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Phenology, biomass and nutrients of *Imperata cylindrica* and *Desmostachya bipinnata* along the water courses in Nile Delta, Egypt

Kamal H. Shaltout[1] · **Tarek M. Galal**[2] · **Thanaa M. El-Komi**[1]

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Abstract Pollution with heavy metals is a major environmental problem, and plants that accumulate these metals might provide efficient and ecologically sound approaches for their removal. Therefore, the present study was conducted to investigate the phenological behavior and the potential to accumulate nutrients and heavy metals in the aboveground phytomass of two perennial grasses (*Imperata cylindrica* and *Desmostachya bipinnata*) along the watercourses in Nile Delta, Egypt. Twenty-five quadrats were selected seasonally, to represent the growth of the two grasses, along canals and drains of the Nile Delta. The phenological behavior of the studied species showed similar seasonal trends along the canals and drains. The average annual biomass of the living and dead parts of *D. bipinnata* (1901.3 g m^{-2}) was higher than that of *I. cylindrica* (1626.4 g m^{-2}). *D. bipinnata* accumulated higher concentrations of Na, and K (14.3, 26.2 mg g^{-1}), while lower Ca, Mg, N, P and Fe (14.2, 11.4, 10.8, 0.3 and 1.4 mg g^{-1}) than *I. cylindrica* (12.8, 24.8, 14.4, 14.7, 11.6, 0.4 and 2.0 mg g^{-1}). The living parts of *I. cylindrica* accumulated the highest contents of carbohydrates and proteins during autumn and spring, respectively, while those of *D. bipinnata* had the highest ash content, but the lowest lipids during summer. *D. bipinnata* accumulated higher concentrations of Cu and Mn, but lower of Zn and Pb, than *I. cylindrica* in their living and dead parts. Heavy metals, except Zn, had BF more than unity, however, the uptake capability was in the order: Pb > Mn > Cu > Zn for *I. cylindrica*, while Pb > Cu > Mn > Zn for *D. bipinnata*. The analysis of the nutritive values for the two studied grasses evaluated them as poor forage. Finally, the high bioaccumulation factors of both species for Mn, Cu and Pb, in addition to their ability to accumulate the highest concentrations of macro- and micronutrient in the dead parts, render these species a powerful phytoremediator for the removal of these metals from contaminated ecosystems.

Keywords Phenology · Nutrients · Heavy metals · Bioaccumulation · Nutritive value

✉ Tarek M. Galal
tarekhelwan@yahoo.com

[1] Botany Department, Faculty of Science, Tanta University, Tanta, Egypt

[2] Botany and Microbiology Department, Faculty of Science, Helwan University, Cairo, Egypt

1 Introduction

Phenology is an important component of plant life history theory affecting both biotic (e.g., competition, herbivory, pollination) and abiotic (e.g., frost, drought) constraints of plant performance (Stanton et al. 2000). The study of plant phenology provides knowledge about the pattern of plant growth and development as well as the effects of environment and selective pressures on flowering and fruiting behavior (Zhang et al. 2006). Phenological changes, including changes in flowering dates, are some of the most obvious effects of climatic changes on biological communities (Chapin et al. 2008). Changes in the timing of important events such as flowering or fruiting could result in failure to produce offspring or they have adequately dispersed (Lesica and Kittelson 2010). Several trends have become apparent from these studies, at least some species were flowering earlier than in the past, and earlier flowering species demonstrated the greatest advance in flowering date (Lesica and Kittelson 2010).

Pollution of air, soil, and water with heavy metals is a major environmental problem (Srivastava and Purnima 1998). Metals cannot be easily degraded and the cleanup usually requires their removal (Lasat 2002). However, this energy intensive approach can be prohibitively expensive. Phytoremediation offers a cost-effective, nonintrusive, and safe alternative to conventional cleanup techniques. Utilizing the ability of certain grass species to remove, degrade, or immobilize harmful chemicals can reduce risk from contaminated soil, sludge, sediments, and ground water through contaminant removal, degradation or containment (Zavoda et al. 2001). With global heavy metal contamination on the rise, plants that can process heavy metals might provide efficient and ecologically sound approaches for their sequestration and removal (Lasat 2002).

Perennial halophytic grasses constitute a valuable fodder and cash crop resource on saline and alkaline wastelands besides ecological applications, such as landscaping or rehabilitation, of damaged ecosystems (Dagar et al. 2004). Warm season grasses are increasingly being researched for biomass production, in addition to their normal use as summer forage and for soil conservation (Madakadze et al. 1998). The produced biomass can be used for energy production or as industrial raw material for chemical production and/or pulp and paper (Sanderson et al. 1996). Utilization of biomass offers the main advantages of: (a) relatively inexpensive renewable resource, (b) reduction of carbon dioxide emissions (Graham et al. 1992), and (c) soil amelioration and reduced pollution of ground water because of reduced fertilization (Gebhart et al. 1994).

Nowadays, Egypt faces a serious problem of feed shortage, especially green summer fodder, which suppresses the improvement of animal production. Therefore, dependence on improving local food and food resources for both animals and humans is necessary for a sound policy. The vegetation covering the wetland areas plays an important role in sequestering large quantitative of nutrients (Cronk and Fennessy 2001) and metals (Baldantoni et al. 2004) from the environment by storing them in the roots and/or shoots. In addition, wetland plants have high remediation potential for macronutrients because of their general fast growth and high biomass production (Dhir et al. 2009).

The present study is the sixth of a series of studies dealing with the evaluation of biomass, nutrients and nutritive values of riparian plants along the watercourses of the Nile Delta (El-Kady 2002; Shaltout et al. 2010, 2012, 2013a, b). The present study aims at evaluating the phenological behavior, aboveground biomass, and nutrient status of two grasses (*Imperata cylindrica* and *Desmostachya bipinnata*) along the water courses of the Nile Delta, Egypt. It aims also at evaluating their ability to accumulate nutrients and heavy metals as well as their nutritive values to be used as forage plants.

2 Materials and methods

2.1 Study area

The study area lies in Nile Delta that is bounded by the two branches of the Nile: Rosetta to the west and Damietta to the east (Fig. 1). Nile Delta is about 22,000 km^2, compared with 13,000 km^2 for the area of the Valley; thus it comprises about 63 % of Egypt's productive agricultural land. Most of the Egyptian cultivated land is irrigated by the river Nile through a network of canals and is drained by a similar network of drains. Most of these canals and drains were dug in the last 200 years. The total length of both networks (excluding private ditches and drains) exceeds 47,000 km: >31,000 km of canals and >16,000 km of drains (Shaltout et al. 2013a). Soil characters of the water courses in the middle Delta region indicated that most soils were consisted of silt (Table 1). The drains were characterized by higher salinity compared with canals. On the other hand, canals were characterized by higher values of N, K and Ca; but lower of organic matter, P, Na and Mg than drains.

The climatic conditions of the northern part of Nile Delta that lies in the arid zone (UNESCO 1977) are characterized by warm summer (20–30 °C) and mild winter (10–20 °C). Though occasional short rainstorms occur in winter, most of the days are sunny. The aridity index (P/PET) is between 0.03 and 0.20 at the North of the Delta (arid region) and less than 0.03 at the south (hyper-arid region); where *P* is the annual precipitation and PET is the potential evapotranspiration.

2.2 Study species

Imperata cylindrica (L.) Beauv. is a perennial grass native to the Old World and is found as well in the warm temperate zone (El-Komy 2002). In Egypt, it is very common in the Nile region, the oases of the Libyan Desert, the Mediterranean coastal strip from El-Sallum to Rafah, the Red Sea coastal region, Sinai proper and all the deserts of Egypt. It grows vigorously because it can thrive on many soil types and in a variety of habitats such as dry or moist sandy places, in waste lands, along channels and in old gardens (Boulos 2009). *I. cylindrica* is frequently used as a sand binder for coastal sand dunes and mobile sand hills in desert areas, and used to stabilize canals and railroad embankments (El-Komy 2002). It is palatable to livestock in the early growth stages, and so grasses often fired to stimulate growth of new sprouts. The value of this grass for

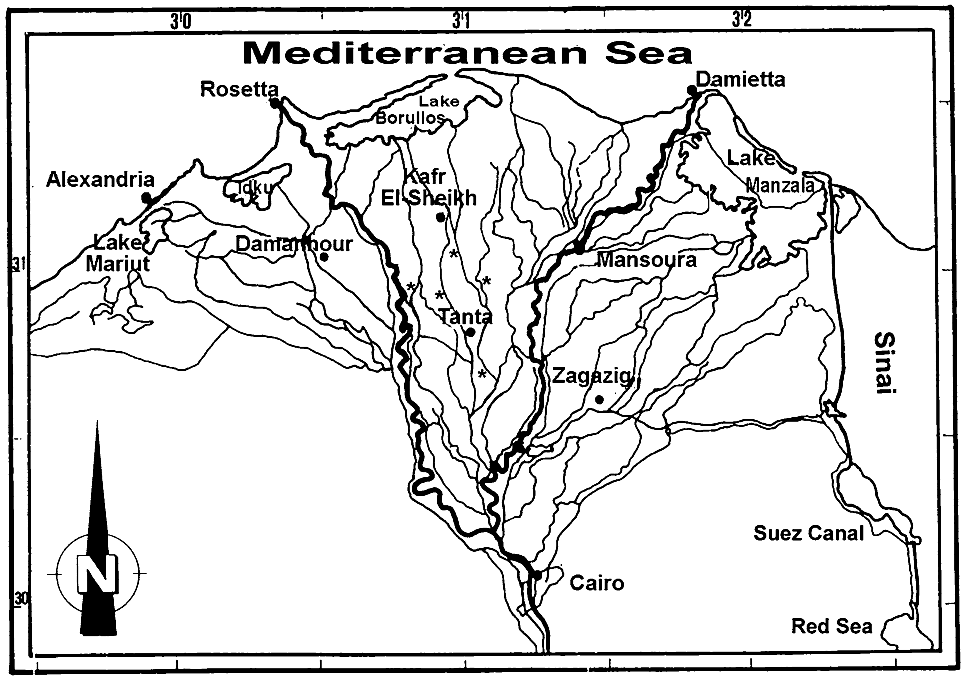

Fig. 1 Map of the Nile Delta indicates the study sites (*asterisk*)

forage may be dependent upon its stage of growth at cutting or grazing and upon a system of management, which keeps the crop in a palatable condition (Holm et al. 1977).

Desmostachya bipinnata (L.) Stapf, a sacrificial grass, is a drought and salt-tolerant grass with a deep, strong rhizome, making it an excellent sand binder. It is not normally regarded as a fodder but is used in some arid areas such as Afghanistan where it is chopped and in mixed with cereals. It is a common and widespread species growing along irrigation channels, in orchards, and associated with cultivation in many countries (Gulzar et al. 2007). *D. bipinnata* is cited by Holm et al. (1977) as a "serious" weed in Pakistan and a "common" weed in Egypt and Iraq. It is among the worst weeds of crops in Yemen (Al-Kouthayri and Hassan 1998). Once established, it can spread very aggressively by rhizome and dominate arid and semi-arid environments.

2.3 Plant sampling and analysis

Sampling process of the studied species was carried out four times a year (seasonally) using 25 quadrats (each of 1 × 1 m) distributed along 15 irrigation and 10 drainage canals within the study area (Fig. 1). In each quadrat, the seasonal variation in the phenological behavior of the two species was assessed visually, where the main described phases were sprouting, vegetative, flowering, fruiting and withering. For estimating the aboveground biomass, all shoots within the sampled quadrat were harvested and transferred to the laboratory in polyethylene bags. In the laboratory, the shoots were separated into living and dead parts, and then the biomass was estimated after oven drying of the plant materials at 60 °C to constant weight. For plant analysis, a composite sample of the living and dead parts was taken from each quadrat and ground into a powder using a metal-free plastic mill. Ash percentage was estimated by ignition at 550 °C for 2 h. Nutrients and heavy metals were extracted from 0.5 to 1 g samples using mixed-acid digestion method. Total nitrogen (N) was assessed by the Kjeldahl method; Na, Ca, and K using a flame photometer (CORNING M410); Mg, Fe, Cu, Mn, Zn and Pb using atomic absorption (Shimadzu AA-6200), and P by applying molybdenum blue method using a spectrophotometer (CECIL CE 1021). Ether extract (i.e., crude fat) and crude fiber were determined by the Soxhlet extraction method. All these procedures are according to Allen (1989).

The content of crude protein was calculated by multiplying the nitrogen concentration by the factor of 6.25 (Adesogon et al. 2000). Carbohydrate (NFE) was calculated according to the equation of Le Houérou (1980): NFE (in % dry matter) = 100 − (CP + CF + crude fat + ash), where CP = crude protein and CF = crude fiber. Digestible crude protein (DCP) was calculated according to the equation of Demarquilly and Weiss (1970): DCP (in % dry matter) = 0.929 CP (in % dry matter) − 3.52. Total digestible nutrients (TDN) were estimated according to the equation applied by Naga and El-Shazly (1971): TDN (in

Table 1 Mean and coefficient of variation (CV) of some soil variables collected from the canals and drains in Nile Delta (after El-Sheikh 1989)

Water course	Sand (%)	Silt (%)	Clay (%)	OM (%)	CaCo$_3$ (%)	EC (µS cm^{-1})	pH (mg 100 gm^{-1})	N (mg 100 gm^{-1})	P (mg 100 gm^{-1})	K (mg 100 gm^{-1})	Na (mg 100 gm^{-1})	Ca (mg 100 gm^{-1})	Mg (mg 100 gm^{-1})
Terrace zone													
Canal													
Mean	44.9	42.9	11.9	6.3	3.4	1523	7.7	249	8.2	111	274	1980	263
CV	0.2	0.1	0.6	0.1	0.5	0.4	0.0	0.1	0.2	0.2	0.1	0.2	0.1
Drain													
Mean	41.5	47.5	11.3	6.8	2.9	2479	7.8	204	11.8	84	340	1546	301
CV	0.1	0.1	0.9	0.1	0.4	0.1	0.0	0.2	0.2	0.2	0.1	0.1	0.1
Slope zone													
Canal													
Mean	42.8	45.2	11.8	6.8	2.1	418	7.8	256	7.7	80	137	1572	257
CV	0.1	0.0	0.4	0.2	0.2	0.3	0.0	0.2	0.1	0.3	0.1	0.2	0.1
Drain													
Mean	40.8	43.2	15.9	7.7	2.3	2154	7.8	209	11.4	74	348	1518	322
CV	0.2	0.1	0.6	0.2	0.2	0.7	0.0	0.2	0.3	0.3	0.4	0.1	0.1

% dry matter) = 0.623 (100 + 1.25 EE) − P0.72, where EE = percentage of ether extract and P = percentage of crude protein. Digestible energy (DE) was estimated following this equation (NRC 1984): DE (Mcal kg^{-1}) = 0.0504 CP (%) + 0.077 EE (%) + 0.02 CF (%) + 0.000377 (NFE)^2 (%) + 0.011 (NFE) (%) − 0.152. Metabolized energy (ME) = 0.82 DE (Garrett 1980), Net energy (NE) = 0.50 ME (Le Houérou 1980), while Gross energy (GE) was calculated following this equation (NRC 1984): GE (Kcal 100 g^{-1}) = 5.72 CP (%) + 9.5 EE (%) + 4.79 CF (%) + 4.03 NFE (%).

Soil analysis was taken from El-Sheikh (1989), while soil heavy metals (Mn, Cu, Zn and Pb) were gathered from Galal and Shehata (2013) on their studies on the water courses of the middle Nile Delta, respectively. One-way ANOVA was applied to assess the significance of variations in standing crop phytomass, elements, organic components and nutritive variables in relation to the type of water course and season (SAS 1985).

Heavy metal concentrations of soils and plants were calculated on the basis of dry weight. The bioaccumulation factor (BF), an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the soil substrate (Ghosh and Singh 2005), was calculated as follows:

$$\mathrm{BF} = C_{\mathrm{plantroot}}/C_{\mathrm{soil}},$$

where $C_{\mathrm{plant\ root}}$ and C_{soil} represent the heavy metal concentrations in the plant root and soils, respectively.

3 Results

3.1 Phenological behavior

The phenological behavior of the two studied species in canals and drains had more or less the same seasonal behavior (Fig. 2). The maximum sprouting and vegetative activities of both grasses were attained during winter with higher activity of *I. cylindrica* in canals, but lower in drains than *D. bipinnata*. On the other hand, flowering and fruiting activities attained their maximum, in canals and drains, during spring and summer, respectively; however, the activity of *D. bipinnata* was greater than that of *I. cylindrica*, except fruiting in drains. Moreover, the maximum senescence was during autumn with higher activity of *I. cylindrica* in drains and lower in canals than the other species. *I. cylindrical* had no sprouting or vegetative activities during summer and autumn, while flowering and fruiting during winter in the drains. On the other hand, *D. bipinnata* did not form flowers and fruits during winter in both canals and drains.

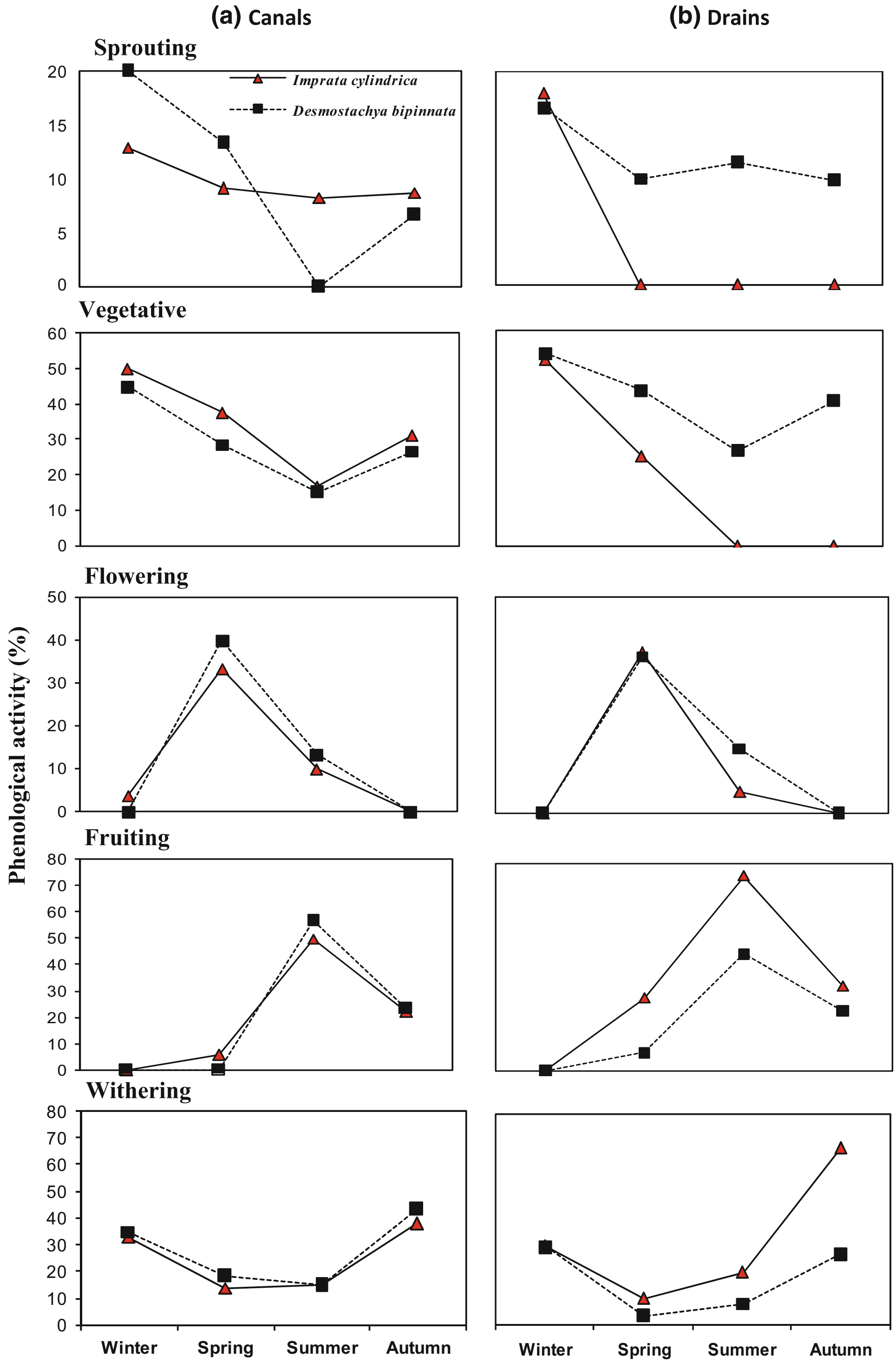

Fig. 2 Seasonal variations in the phenological activities (% of phases) of the two studied species along the canals and drains in Nile Delta

3.2 Aboveground Biomass

The seasonal variation of the aboveground standing crop biomass (Fig. 3) indicated that the average annual biomass of the living and dead parts of *D. bipinnata* (1901.3 g m^{-2}) was higher than that of *I. cylindrica* (1626.4 g m^{-2}). Significant seasonal variations in the biomass of the living and dead parts of both species were recognized. The biomass of the living parts of *I. cylindrica* and *D. bipinnata* had its maximum (1681.4 and 2076.1 g m^{-2}) in autumn and the minimum in winter (678.5 and 909.0 g m^{-2}). In addition, the dead parts of the *I. cylindrica* attained its maximum biomass (662.7 g m^{-2}) during summer, while that of *D. bipinnata* (847.7 g m^{-2}) during autumn. However, the

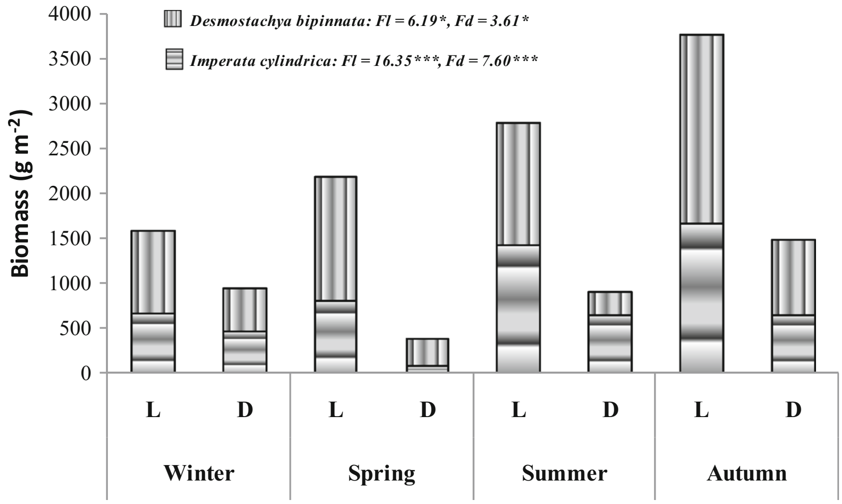

Fig. 3 Seasonal variations in the biomass of living (*L*) and dead (*D*) parts of the two studied species along the water courses of north Nile Delta. F_l: *F* value for living parts, F_d: *F* value of dead parts, $^*P < 0.05$, $^{***}P < 0.001$

dead parts of *I. cylindrica* and *D. bipinnata* attained their minimum biomass during spring and summer, respectively.

3.3 Nutrient accumulation

The inorganic nutrient analysis of the aboveground living parts of study species showed significant seasonal variation in the concentration of Na, Mg and P for *I. cylindrica,* while Na, Ca, Mg and Fe for *D. bipinnata.* However, variations in the dead parts of both plants were non-significant (Table 2). *I. cylindrica* accumulated the highest concentrations of Ca and N (8.6 and 6.5 mg g^{-1}) during spring, K (16.2 mg g^{-1}) during summer, and Mg and P (8.5 and 0.4 mg g^{-1}) during autumn, in their living parts, while Na and Fe (8.1 and 1.8 mg g^{-1}) during summer and spring, respectively, in their dead parts. On the other hand, the living parts of *D. bipinnata* accumulated the highest concentrations of K and Ca (17.9 and 9.1 mg g^{-1}) during autumn, N (7.1 mg g^{-1}) during spring, and Fe (0.9 mg g^{-1}) during summer, while the dead parts had the maximum of Na and Mg (10.7 and 8.8 mg g^{-1}) during summer and spring, respectively. On the average, *D. bipinnata* accumulated concentrations of Na, K and Mg in its dead tissues, but K and N in the living ones higher than those of *I. cylindrica.* However, the later species had concentrations of Ca, N and Fe in the dead parts; and Ca, Mg and P in the living ones higher than those of the former one.

The seasonal variations in the organic contents of the living parts of *I. cylindrica* were significant for carbohydrates (NTF), crude fibers (CF) and ash content, while the dead parts had significant ether extract (EE) variations (Table 3). However, the living and dead parts of *D. bipinnata* had non-significant seasonal variations. The living parts of *I. cylindrica* accumulated the highest contents of NTF (57.6 %) during autumn, TP and Ash (4.1 and 10.3 %) during spring, CF (33.4 %) during summer, and EE (2.4 %) during winter, while those of *D. bipinnata* had the highest TP (4.4 %) during spring, EE (2.4 %) during winter, and ash content (11.9 %) during summer. Moreover, the dead parts of *D. bipinnata* attained the highest contents of NTF and CF (57.4 and 37.3 %) during summer and autumn, respectively. On the average, *I. cylindrica* accumulated concentrations of NTF and EE, in the living tissues, while TP, EE, CF and ash contents in the dead ones higher than those of *D. bipinnata*. On the contrary, the later species accumulated concentrations of TP, CF and ash contents in their living, and NTF in dead tissues higher that the former one.

3.4 Heavy metals accumulation

The heavy metals analysis data indicated that the dead parts of the study species accumulated higher annual concentrations of Cu and Mn, in addition to Zn in *I. cylindrica* and Pb in *D. bipinnata*, than the living parts (Fig. 4). In addition, *D. bipinnata* accumulated higher concentrations of Cu and Mn, but lower of Zn and Pb, than *I. cylindrica* in their living and dead parts. The aboveground dead parts of *D. bipinnata* accumulated the highest concentrations of Cu, Mn (33.9 and 86.4 µg g^{-1}), while those of *I. cylindrica* had the highest of Zn (89.3 µg g^{-1}) and the lowest of Pb (23.6 µg g^{-1}) during spring and summer, respectively. Moreover, the highest Pb concentration (106.9 µg g^{-1}) was recorded in the living tissues of *I. cylindrica* during spring. It is worth to note that the living parts of both species had more or less the same trend in accumulating heavy metals, while the dead parts showed variations.

The bioaccumulation factors (BF) of the studied species indicated that all the investigated heavy metals, except Zn, had BFs more than unity (Fig. 5). *I. cylindrica* had higher BF of Pb and Mn (90.1 and 1.6) and lower of Cu (1.5) than those of *D. bipinnata* (62.4, 1.2 and 1.7, respectively). The

Table 2 Variation in the concentration (Mean ± SD) of inorganic elements (mg g^{-1}) in the aboveground living (L) and dead (D) parts of the studied species

Season	Na	K	Ca	Mg	N	P	Fe
Imperata cylindrica							
Winter							
L	4.8 ± 0.2	12.7 ± 0.6	7.2 ± 0.4	7.7 ± 0.5	6.1 ± 0.4	0.2 ± 0.1	<u>0.6 ± 0.0</u>
D	7.1 ± 0.1	10.3 ± 0.3	6.6 ± 0.2	8.4 ± 0.5	6.2 ± 0.3	0.1 ± 0.1	0.9 ± 0.1
Spring							
L	7.8 ± 0.5	15.1 ± 0.5	<u>8.6 ± 0.3</u>	7.1 ± 0.3	<u>6.5 ± 0.4</u>	0.2 ± 0.1	1.0 ± 0.1
D	<u>4.4 ± 0.3</u>	10.6 ± 0.6	7.1 ± 0.1	7.9 ± 0.1	6.0 ± 0.4	0.1 ± 0.1	<u>1.8 ± 0.1</u>
Summer							
L	7.9 ± 0.6	<u>16.2 ± 0.3</u>	8.3 ± 0.1	<u>4.6 ± 0.2</u>	<u>4.4 ± 0.3</u>	0.2 ± 0.1	0.9 ± 0.1
D	<u>8.1 ± 0.3</u>	11.5 ± 0.9	6.3 ± 0.0	6.3 ± 0.2	6.1 ± 1.8	0.1 ± 0.1	0.9 ± 0.0
Autumn							
L	5.5 ± 0.4	14.7 ± 0.5	7.9 ± 0.5	<u>8.5 ± 0.5</u>	6.4 ± 0.3	<u>0.4 ± 0.2</u>	<u>0.6 ± 0.0</u>
D	5.4 ± 0.1	<u>8.0 ± 0.2</u>	<u>5.5 ± 0.1</u>	8.0 ± 0.2	4.5 ± 1.2	0.1 ± 0.1	1.3 ± 0.1
Mean							
L	6.5 ± 1.6	14.7 ± 1.5	8.0 ± 0.6	7.0 ± 1.7	5.9 ± 1.0	0.3 ± 0.1	0.8 ± 0.2
D	6.3 ± 1.7	10.1 ± 1.5	6.4 ± 0.7	7.7 ± 0.9	5.7 ± 0.8	0.1 ± 0.0	1.2 ± 0.4
F value							
L	2.91*	ns	ns	4.51**	ns	4.57**	ns
D	ns	ns	ns	ns	ns	ns	ns
Desmostachya bipinnata							
Winter							
L	<u>5.4 ± 0.1</u>	11.6 ± 0.3	6.5 ± 0.0	5.3 ± 0.1	5.5 ± 0.2	0.2 ± 0.0	<u>0.6 ± 0.0</u>
D	6.5 ± 0.4	9.4 ± 0.2	<u>5.3 ± 0.1</u>	5.9 ± 0.1	<u>4.0 ± 0.1</u>	0.1 ± 0.0	0.4 ± 0.0
Spring							
L	6.3 ± 0.1	16.5 ± 0.4	7.5 ± 0.1	5.1 ± 0.1	<u>7.1 ± 0.1</u>	0.2 ± 0.0	0.8 ± 0.0
D	7.9 ± 0.1	14.4 ± 0.3	6.3 ± 0.1	<u>8.8 ± 0.1</u>	5.9 ± 0.1	0.1 ± 0.0	0.5 ± 0.0
Summer							
L	8.5 ± 0.3	15.6 ± 0.2	8.5 ± 0.1	<u>2.6 ± 0.1</u>	5.6 ± 0.1	0.2 ± 0.0	<u>0.9 ± 0.0</u>
D	<u>10.7 ± 0.3</u>	10.8 ± 0.4	7.1 ± 0.1	7.4 ± 0.1	4.3 ± 0.2	0.1 ± 0.0	0.5 ± 0.0
Autumn							
L	5.7 ± 0.1	<u>17.9 ± 0.6</u>	<u>9.1 ± 0.1</u>	3.1 ± 0.1	5.9 ± 0.2	0.2 ± 0.0	0.7 ± 0.0
D	6.0 ± 0.1	<u>8.6 ± 0.4</u>	6.5 ± 0.2	7.4 ± 0.2	5.0 ± 0.3	0.1 ± 0.0	0.8 ± 0.2
Mean							
L	6.5 ± 1.4	15.4 ± 2.7	7.9 ± 1.1	4.0 ± 1.4	6.0 ± 0.7	0.2 ± 0.0	0.8 ± 0.1
D	7.8 ± 2.1	10.8 ± 2.6	6.3 ± 0.7	7.4 ± 1.2	4.8 ± 0.8	0.1 ± 0.0	0.6 ± 0.2
F value							
L	4.04*	ns	10.67***	7.29***	ns	ns	3.09*
D	ns	ns	ns	ns	ns	ns	ns

Maximum and minimum values are underlined

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, and *ns* insignificant difference ($P > 0.05$)

uptake capability from soil to plant was in the order of Pb > Mn > Cu > Zn for *I. cylindrica*, and in the order of Pb > Cu > Mn > Zn for *D. bipinnata*.

3.5 Nutritive value

The nutritive values of the aboveground parts of the studied species indicated that the dead parts of *D. bipinnata* had the highest Ca/P ratio (71.1), while the living parts had the highest Ca/Mg (3.0) during summer (Table 4). The dead parts of *I. cylindrica* had the highest values of digestible crude protein and total digestible nutrients (1.3 and 63.9 %) during winter, while the lowest of total digestible nutrients (1.3 %), digestible energy and net energy (1.7 and 0.7 Mcal kg^{-1}, respectively) during spring. Moreover, the dead parts of *D. bipinnata* had the highest values of

Table 3 Seasonal variation in the organic contents (Mean ± SD) in the aboveground living (L) and dead (D) parts of the studied species

Variable	NFE	TP	EE	CF	Ash
Imperata cylindrica					
Winter					
L	51.2 ± 3.2	3.8 ± 2.0	2.4 ± 0.7	32.4 ± 3.6	10.2 ± 1.7
D	51.8 ± 3.8	3.9 ± 1.8	2.2 ± 0.5	32.3 ± 1.9	9.8 ± 1.7
Spring					
L	54.1 ± 3.1	4.1 ± 2.6	1.9 ± 0.6	29.7 ± 2.3	10.3 ± 1.8
D	48.8 ± 7.5	3.8 ± 2.6	1.7 ± 1.1	35.7 ± 2.1	10.0 ± 4.1
Summer					
L	53.1 ± 1.9	2.8 ± 1.6	1.7 ± 0.6	33.4 ± 0.7	9.0 ± 1.0
D	53.1 ± 3.7	3.8 ± 1.6	1.7 ± 0.8	32.4 ± 2.8	9.0 ± 1.9
Autumn					
L	57.6 ± 2.7	4.0 ± 2.0	1.5 ± 0.4	29.5 ± 2.5	7.4 ± 1.4
D	50.4 ± 1.7	2.8 ± 1.3	1.8 ± 0.5	34.8 ± 2.3	10.2 ± 1.4
Mean					
L	53.8 ± 2.3	3.7 ± 0.6	1.9 ± 0.4	31.3 ± 2.0	9.2 ± 1.3
D	51.0 ± 1.8	3.6 ± 0.5	1.9 ± 0.2	33.8 ± 1.7	9.8 ± 0.5
F value					
L	5.81*	ns	ns	3.87*	4.12*
D	ns	ns	3.60*	ns	ns
Desmostachya bipinnata					
Winter					
L	50.5 ± 4.8	3.5 ± 1.1	2.4 ± 0.6	34.9 ± 3.4	8.7 ± 2.2
D	55.2 ± 7.6	2.5 ± 0.4	2.1 ± 0.0	32.4 ± 4.2	7.8 ± 3.0
Spring					
L	51.2 ± 3.6	4.4 ± 0.4	1.6 ± 0.2	32.1 ± 1.8	11.0 ± 3.3
D	52.7 ± 6.9	3.7 ± 0.4	1.5 ± 0.6	31.6 ± 5.4	10.5 ± 1.3
Summer					
L	50.3 ± 4.0	3.5 ± 0.8	1.3 ± 0.4	33.0 ± 1.6	11.9 ± 2.4
D	57.4 ± 5.4	2.7 ± 1.3	2.0 ± 0.9	30.4 ± 4.8	7.5 ± 1.4
Autumn					
L	52.0 ± 5.3	3.9 ± 1.1	2.0 ± 0.6	32.6 ± 3.9	9.2 ± 0.5
D	46.1 ± 1.4	3.1 ± 1.9	1.6 ± 0.8	37.7 ± 2.2	11.5 ± 1.5
Mean					
L	51.0 ± 0.8	3.8 ± 0.4	1.8 ± 0.5	33.2 ± 1.2	10.2 ± 1.5
D	52.9 ± 4.9	3.0 ± 0.5	1.8 ± 0.3	33.0 ± 3.2	9.3 ± 2.0
F value					
L	ns	ns	ns	ns	ns
D	ns	ns	ns	ns	ns

NFE total carbohydrates, *TP* total protein, *EE* ether extract, *CF* crude fiber

Maximum and minimum values are underlined

* $P < 0.05$, and *ns* insignificant difference ($P > 0.05$)

digestible and metabolized energy (2.7 and 2.2 Mcal kg^{-1}), while those of *I. cylindrica* had the highest of gross energy (418.1 kcal 100 g^{-1}) during summer. On the average, the living parts of *I. cylindrica* had higher digestible crude protein, total digestible nutrients, digestible and metabolized energy, but lower Ca/P, Ca/Mg and gross energy than those of *D. bipinnata*.

4 Discussion

Plant phenology is the seasonal timing of environment-mediated events such as growth and reproduction (Rathcke and Lacey 1985). It is expected to be one of the most sensitive and easily observable natural indicators of climate change (Badeck et al. 2004). The phenological behavior of

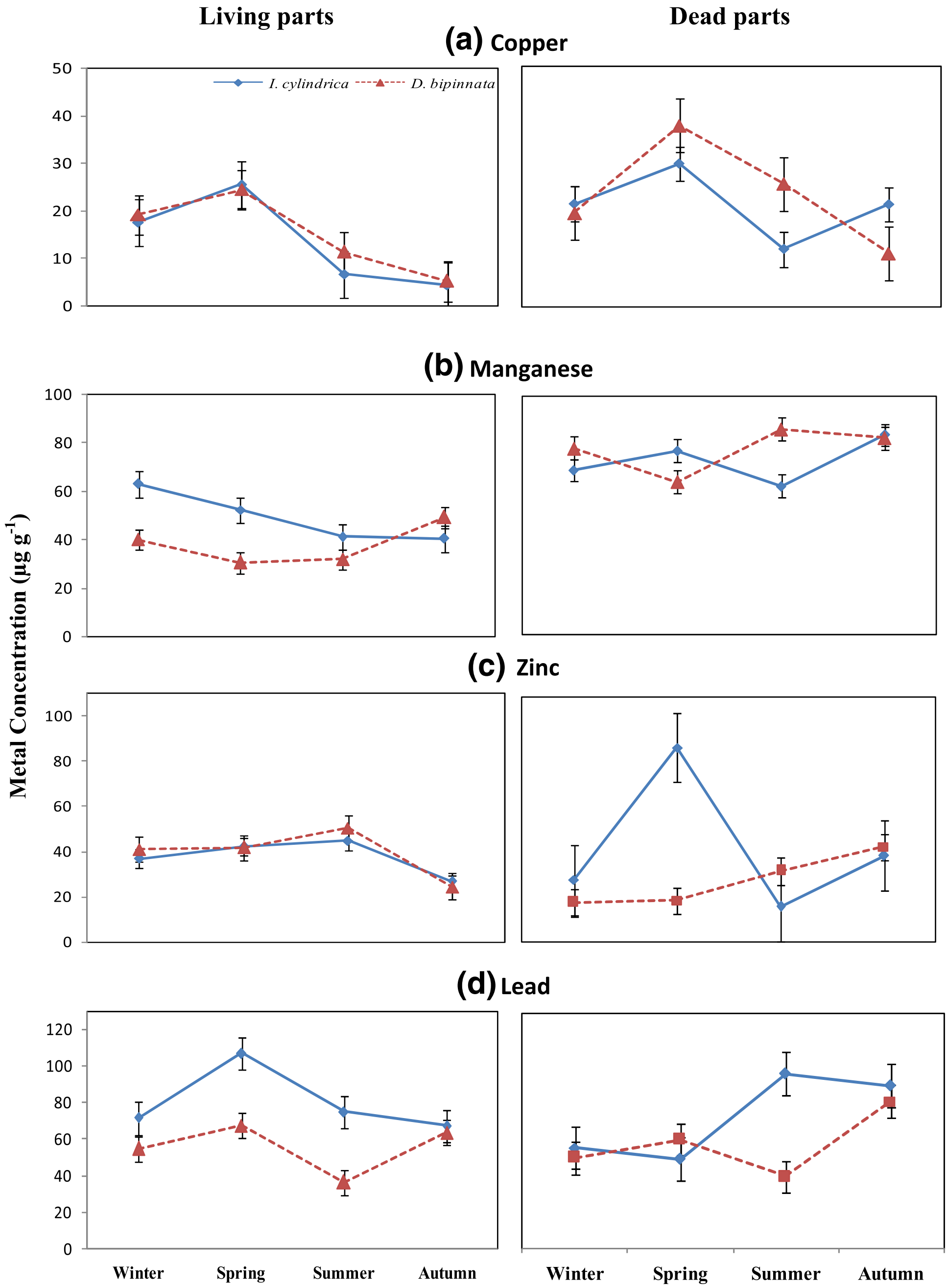

Fig. 4 Seasonal variation in the heavy metal concentrations in the living and dead parts of the two studied species in the water courses of Nile Delta

the plant species in the present study indicated that maximum sprouting and vegetative activities of both grasses were attained during winter, while those of flowering and fruiting were recorded during spring and summer. This behavior coincided with that of *Cynodon dactylon* in the water courses of Nile Delta (Shaltout et al. 2013a). It was reported that water availability in winter played an essential role in seed germination and recruitment of new individuals (Farahat et al. 2015). However, flowering has most often been correlated with warmer temperatures in the months prior to anthesis (Lesica and Kittelson 2010). Moreover, the two species exhibited high withering during autumn and high vegetative growth during winter. Xi and Zhang (2005) demonstrated that drought and low temperature in winter reflected withered and yellow leaves on *Zoysia japonica*, while maintained normal vegetative growth by extended duration of light at similar water and temperature conditions.

The seasonal variation in biomass indicated that the two studied species had the same pattern with its maximum in autumn, while the minimum in winter for *D. bipinnata* and spring for *I. cylindrica*. A similar finding was postulated by

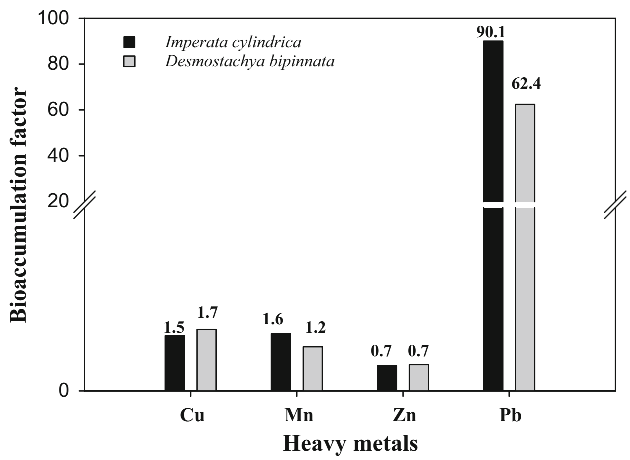

Fig. 5 Average bioaccumulation factors of heavy metals in the two studied species grown along the water courses of Nile Delta

El-Kady (2002) on *P. australis,* and Shaltout et al. (2010) on *E. stagnina* and Shaltout et al. (2013a) on *C. dactylon* and *Panicum repens*. The biomass of *I. cylindrica* and *D. bipinnata* (1626.4 and 1901.3 g m^{-2}) was greater than 1499.2 g m^{-2} of *D. bipinnata* on the canal banks (Galal and Shehata 2013), 921.7 g m^{-2} of *P. australis* (El-Kady 2002) and 803.6 g m^{-2} of *Echinochloa stagnina* (Shaltout et al. 2010). This may be due to the strong rhizomatus nature of these plants which is believed to be more resistant to trampling along the canal terraces by farmers and their grazing animals (e.g., buffalos, cows, sheep, goats and donkeys) than the other life forms (Shaltout et al. 2010). In addition, the rapid development of these plants caused by the rich reserve material at the beginning of the growing season enables the photosynthetic apparatus to be active for a longer period under favorable conditions (Engloner 2009).

Plants with potentially high annual primary production can extract large amounts of nutrients from their environment and store them in biomass and litter (Eid et al. 2010). It has long been recognized that metal accumulation capacity varies greatly between different species and varieties, and is affected by various edaphic conditions (Shu et al. 2002). The present study indicated that *D. bipinnata* accumulated higher values of Na, K, Ca and Mg; while *I. cylindrica* higher values of N, P and Fe. Both species had lower concentrations of Na, Ca and Mg than *C. dactylon* and *P. repens* (Shaltout et al. 2013a) and *P. australis* (El-Kady 2002), but lower than *E. stagnina* (Shaltout et al. 2010). In addition, Na, K, Ca and Mg concentrations of the study species were higher, while those of N and P were lower than those recorded by Galal and Shehata (2013) in *D. bipinnata* along the canal banks of Nile Delta.

The dead parts of the study species accumulated higher annual concentrations of Cu and Mn, in addition to Zn in *I. cylindrica* and Pb in *D. bipinnata*, than the living parts. This disagrees with Mortimer (1985) who reported that the rates of metal absorption are lower in senescent than in active growing plants. According to Welsh (1977), some exceptions in which rates of heavy metals absorption were higher in old and dead than in the young leaves are recognized. The aboveground parts of *I. cylindrica* accumulated higher concentrations of Mn, Zn and Pb and lower of Cu than those of *D. bipinnata*. Elevated Pb, Zn and Cu might impose phytotoxic effects to higher plants (Shaltout et al. 2013a). Moreover, the study species had higher Mn, Cu and Pb, while lower Zn concentrations than that recorded by Galal and Shehata (2013) on *D. bipinnata*. In the present study, *I cylindrica* accumulated concentrations of heavy metals in the order of Pb > Mn > Zn > Cu and *D. bipinnata* in the order of Mn > Pb > Zn > Cu, which is more or less in agreement with the previous studies (Yan et al. 2012; Zhang et al. 2012; Shaltout et al. 2013a; Galal and Shehata 2013). It can be concluded that even though the types of grasses are different, the order for heavy metal absorbing capability from soil to grass is more or less similar (Yan et al. 2012).

Plant species and populations differ widely in their ability to accumulate heavy metals (Denga et al. 2004). In the present study, Cu and Zn concentration did not exceed the toxic levels for normal plants (66 and 20 µg g^{-1}) reported by Borkert et al. (1998). In addition, the concentrations of Mn, Cu and Pb in the aboveground tissues were higher than that of the soils in which the plant grows, which agrees with the study of Galal and Shehata (2013). Moreover, the relationship between the heavy metal content of soils and corresponding grasses was investigated using the bioaccumulation factor (BF), which has been applied to assess plants' capability to absorb heavy metals from the soil (Ratko et al. 2011; Xiao et al. 2011). The BF generally showed the movement of heavy metals from sediment to root and shoot, indicating the efficiency to uptake of the bio-available metals from the environment and gives an idea whether the plant is an accumulator, excluder or indicator (Bose et al. 2008). The order of uptake capability is Pb > Mn > Cu > Zn for *I. cylindrica*, while Pb > Cu > Mn > Zn for *D. bipinnata*, which disagree with Zn > Cu > Mn (Galal and Shehata 2013). Zu et al. (2005) reported that BF >1 in metal accumulating plants, whereas it was typically <1 in metal excluding plants. In the present study, the heavy metals had BF >1 for Mn, Cu and Pb, which indicate that both species are powerful accumulator for these metals.

The organic nutrients contents of the study grasses indicated that carbohydrates, ether extract, total protein and ash content were lower than that recorded for *D. bipinnata* (Galal and Shehata 2013), *P. australis* (El-Kady 2002), *C. dactylon* and *P. repens* (Shaltout et al. 2013a) *E. stagnina*

Table 4 Nutritive value (Mean ± SD) of the aboveground living (L) and dead (D) parts of the studied species

Season	Ca/P	Ca/Mg	DCP (%)	TDN (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE (Mcal/kg)	GE (Kcal/100g)
Imperata cylindrica								
Winter								
L	36.0 ± 34.0	0.9 ± 0.2	1.2 ± 1.8	61.0 ± 6.5	2.4 ± 0.1	2.0 ± 0.1	1.0 ± 0.1	404.7 ± 6.8
D	66.0 ± 71.0	0.8 ± 0.5	1.3 ± 1.1	63.9 ± 3.5	2.5 ± 0.2	2.1 ± 0.1	1.1 ± 0.1	407.7 ± 8.2
Spring								
L	43.0 ± 3.9	1.2 ± 0.2	1.1 ± 1.1	62.0 ± 3.5	2.5 ± 0.2	2.1 ± 0.1	1.0 ± 0.1	401.7 ± 9.3
D	71.0 ± 26.0	0.9 ± 0.2	0.4 ± 0.7	42.9 ± 2.9	1.7 ± 1.2	1.4 ± 0.9	0.7 ± 0.4	414.6 ± 8.0
Summer								
L	41.5 ± 11.5	1.8 ± 0.5	0.2 ± 0.4	61.3 ± 1.7	2.4 ± 0.1	2.0 ± 0.1	1.0 ± 0.0	388.9 ± 40.9
D	63.0 ± 23.0	1.0 ± 0.3	1.1 ± 1.3	58.6 ± 6.4	2.5 ± 0.1	2.1 ± 0.1	1.1 ± 0.1	418.1 ± 25.0
Autumn								
L	19.8 ± 7.0	0.9 ± 1.1	0.8 ± 1.0	62.4 ± 3.7	2.7 ± 0.1	2.2 ± 0.1	1.1 ± 0.0	411.0 ± 6.0
D	55.0 ± 18.0	0.7 ± 0.2	0.1 ± 0.3	58.9 ± 4.9	2.3 ± 0.1	1.9 ± 0.1	1.0 ± 0.0	403.4 ± 6.8
Mean								
L	35.1 ± 10.6	1.2 ± 0.4	0.8 ± 0.5	61.7 ± 0.6	2.5 ± 0.1	2.1 ± 0.1	1.0 ± 0.1	401.6 ± 9.3
D	63.8 ± 6.7	0.9 ± 0.1	0.7 ± 0.6	56.1 ± 9.1	2.3 ± 0.4	1.9 ± 0.3	1.0 ± 0.2	411.0 ± 6.6
F value								
L	ns	4.09*	ns	ns	ns	ns	ns	ns
D	ns	ns	ns	ns	ns	ns	ns	ns
Desmostachya bipinnata								
Winter								
L	32.5 ± 45.6	1.2 ± 0.4	0.3 ± 0.3	58.3 ± 6.3	2.3 ± 0.1	1.9 ± 0.1	1.0 ± 0.0	413.7 ± 6.8
D	53.0 ± 47.7	0.9 ± 0.2	0.0 ± 0.0	61.1 ± 2.7	2.5 ± 0.3	2.1 ± 0.2	1.1 ± 0.1	411.9 ± 8.1
Spring								
L	37.5 ± 25.0	1.4 ± 0.1	0.6 ± 0.4	57.0 ± 5.3	2.4 ± 0.1	2.0 ± 0.1	1.0 ± 0.1	406.9 ± 6.6
D	63.0 ± 43.0	0.7 ± 0.0	0.1 ± 0.1	62.0 ± 3.0	2.4 ± 0.2	2.0 ± 0.2	1.0 ± 0.1	399.3 ± 0.9
Summer								
L	42.5 ± 27.6	3.0 ± 1.2	0.2 ± 0.4	60.3 ± 1.0	2.3 ± 0.1	1.9 ± 0.1	1.0 ± 0.0	393.0 ± 8.4
D	71.0 ± 26.7	0.9 ± 0.1	0.1 ± 0.2	59.9 ± 1.4	2.7 ± 0.1	2.2 ± 0.1	1.1 ± 0.1	408.5 ± 12.0
Autumn								
L	45.5 ± 17.8	2.8 ± 0.7	0.3 ± 0.5	58.0 ± 5.6	2.4 ± 0.1	2.0 ± 0.1	1.0 ± 0.0	407.9 ± 7.0
D	65.0 ± 38.5	0.9 ± 0.2	0.5 ± 1.0	55.6 ± 5.1	2.2 ± 0.1	1.8 ± 0.1	0.9 ± 0.0	399.4 ± 9.0
Mean								
L	39.5 ± 5.7	2.1 ± 0.9	0.4 ± 0.2	58.4 ± 1.4	2.4 ± 0.1	2.0 ± 0.1	1.0 ± 0.0	405.5 ± 8.6
D	63.0 ± 7.5	0.9 ± 0.1	0.2 ± 0.2	59.7 ± 2.8	2.5 ± 0.2	2.0 ± 0.2	1.0 ± 0.1	406.9 ± 5.4
F value								
L	ns	ns	ns	ns	ns	ns	ns	ns
D	ns	ns	ns	ns	ns	ns	ns	ns

DCP digestible crude protein, *TDN* total digestible nutrients, *DE* digestible energy, *ME* metabolized energy, *NE* net energy, *GE* gross energy

Maximum and minimum values are underlined

* $P < 0.05$, and *ns* insignificant difference ($P > 0.05$)

(Shaltout et al. 2010), while crude fibers were higher. The total protein and crude fibers lay far the maintenance range of sheep, goat, dairy cattle and beef cattle (NRC 1975, 1981, 1978, 1984). Ministry of Agriculture, Fisheries and Food in England (Anonymous 1975) reported that minimum protein in the animal diet ranges between 6 and 12 % depending on the animal species. NRC (1975) indicated that sheep are known to require 8.9 % protein for maintenance. Our investigations of both grasses agreed with the scale of the protein content of some rough fodder materials (2.7–13.4 %: Shoukry 1992). The same is true regarding ash content (1.3–23.1 %). On the other hand, lipids lay within the scale of some rough fodder materials (0.5–3.1 %: Shoukry 1992), but lower than that of *T. alexandrinum* (2.9 %: Chauhan et al. 1980). Moreover, total carbohydrates exceed the range of some rough fodder material (27.8–51.9 %: Shoukry 1992) and higher than that of *T. alexandrinum* (43.4 %: Chauhan et al. 1980). This result coincided with Galal and Shehata (2013) on *D. bipinnata*.

Digestible crude protein attained its maximum values (1.3 %) in *I. cylindrica*, which is lower than the value required for the diet of sheep (6.1 %; NRC 1975), while TDN had a value (63.9 %) for *I. cylindrica,* which is lower than 68.8 and 66.4 % reported by Heneidy and Bidak (1996) on *P. australis* and Shaltout et al. (2010) on *E. stagnina*, respectively. In the present study, *D. bipinnata* attained the maximum value of digestible energy (2. 7 Mcal/kg) in their living tissues; however, sheep are known to require the same value for diet (NRC 1975).

Abd El-Salam (1985) recognized the importance of the adequate Ca:P ratio of 2:1 as a major factor affecting the utilization of the whole diet. In the present study, this ratio is far higher than the optimum, while El-Kady (1987) in his study on range ecosystems in the western Mediterranean region of Egypt reported a ratio of 25.8 and Shaltout et al. (2012) on *Azolla filiculoides* reported a ratio of 33.3. Such a high ratio would lead to lower utilization of both Ca and P by animals. It is also asserted that if too little P is available, the N absorption, and hence biomass production are reduced (Shaltout et al. 2012). On the other hand, the Ca:Mg ratio was 0.9 for *I. cylindrica* and 1.5 for *D. bipinnata*, while it was 1.2–2.8 in the browse plants in North Africa (Le Houérou 1980). It seems that the nutritive values of the living and dead parts of both species are too low from the range of nutritive value of sheep (NRC 1975), goat (NRC 1981), dairy cattle (NRC 1978) and beef cattle (NRC 1984). Thus, using the scale suggested by Boudet and Riviere (1968), the living and dead parts of the two grasses under investigations were evaluated as poor forage.

5 Conclusion

Nutrients and heavy metals are removed in constructed wetland systems by many different processes including plant uptake and accumulation. Harvesting the aboveground biomass is therefore an option to remove accumulated elements. In order to maximize removal, harvest should be done during the period of maximum content of heavy metals in the plant tissues. Autumn is the suitable season to harvest both *I. cylindrica* and *D. bipinnata* for removal of nutrients and heavy metals. The high bioaccumulation factors of both species for Mn, Cu and Pb, in addition to their ability to accumulate the highest concentrations of macro- and micronutrient in the dead parts, render this species a powerful phytoremediator for the removal of these metals from contaminated ecosystems. The analysis of the nutritive values for the two study grasses evaluated them as poor forage.

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