidly degrading worldwide as a result of eutrophication and other factors that have caused waterbodies to transition from clear water states dominated by

aquatic plants to turbid water states dominated by algal blooms (Lin et al., 2022). Moreover, a reduction in water oxygen levels resulting from the eutrophication-induced proliferation of algae may reduce biodiversity (Hautier et al., 2014).

Today, the problem of efficient use of natural resources has become extremely serious, so the application of environmental technologies enabling to obtain nutrients and energy carriers from industrial wastes, biological objects and organic pollutants is an important task (Malovany et al., 2016; Kanda et al., 2019). Nitrogen's organic and mineral components can be found in subterranean and home waters, as well as in wastewater from a variety of industries, including food, agrochemical, petrochemical, and chemical (Tymchuk et al., 2020). Recent concerns on environmental sustainability have led to research works exploring the potential application of wetland plants as a natural means to solve the problem (Dhir et al., 2009). Wetland plants are observed in waterbodies worldwide, especially where water is enriched with nutrient runoff from a natural process or by urban and agricultural practices, supporting aquatic plants' luxuriant growth (Dhote and Dixit, 2009). The interest and hope for the successful application of wetland plants in environmental pollution management have been rekindled by recent studies on their prospective use in eliminating contaminants from waste water and their secondary usage as energy feedstock (Kumar et al., 2022). Using emergent wetland plants to clean up wastewater is a cheap, environmentally friendly, and organic way to manage contaminated aquatic ecosystems (Ali et al., 2024). A number of wetland plants exhibit pollution tolerance by reducing the stress response to different metabolic systems (Singh et al., 2023a).

Macronutrients, such as N, P and K have more often been the focus of nutritional studies because of their potential role in limiting plant growth (Singh et al., 2023b). The ability of emergent macrophytes to absorb these elements through their roots and transfer them to their shoots, where they acquire them from the sediments, hampered their overall capacity to serve as aquatic environmental pollution monitors (Barko and Smart, 1981). Wetland plants can take up large quantities of nutrients from the environment, and releasing them when they decay; therefore, periodic harvesting of their biomass is an efficient strategy to restore eutrophic aquatic environments (Galal et al., 2023). Also, harvesting can enhance water purification because it removes the labile N and P that would otherwise be partially released after plant's death at the end of the growing season (Jabłońska et al., 2020; Xiao, 2021). Large amounts of nutrients are removed when wetland plant biomass is harvested, which probably reduces eutrophication in aquatic habitats, increases biodiversity, and may even provide income to cover restoration expenses (Carson et al., 2018). Because harvesting eliminates nutrients that would otherwise be partially released following plant death at the end of the growing season, it can improve water purification (White, 2021). Harvested plant biomass can be used as an agricultural nutrient source, incorporated into bioenergy economy or forage production (Galal et al., 2023).

Wetland plants have high remediation potential for macronutrients because of their general fast growth and high biomass production (Shaltout et al., 2016). The wild mint (*Mentha longifolia*; Lamiaceae) is an emergent wetland plant widely distributed in India, Pakistan, Sri Lanka, Greece, Egypt, China, Mediterranean regions, Canaries, S. Africa, Iraq, Iran, Syria and Turkey (Jena et al., 2013). It is a fast-growing aromatic perennial herb that is widespread throughout the Eastern Cape province of South Africa (Gharib et al., 2020). It is Widely utilized in herbal medicine; it is thought to be very helpful in strengthening the immune system and thwarting recurrent infections (Ghazi et al., 2019).

Additionally, it has the capacity to accumulate various heavy metals from contaminated wetlands, the majority of which are held in its subterranean portions (Gharib et al., 2020). This research is part of a series on emergent macrophytes' ability to recycle harvested biomass and recover eutrophication in aquatic habitats in Egypt (Galal et al., 2023). The current study intends to estimate and assess the seasonality effect on the plant biomass and nutrient sequestration performance of the wild mint in eutrophic wetlands. It also assessed the possible recycling strategies of the harvested biomass to be used as animal fodder. Our hypotheses tested how the great biomass accumulation of the study plant can sequester high contents of nutrients to restore eutrophic environment. Also, the harvested biomass has high forage quality to be reused for animal fodder.

Materials and methods

Sampling design and biomass estimation

Two main wetlands were selected during 2019 for the present study in Greater Cairo: River Nile at South Cairo and Nahia drain at North Giza (*Fig. 1*). The Nile River (Freshwater or unpolluted) is the main source of drinking water for Egyptians, while Nahia drain (Eutrophic or polluted) receives sewage and agricultural wastes (Gharib et al., 2020). The study area lies in the hyper-arid zone (Ayyad et al., 1983). Sampling of the wild mint was carried out seasonally through six eutrophic sites evenly distributed on Nahia drain, and during spring and autumn (due to some difficulties) through three freshwater sites along the Nile River (n = 120 and 30, respectively). The sampling sites lied on the moist shoreline of the watercourses. At each site, 5 quadrats (0.5 × 0.5 m) were selected randomly to represent the growth of mint plant population. In each quadrat, all plants were collected using shovel and transferred to the laboratory in polyethylene bags. Then, the plants were washed thoroughly with de ionized distilled water, separated into shoot and root, left to air dry for the determination of the fresh biomass as g FW/m², and then oven-dried at 105 °C till constant weight to determine the dry biomass as g DW/m².

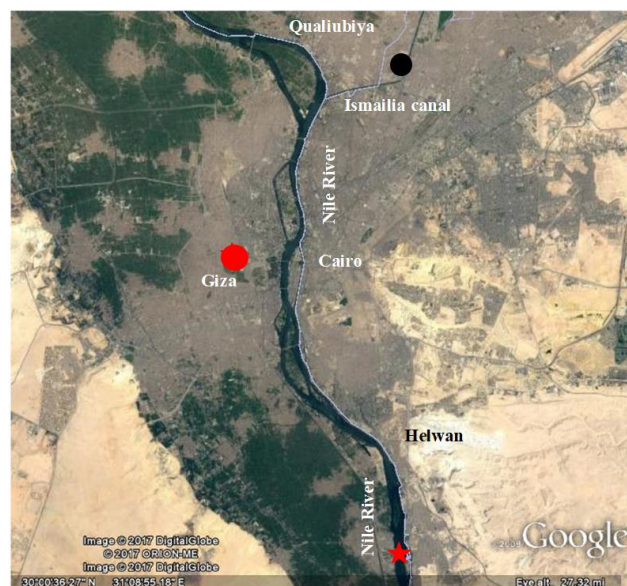


Figure 1. Location map showing the eutrophic (●) and the freshwater (★) sites of the study area and its surrounding agricultural lands. 30° 00' 36.27" N and 31° 08' 5.18" E. Source: Google earth 19 April 2017

Plant analysis

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

Inorganic nutrients

A ground sample of 1 g was digested in a 20 ml tri-acid mixture of HNO₃:HClO₄: HF (1:1:2 v:v:v). Total nitrogen (N) was assessed by the Kjeldahl method; P was analyzed using molybdenum blue method using spectrophotometer (CECIL CE 1021; Cecil Instruments Ltd, UK); Ca, Na, and K were analyzed using a flame photometer (CORNING M410; Corning Co. Ltd, UK); and Mg was measured using atomic absorption photometer (Shimadzu AA-6200; Shimadzu Co. Ltd, Japan). All these procedures for plant analysis were outlined by Allen (1989). Furthermore, the nutrient contents of the above- and below-ground parts (g DM m⁻²) were calculated by multiplying the nutrient concentrations by the biomass of the respective organ.

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. (2000), the total protein (TP) content was determined by multiplying the total nitrogen by 100/16, or 6.25. Moreover, the formula mentioned by Le Houérou (1980) was used to calculate the amount of carbohydrates (NFE):

$$\begin{aligned} \text{NFE (in \% dry matter)} &= \text{NFE (in \% dry matter)} \\ &= 100 - (\text{TP} + \text{CF} + \text{crude fat} + \text{ash}) \end{aligned} \quad (\text{Eq.1})$$

Fodder quality

The digestible crude protein (DCP) was estimated according to the formula (Demarquilly and Weiss, 1970):

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

The total digestible nutrients (TDN) were calculated using the formula (Naga and El-Shazly, 1971):

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

The digestible energy (DE) was evaluated following the formula (NRC, 1984):

$$\begin{aligned} \text{DE} \left(\frac{\text{Mcal}}{\text{kg}} \right) = & 0.0504 \text{ TP (\%)} + 0.077 \text{ EE (\%)} + 0.02 \text{ CF (\%)} \\ & + 0.000377 \text{ (NFE)}^2 \text{ (\%)} \\ & + 0.011 \text{ (NFE)} \text{ (\%)} - 0.152 \end{aligned} \quad (\text{Eq.4})$$

The metabolized energy (ME) was calculated as Garrett (1980):

$$\text{ME} = 0.82\text{DE} \quad (\text{Eq.5})$$

Following Le Houérou (1980), the net energy

$$\text{(NE)} = 0.82 \text{ ME} \quad (\text{Eq.6})$$

The gross energy (GE) was calculated following the equation (NRC, 1984):

$$\begin{aligned} \text{GE} \left(\frac{\text{Kcal}}{100 \text{ g}} \right) = & 5.72 \text{ TP (\%)} + 9.5 \text{ EE (\%)} + 4.79 \text{ CF (\%)} \\ & + 4.03 \text{ NFE (\%)} \end{aligned} \quad (\text{Eq.7})$$

Sediments sampling and analysis

Using stainless steel crab, sediment samples (three composite samples) were collected from each site, air-dried, and then were 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 (1989) 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 estimate during 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 0.01 N HCl, and sulphates were estimated as barium sulphate turbid metrically at 500 nm.

Statistical 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, 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 wild mint 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 (SPSS, 2012).

Results

Sediments properties

The chemical analysis of the sediments revealed substantial differences ($P < 0.05$) in all measured variables between polluted and unpolluted waterbodies (Table 1). The fresh waterbody's sediment was slightly alkaline (7.3) with lower salinity (372.7 $\mu\text{S/cm}$), whereas the eutrophic drain's sediment was slightly acidic (pH: 6.8) with higher salinity (EC: 499.6 $\mu\text{S/cm}$). Furthermore, compared to the freshwater Nile's sediment, the eutrophic sediment contained noticeably ($P < 0.05$) larger contents of all the anions and cations under investigation.

Table 1. Chemical characteristics (Mean \pm SD) of the sediment of the studied eutrophic and freshwater wetlands

Variable	Sediment		t-value
	Freshwater	Eutrophic	
PH	7.3 \pm 0.4	6.8 \pm 0.2	2.2*
EC ($\mu\text{S/cm}$)	372.7 \pm 32.7	499.6 \pm 12.2	4.6**
CO ₃ ²⁻	254.2 \pm 2.2	379.4 \pm 3.1	3.2*
HCO ₃ ⁻	241.9 \pm 21.7	480.5 \pm 6.4	8.1**
SO ₄ ²⁻	251.3 \pm 9.8	499.3 \pm 13.1	5.8**
N ⁻³	132.4 \pm 12.3	226.2 \pm 4.1	6.2**
P ⁻³	68.6 \pm 4.1	81.8 \pm 2.1	2.2*
Na ⁺	142.7 \pm 6.2	195.8 \pm 4.6	2.6*
K ⁺	124.6 \pm 6.9	143.4 \pm 4.4	3.2*
Cl ⁻	156.2 \pm 11.2	226.6 \pm 17.3	6.7**

*, $P < 0.05$, **, $P < 0.01$

Plant biomass

The wild mint fresh and dry biomass showed notable ($P < 0.05$) seasonal variation between plants collected from eutrophic and fresh water wetlands (Fig. 2). Spring season recorded significantly the highest fresh and dry biomass (54.4 and 26.6 g/m^2) in the freshwater Nile. Whereas, in the eutrophic sites, summer had the highest fresh and dry biomass (47.9 and 22.4 g/m^2 , respectively), which was not differ significantly from spring, while autumn had the lowest (23.6 and 9.5 g/m^2 , respectively). Additionally, the plant dry biomass in the fresh water Nile (26.6 and 21.4 g/m^2) was substantially ($P < 0.05$) higher than the values (17.9 and 9.5 g/m^2) recorded in the eutrophic drain during spring and autumn, respectively. It is worth to note that the fresh and dry biomass (50.5 and 23.9 g/m^2) in the freshwater Nile was remarkably higher than those (33.7 and 15.7 g/m^2) in the eutrophic drain.

Inorganic nutrients

The wild mint above- and below-ground tissues showed notable seasonal variations in their inorganic nutrient levels (Fig. 3). The aboveground parts had their highest contents of Na, K, and Ca (212.3, 327.2, and 16.7 mg/kg , respectively) and the lowest N (14.5 mg/kg) during autumn. Besides, they had their highest contents of N (24.4 mg/kg) and the lowest k, Ca, P and Mg (245.3, 14.4, 5.2 and 1.1 mg/kg , respectively) during summer. Moreover, the lowest Na contents (175.2 mg/kg) were recorded during winter.

On the other side, the belowground parts of the wild mint had its highest Na, Ca and P content (221.0, 14.5, and 7.8 mg/kg, respectively) and the lowest total N (8.9 mg/kg) in autumn. Besides, they had their highest contents of K and Mg (318.8 and 2.4 mg/kg) in summer and the highest N contents (13.1 mg/kg) in winter.

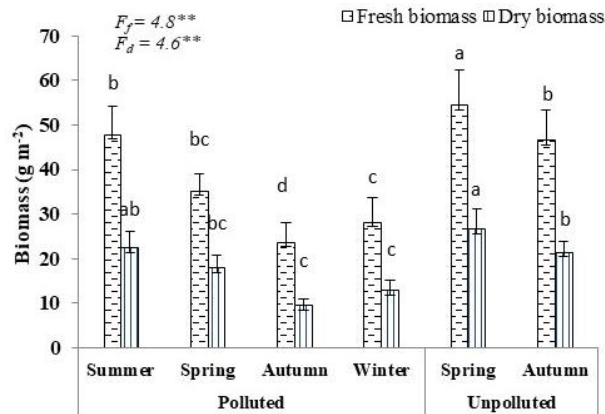


Figure 2. Seasonal variation in the fresh and dry biomass of the aboveground organs of *Mentha longifolia* collected from polluted and unpolluted waterbodies. Means with the same letters are not significant

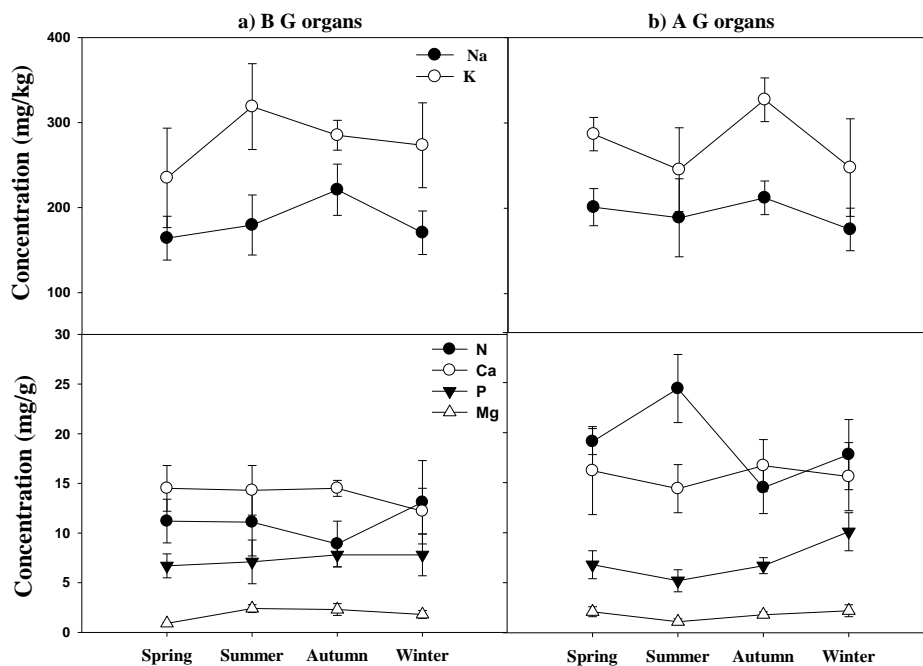


Figure 3. Seasonal variation in the nutrient concentrations of the a) belowground (BG) and b) aboveground (AG) organs of *Mentha longifolia* collected from eutrophic drains. Vertical bars represent the standard deviation

The paired sampled t-test indicated that the examined inorganic elements in the wild mint plant organs differ significantly ($P < 0.05$) between eutrophic and freshwater bodies (Table 2). The eutrophic water body's plant roots Na, N, Ca, P and Mg concentrations

(183.8, 11.1, 11.4, 7.4 and 1.9 mg/kg, respectively) were substantially greater than (165.2, 3.6, 13.4, 5.6 and 0.8 mg/kg, respectively) those in the fresh water Nile's plant roots. While, fresh water Nile's plant root K concentration (297.4 mg/kg) is greater than (278.1 mg/kg) that in the eutrophic water body. In a similar manner, the shoots' Na, N, Ca, P and Mg concentrations (194.5, 18.9, 15.7, 7.2 and 1.8 mg/kg, respectively) in the eutrophic waterbody was noticeably greater ($P < 0.05$) than (160, 14.1, 11.1, 4.5 and 4.4 mg/kg respectively) those of the freshwater body. Furthermore, the fresh water Nile's plant shoot K concentration (301.1 mg/kg) was greater than (276.8 mg/kg) that in the eutrophic water body.

Table 2. Inorganic nutrient concentrations (Mean±standard deviation) of the belowground roots (BG) and aboveground shoots (AG) of *Mentha longifolia* collected from Eutrophic (P) and freshwater (U) wetlands

Inorganic element	Root		t-value	Shoot		t-value
	P	U		P	U	
Na (mg/kg)	183.8±25.6	165.2±43.5	2.7*	194.5±16.2	160.2±21.2	3.2*
K (mg/kg)	278.1±34.6	297.4±32.3	2.4*	276.8±38.7	301.1±52.5	2.6*
Total N (mg/g)	11.1±3.1	3.6±0.6	3.1*	18.9±2.7	14.1±2.3	2.2*
Ca (mg/g)	11.4±1.9	13.4±1.3	2.3*	15.7±3.2	11.1±1.6	4.6**
P (mg/g)	7.4±1.4	5.6±0.5	2.3*	7.2±1.3	4.5±0.1	2.9*
Mg (mg/g)	1.9±0.4	0.8±0.3	3.1*	1.8±0.4	4.4±0.2	3.4*

*: $P < 0.05$, **: $P < 0.01$

Nutrients content

The inorganic nutrient contents (standing stock) in the wild mint plant shoots were significantly ($P < 0.05$) varied seasonally as validated by ANOVA I statistical analysis (Fig. 4). The plant shoots during spring months had the potential to sequester the highest contents of Na, K, N, Ca, P and Mg (4.5, 6.4, 428.1, 363.0, 152.4, and 47.1 g/m², respectively) from the eutrophic drain. Conversely, autumn had the lowest potential to remove nutrients, where their nutrient contents were the lowest (3.4, 3.1, 138.2, 159.2, 63.9, and 17.2 g/m², respectively). The order of the annual average nutrient contents (g/m²) sequestered by the aboveground tissues of the wild mint was: N (308.3) > Ca (245.3) > P (109.9) > Mg (28.1) > K (4.3) > Na (3.1). Furthermore, the seasonal sequence of the shoot removal efficiency for Na, K, N, and Ca was: spring > summer > winter > autumn, while that for P and Mg was: spring > winter > summer > autumn.

Organic nutrients

Significant seasonal fluctuation ($P < 0.05$) was observed in the examined organic nutrients in the wild mint above- and below-ground tissues (Table 3). Summer season recorded the highest shoot contents of ether extract (EE), crude fibers (CF), and total protein (TP) (1.4, 53.5 and 15.1%) and the lowest carbohydrate (NFE) content (22.2%), while spring and autumn contributed the highest ash and NFE content (10.7 and 52.6), respectively in the plant shoots. Besides, autumn months had the lowest shoot contents of CF, ash and TP (29.3, 7.1, and 9.6), and spring had the lowest EE (0.6%). On the other hand, the belowground organs had the greatest amounts of EE and ash contents (2.3 and 18.2%) during the spring, while the highest TP and NFE contents (8.4 and 50.3%) during

winter, and the highest CF (59.1%) during summer. Moreover, the lowest roots EE and TP (0.6 and 5.6%) were obtained during autumn, while the lowest CF and ash contents (29.8 and 9.7) during winter, and the lowest NFE (21.8%) was in summer.

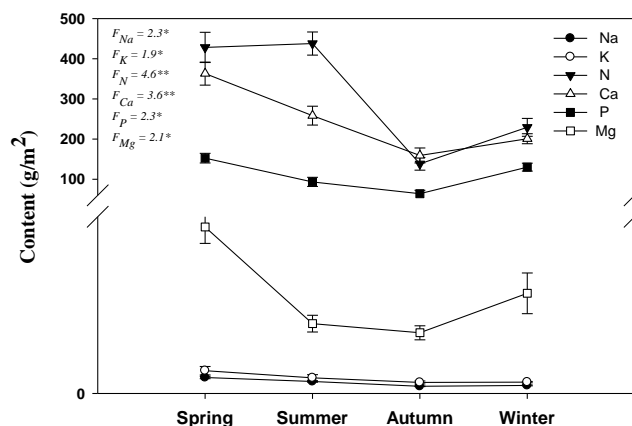


Figure 4. Seasonal variation in the nutrients standing stock (g/m^2) of the aboveground tissues of *Mentha longifolia* collected from polluted waterbody. Vertical bars represent standard deviation

Table 3. Seasonal variation in the organic nutrient contents (Mean \pm standard deviation) of the belowground (BG) and aboveground (AG) organs of *Mentha longifolia* grown in eutrophic waterbody

Season		Organic nutrient				
		EE	CF	Ash	TP	NFE
Spring	BG	2.3 \pm 0.3a	32.6 \pm 8.6d	18.2 \pm 2.5a	7.0 \pm 0.9d	39.9 \pm 9.8cd
	AG	0.6 \pm 0.1c	36.5 \pm 4.4c	10.7 \pm 1.2bc	11.9 \pm 3.9b	40.3 \pm 3.9c
Summer	BG	1.3 \pm 0.5b	59.1 \pm 8.9a	11.1 \pm 1.1b	6.7 \pm 1.2de	21.8 \pm 6.9e
	AG	1.4 \pm 0.3b	53.5 \pm 5.7b	7.9 \pm 1.6d	15.1 \pm 1.2a	22.2 \pm 6.1e
Autumn	BG	0.6 \pm 0.3c	35.8 \pm 6.3cd	10.8 \pm 0.9bc	5.6 \pm 1.9e	47.2 \pm 5.6bc
	AG	1.4 \pm 0.4b	29.3 \pm 7.5de	7.1 \pm 1.8d	9.6 \pm 2.2cd	52.6 \pm 9.6a
Winter	BG	1.9 \pm 0.7ab	29.8 \pm 8.4de	9.7 \pm 1.7bcd	8.4 \pm 1.5cd	50.3 \pm 9.3ab
	AG	1.1 \pm 0.2bc	32.4 \pm 5.6d	8.1 \pm 1.4cd	10.9 \pm 2.9c	47.5 \pm 5.1bc
F-value		2.8*	9.6***	10.9***	4.8**	6.4**

EE: ether extract, CF: crude fiber, TP: total protein, NFE: nitrogen free extract (soluble carbohydrate). Maximum and minimum values are underlined. Means with the same letters are not significant based on Duncan's test. *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$

Statistically, there were significant differences ($P < 0.05$) in the estimated shoot organic nutrients and root EE, CF, and TP between eutrophic and fresh water wetlands (Table 4). The belowground tissues in the eutrophic drains showed significant increase in CF, and TP from 26.8 and 3.8% to 39.3 and 6.9%, respectively. Nonetheless, under eutrophication stress, the aboveground tissues showed a considerable decline in the EE (2.4 to 1.1%), CF (45.9 to 37.9%), and NFE (55.6 to 40.6%), while rise in TP (8.9 to 11.9%) and ash content (6.4 to 8.4%).

Table 4. Average organic nutrient concentrations (Mean±standard deviation) of the of the belowground (BG) and aboveground (AG) organs of *Mentha longifolia* collected from eutrophic (P) and freshwater (U) sites

Organic nutrient (%)	Root		t-value	Shoot		t-value
	P	U		P	U	
EE	1.2±0.8	1.5±0.4	2.1*	1.1±0.4	2.4±0.3	2.6*
CF	39.3±13.4	26.8±5.1	3.1*	37.9±10.8	45.9±10.1	4.7**
Ash	12.4±3.9	11.7±2.2	0.5	8.4±1.6	6.4±1.1	3.1*
TP	6.9±1.1	3.8±0.1	12.2***	11.9±2.3	8.9±2.6	2.6*
NFE	39.8±12.8	40.4±11.1	0.9	40.6±13.3	55.6±4.1	5.1**

*: P < 0.05, **: P < 0.01, ***: P < 0.001

Fodder quality

Significant seasonal variations were found in all estimated nutritional elements of the wild mint's above- and below-ground organs (Table 5). The aboveground shoots attained the highest DE, ME and NE (2.7, 2.2 and 1.1 Mcal/kg, respectively) during autumn, the highest DCP and GE (10.5% and 445.1Mcal/kg) during summer, and the highest TDN (59.0%) during spring. On the other hand, the belowground roots had the lowest DE, ME and NE (1.9, 1.6 and 0.8 Mcal/kg, respectively) in summer and the lowest GE (378.7 Mcal/kg) in spring. Furthermore, the lowest TDN (54.2%) was recorded in the shoot tissues during spring months.

Table 5. Seasonal variation in the fodder quality (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs of *Mentha longifolia* grown in eutrophic waterbodies

Season		Fodder quality					
		DCP	TDN	DE	ME	NE	GE
Spring	BG	3.0±0.9d	<u>59.0±2.9a</u>	2.1±0.2de	1.7±0.2cd	0.9±0.1cd	<u>378.7±9.8d</u>
	AG	7.6±1.9b	<u>54.2±1.4de</u>	2.3±0.1cd	1.9±0.1bc	0.9±0.1cd	411.3±8.6bc
Summer	BG	2.7±0.9de	58.5±2.3ab	<u>1.9±0.1e</u>	<u>1.6±0.2c</u>	<u>0.8±0.1d</u>	421.3±27.1b
	AG	<u>10.5±1.2a</u>	52.6±1.9e	2.2±0.1cd	1.8±0.4cd	0.9±0.1c	<u>445.1±11.9a</u>
Autumn	BG	<u>1.7±1.1e</u>	58.7±5.1ab	2.3±0.2cd	1.9±0.2bc	0.9±0.1c	399.3±6.3c
	AG	5.4±2.1c	56.5±2.1bc	<u>2.7±0.3a</u>	<u>2.2±0.3a</u>	<u>1.1±0.1a</u>	420.8±19.8b
Winter	BG	4.3±1.4cd	57.8±2.9bc	2.5±0.3ab	2.1±0.3ab	1.0±0.1ab	411.4±7.7bc
	AG	6.6±2.7bc	55.3±1.8cd	2.5±0.2bc	2.1±0.2ab	1.0±0.1bc	419.5±9.4b
F-value		10.8***	12.5***	6.4**	6.2**	4.6**	8.5***

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

With the exception of DCP, there were no significant changes in the nutritional elements of the above- and below-ground tissues of the wild mint grown in eutrophic or freshwater wetlands (Table 6). The contents of TDN and DE (2.9% and 2.2 Mcal/kg) of the belowground roots in the eutrophic sites were higher than (0.8 and 2.0 Mcal/kg) in the freshwater Nile. Nonetheless, for the aboveground shoots, the TDN, DE, ME, and NE values (57.8%, 2.8, 2.3 and 1.1 Mcal/kg, respectively) in the freshwater Nile were greater

than those (54.6%, 2.4, 2.0 and 1.0 Mcal/kg) in the eutrophic drain. Besides, the eutrophic sites recorded higher shoot DCP and GE (7.5% and 424.2 Mcal/kg) than those (4.7% and 419.5 Mcal/kg) from the freshwater Nile.

Table 6. Average nutritive value (Mean±standard deviation) of the belowground (BG) and aboveground (AG) organs of *Mentha longifolia* grown in eutrophic (P) and freshwater (U) wetlands

Nutritive value	Root		t-value	Shoot		t-value
	P	U		P	U	
DCP %	2.9±1.1	0.8±0.1	6.9**	7.5±2.2	4.7±2.5	3.2*
TDN %	58.5±5.2	62.6±3.2	1.4	54.6±1.7	57.8±4.7	1.2
DE Mcal/kg	2.2±0.3	2.0±0.3	1.1	2.4±0.2	2.8±0.1	0.8
ME Mcal/kg	1.8±0.2	1.6±0.2	0.8	2.0±0.2	2.3±0.1	0.8
NE Mcal/kg	0.9±0.1	1.0±0.1	0.8	1.0±0.1	1.1±0.2	0.8
GE Mcal/kg	402.7±18.3	411.4±7.7	0.8	424.2±14.6	419.5±9.4	1.1

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. *: $P < 0.05$, **: $P < 0.05$

Discussion

There are several ways that nutrients and sediment can get into waterbodies, such as surface runoff, wastewater discharge, air deposition, etc. (EPA, 2021). The habitat and populations of aquatic plants and animals depend on a certain quantity of nutrients and sediment, but too much of either can be detrimental (Conley et al., 2009). The kind and contamination severity caused by wastewater discharge may be reflected in the bottom sediment composition of wetlands (Galal et al., 2023). The eutrophic drain's sediment showed a high salinity (EC: 476.4 μ S/cm) and a slightly acidic pH (5.1), whereas the fresh water body's sediment had a salinity of 372.7 μ S/cm and was relatively alkaline (pH = 7.3). The identified anions and cations are found in much higher concentrations in the eutrophic sediment than in the freshwater Nile sediment. These results agreed with those of Galal et al. (2021a,b), who found that the sediment from polluted contained more nutrients and heavy metals than the sediment from the unpolluted water bodies. According to Eid et al. (2020), excessive amounts of nutrients in the contaminated waterbodies are the result of drainage from surrounding companies and residential areas, cities, and farms. The N content in the Nahia drain's sediment was approximately twice than that of the freshwater Nile, which increase the risk of eutrophication in the drain (Galal et al., 2024).

The assessment of biomass holds significant value in the investigation of dry matter movement and plant functioning (Galal et al., 2021a). The wild mint dry biomass varied seasonally and averagely, there is a notable difference between plants collected from eutrophic and freshwater wetlands. The plant biomass of the eutrophic waterbody was less than that of the freshwater Nile. The lower biomass in the eutrophic waterbodies may be caused by the higher salinity of the contaminated sediment and the increased levels of heavy metals, which have a detrimental effect on plant growth (Wang et al., 2024). Also, Galal and Shehata (2016) attributed the low plant biomass in eutrophic waterbodies to eco-physiological limitations, which included variations in watercourse management

techniques, a short growing season, low temperatures, poor water trophic status, and adverse factors like light, competition, and animals. In the eutrophic sites, summer had the highest fresh and dry biomass, while autumn had the lowest. This result was in line with those reported by Eid et al. (2016) on *Arundo donax* and Galal et al. (2017) on *Vossia cuspidata*, and Ghazi et al. (2019) and Gharib et al. (2020) on the wild mint, but disagreed with those reported by Galal et al. (2019a, b, 2024) on *Cyperus articulatus*, *Pistia stratiotes*, and *Ludwigia stolonifera*, respectively.

The ability and quantity of nutrients that plants can take up from the soil, the concentrations of nutrients in their tissues, and the timing and degree of nutrient withdrawal during leaf senescence vary throughout species (Abdallah et al., 2020; Galal et al., 2023). The inorganic nutrients in the various tissues of the wild mint statistically vary significantly with the season. This result agrees with results of Galal et al. (2022a) and Klaus et al. (2011), who determined that the primary causes of variance in nutrients are plant size and growth season. In the present study autumn brought the largest concentrations of Na, K, and Ca, whereas summer brought the highest contents of N to the aboveground sections. On the other hand, the belowground parts had its highest Na and P in autumn. Besides, they had their highest contents of K and Mg in summer and had their highest contents of N in winter. Vymazal (2020) stated that the plant tissues stored nutrients at their lowest levels during senescence and maturation, and at their maximum concentrations at the beginning of the growing season. The roots and shoots of the plants in the eutrophic waterbody acquired significantly more nutrients than the plants in the freshwater Nile. As reported by Ruiz and Velasco (2010) and Eid et al. (2012, 2020), wetland plants' nutrient concentrations rise as environmental levels rise; this relationship is largely influenced by the species and the elements. It was worthy to note that the wild mint shoots can accumulate higher concentrations of Ca, but lower K than some emergent plants such as *Desmostachya bipinnata* (Shaltout et al., 2016); *Phragmites australis*; and *C. articulatus*, *C. alopecuroides*, *V. cuspidata*, and *Typha domingensis* (Galal et al., 2023).

Chemical composition and biomass data can be used to calculate the nutrient content of a particular species. These data are essential for calculating the nutrient budget of wetland ecosystems (Eid et al., 2020). For the wild mint's aboveground tissues, the spring months exhibited the highest nutrient standing stock (g/m^2) of Na, K, Ca, P and Mg whereas autumn exhibited the lowest contents. In a related investigation on *C. alopecuroides*, Galal et al. (2022a) found that summer had the highest standing stock of nutrients for Na, K, and N, while spring yielded the highest Mg. The wild mint shoots possessed the capability to restore nutrients from eutrophic wetland bodies in a manner $\text{N} > \text{Ca} > \text{P} > \text{Mg} > \text{K} > \text{Na}$, which differs from $\text{N} > \text{K} > \text{Na} > \text{Mg}$ that of *P. australis* (Eid et al., 2020). The current findings noted that the best time to harvest the wild mint plants for the efficient remediation of Na, K, Ca, P, and Mg from eutrophic wetlands is spring, and the best time to remove N is summer. This finding is consistent with that of Galal et al. (2021a, b), who linked the highest plant biomass to the maximum accumulation of nutrients (particularly N and P). Besides, restoring eutrophic wetlands heavily N and P-loaded can benefit from the removal of nutrients by biomass harvesting (Kasak et al., 2020) during summer and spring months, respectively.

For animals to be productive, feed quality which is primarily determined by the amounts of total protein (TP), crude fiber (CF), digestibility, and other related factors is essential (Vasileva et al., 2019). Additionally, TP and CF are generally considered to as indicators of how nutrient-dense food is for grazing animals (Heneidy and Halmy, 2009).

In accordance with the recommendation of Geurts et al. (2020), which states that plants should be harvested when the protein content is highest for high forage quality, the wild mint should be harvested in the summer for efficient use as fodder, where their aboveground parts had the highest protein content (15.1%). The average root and shoot protein content (6.9 and 11.9%) from eutrophic plants as well as freshwater plant shoot (8.9%) meet the minimal protein level (6-12%) needed for animal feed (Shaltout et al., 2016), and is in line with the rough fodder's protein level (2.7-13.4%) reported by Shoukry (1992).

The TDN of the wild mint above- and below-ground portions exceed 50.0% of the breeding cattle's dietary needs (NRC, 1984). Besides, the ME (1.6-2.2 Mcal/kg) approximated the requirements for breeding cattle and sheep, while the mean value of DE (1.9-2.7 Mcal/kg) meets the amount (2.7 Mcal/kg) needed by sheep (NRC, 1985). The wild mint's nutritive value (except DCP) did not significantly differ between eutrophic and freshwater wetlands; consequently, both water bodies' above- and below-ground fodder quality meets the NRC standards for beef cattle, dairy cattle, goat, and sheep (Galal et al., 2023). Comparable outcomes were noted by Farahat et al. (2021) for *V. cuspidata* and Galal et al. (2022a, 2024) for *C. alopecuroides* and *C. articulatus*. It is imperative to acknowledge the possibility that this species may accumulate heavy metal pollutants into its tissues (Ghareeb et al., 2020). For this reason, caution should be exercised while gathering wild mint plants for animal feed from polluted waterbodies.

Conclusion

In eutrophic wetlands, the wild mint attained its highest fresh and dry biomass during summer and the lowest during the autumn. However, in the freshwater bodies, the fresh and dry biomass were significantly higher. The aboveground parts had their highest contents of Na, K, and Ca during autumn, and the highest N during summer. Also, the aboveground shoots accumulated higher concentrations of K, N, Ca, and P than the belowground roots. The best time to harvest the wild mint plants for efficient remediation of Na, K, Ca, P, and Mg from eutrophic wetlands is spring, and the best time to remove N is summer. The wild mint should be harvested in the summer for efficient use as fodder, where their aboveground parts had the highest protein content. The wild mint's nutritive value (except DCP) did not significantly differ between eutrophic and freshwater wetlands; consequently, both waterbodies' above- and below-ground fodder quality meets the NRC guidelines for sheep, goats, dairy cattle, and beef cattle. Caution should be exercised while gathering wild mint plants for animal feed from polluted waterbodies as it can accumulate high concentrations of heavy metals, in addition to the plant's essential oil content, which can impact the quality of cattle products such as the flavour of the milk and meat.

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