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FULL LENGTH ARTICLE

Nutritional value of *Cymodocea nodosa* and *Posidonia oceanica* along the western Egyptian Mediterranean coast

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Abstract The nutritional value of the two seagrasses *Cymodocea nodosa* and *Posidonia oceanica* and their potential use as fertilizers were evaluated based on the determination of biochemical content, major and trace element content in the leaves of the two species, occurring in five sites along the western Egyptian Mediterranean coast during summer (2006 and 2009). The total carbohydrates, total proteins and total lipids in *C. nodosa* were 47.22, 510.44 and 100.78 mg/g, respectively, and in *P. oceanica* 28.98, 607.50 and 40.50 mg/g, respectively. The calorific content was 4.03 K cal/g for *C. nodosa* and 3.93 K cal/g for *P. oceanica*. N%, P_2O_5% and K_2O% and C:N ratio were 8.45%, 1.21%, 0.81% and 1.50:1 in *C. nodosa*, respectively, and 10.60%, 2.13%, 0.58% and 1.25:1 in *P. oceanica*, respectively. The concentrations of trace elements (Cu, Ni, Pb and Zn) in the two species were lower than in composts, while the major element concentrations in *C. nodosa* coincided with the typical concentrations in composts (P, 530.00; Na, 1044.44; Ca, 2470.00 mg/ 100 g), respectively, but higher in *P. oceanica* (P, 930.00; Na, 2765.00; Ca, 3890.00 mg/100 g), respectively.

Cymodocea nodosa only can be potentially used as supplementary powdered organic fertilizer and/or additive compost.

Introduction

Seagrasses are submerged marine angiosperms (Wright and Jones, 2006), producing flowers, fruits and seeds and they have separate roots, leaves and underground stems (rhizomes), which enable them to form an extensive network below the surface of water (Tropical topics, 1993).

However, the rapidly expanding scientific knowledge on seagrasses has led to a growing awareness that seagrasses are a valuable coastal resource (Garcia-Sanchez et al., 2006). As primary producers, seagrasses play a key role in marine ecosystems (Hemminga and Duarte, 2000). Their beds provide water purification, nutrient cycling, stabilize sediment, and dampen wave and current energy (Haznedaroglu and Zeybeck, 2007).They also act as a "carbon sink" by absorbing carbon dioxide from the atmosphere and thereby helping to slow down the effects of global warming (Hemminga and Duarte, 2000). On the other hand, they provide food for a wide array

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of species, including manatees, sea turtles (Aketa and Kawamura, 2001), sea urchins, waterfowl, gar and pinfish, and they are also considered as a source of food production for man as they serve as a nursery ground to juvenile stages of economically important species of finfish, oysters, clams, and shellfish (Haznedaroglu and Zeybeck, 2007).

On the other hand, seagrasses are valued because of the plants yielded material it offers for various practical purposes (Tobatinejad et al., 2007; Ben Jenana et al., 2009). Archeological evidence suggests that Seri Indians living along the Gulf of California harvested the carbohydrate-rich seeds of *Zostera marina* to obtain flour that was used in different dishes (Hemminga and Duarte, 2000), whereas the north–west of European countries used the species in dike building, as filling material for pillows and mattresses, roofing material, and as fodder, while in USA the blades were used in insulation (Hemminga and Duarte, 2000; Karleskint et al., 2009). Yet, agar like substance, zosterin is extracted from *Zostera* spp. (Phillips and McRoy, 1980). Human consumption of seagrass is not entirely confined to the past. In South–East Asia, seeds of *Enhalus acoroides* are still a food source for coastal populations (Montano et al., 1999), whereas the rhizomes of *Cymodocea* spp. are used in the preparation of salad.

Furthermore, *Posidonia* spp., *Zostera* spp. *Heterozostera tasmanica* and other seagrasses are still extensively harvested for burning of peat to obtain minerals and their use for the production of soil improvers, compost and fertilizer in the fields (Ben Jenana et al., 2009). In addition, *Posidonia oceanica* leaves are used as shock-absorbing material for the transport of glassware; to keep fish catches moist during transportation, as filling material for mattresses, whereas *Posidonia* balls are used for their fibers (Karleskint et al., 2009). Recently, seagrasses are used experimentally in the production of methane, nitrocellulose, in addition to their medicinal uses as herbal remedies for rheumatism and skin ailments (Karleskint et al., 2009).

Along the Egyptian Mediterranean coasts five species were recorded, among which, *Cymodocea nodosa* and the endemic species *P. oceanica* (Boudouresque et al., 2006) are the common species and the abundant ones, which were recorded previously at many sites, extending from El Salloum at the extreme west to El Arish at the extreme east of the Egyptian Mediterranean coast. Whereas the other recorded species *Zostera marina*, *Zostera noltii* and the immigrant species *Halophila stipulacea* are scarcely represented and were recorded previously at restricted sites.

However, there are very few literatures interested in the nutritional value of seagrass in Egypt (Geneid and El-Hady, 2006; Mohamed and Geneid, 2007). In fact, almost all of the studies in Egyptian Mediterranean Sea on the common two species were surveys or ecological studies concerning the effects of physico-chemical characteristics on seagrass phenology, morphology and their distribution or investigating their associated communities (ex: Mostafa, 1997a,b, 2006; Shabaka, 2004; Geneid and Mourad, 2007). These previous works may reflect only the conditions of seagrass meadows but not the importance of seagrasses and their great nutritional value. This study is conducted along the Western Egyptian Mediterranean coast on *C. nodosa* and *P. oceanica* in order to evaluate their nutritional value as food for other living organisms of great ecological importance and for the first time in Egypt as organic fertilizer and/or compost, in addition to compare *C. nodosa* with *P. oceanica* based on their biochemical contents, major and trace elements content.

Materials and method

Study area

Two cruises were carried out during summer 2006 and summer 2009, along the western Egyptian Mediterranean coast using the Egyptian r/v "El-Salsabil", covering five stations, with different depths, namely: Zawyet El Shamass (El Shalia) (St. I), Alam El Roum (St. II), El Dabaa (St. III), Sidi Abdel Rahman (St. IV), El Alamein (St. V) (Fig. 1). The study area is influenced by prevailing wind and current regime (Sharaf El-Din et al., 2006). However, these stations are considered unprotected, since there are no marine protected areas along the Egyptian Mediterranean coast, except at El Salloum.

The physico-chemical parameters

The physico-chemical parameters of the five stations of the study area were measured at the same time of collecting the seagrass samples. The measurements of dissolved oxygen (D.O.) and nutrients (ammonia NH_4, nitrite NO_2, nitrate NO_3, reactive soluble phosphate PO_4, and silicate SiO_4) at St. I and II during summer (2006) were reported after Hemaida et al. (2008) and their measurement at St. III and V during summer (2009) was reported by personal communication with Abdel Halim, whereas the data of temperature and salinity at the depth of each station were reported by personal communications with Maiyza (Table 1).

Sample collections

The collected leaves of the two seagrasses; *C. nodosa* (Ucria) Asch. and *P. oceanica* (L.) Delile from the five stations were used to determine total carbohydrates (TCH), total lipids (TL), total proteins (TPr), total organic nitrogen content, total organic carbon content, major elements (phosphorus, potassium, sodium, and calcium), and trace elements (copper, nickel, lead and zinc).

Seagrass samples were collected from sandy bottoms by Van-Veen Grab sampler equivalent to $0.10\ m^2$, washed with seawater *in situ* to remove the adhered sediments, impurities and separated in clean labeled polyethylene bags and stored under refrigeration 4 °C. Quick rinsing of seagrass leaves was carried out in the Lab throughout the same day to get rid of the remaining impurities and epiphytes by using a glass strip. Herbarium sheets of complete specimens with identification of the two species (*P. oceanica and C. nodosa*) were done and/or preserved in 4.00% formalin. The two taxa were identified according to Short and Coles (2001). The samples of the species *C. nodosa* were collected at St. (I, II and IV) at the depths of 52.00, 50.00 and 60.00 m, respectively during summer (2006), whereas those of *P. oceanica* were collected from St. (III and V) at the depths of 40.00 and 68.00 m, respectively during summer (2009). The leaves of the two species were divided separately into three sub-samples: the first to carry out the measurements for biochemical components, the second for the major and trace elements and the third for determination of total organic nitrogen and total organic carbon

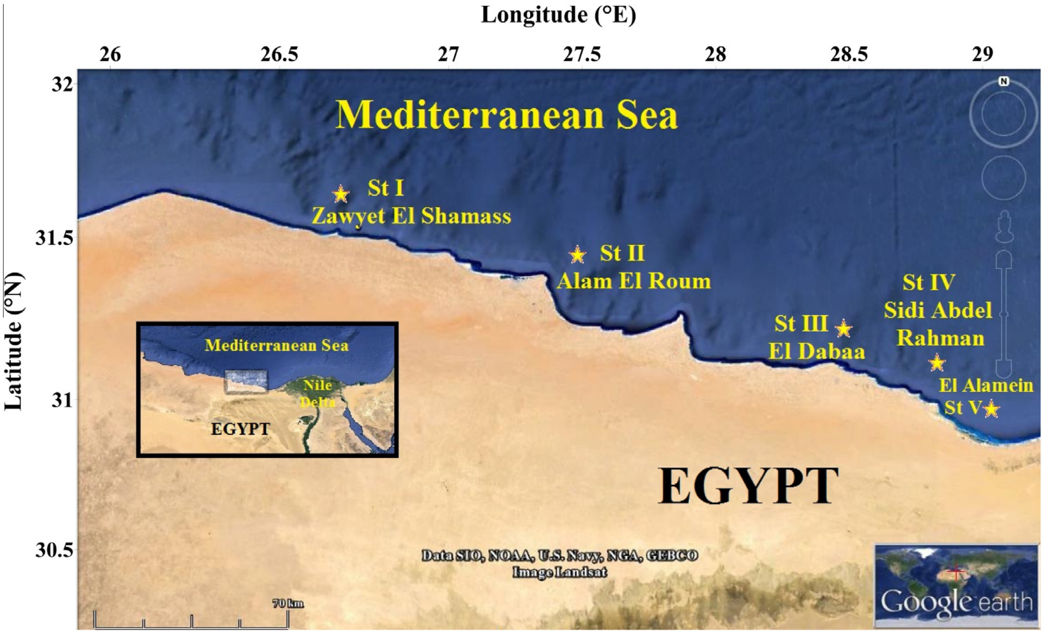

Figure 1 Study area and sampling stations during 2006 and 2009.

contents. The total average of three replicas and the standard deviation for each constituent of each species were calculated.

Measurements of components

Biochemical components (total carbohydrates, total protein and total lipids)

The first seagrass sub-samples were dried at room temperature (25.00 °C) to a constant weight and then ground to fine powder. For each component, 1.00 g dry weight of the seagrass samples was taken. Total protein content was estimated spectrophotometry using Japanese Spekoll 11 spectrophotometer at 650 nm by the method described by Lowry et al. (1951), using a salt-free bovine serum albumin as a standard. Total carbohydrates content was estimated according to Dubois et al. (1956), Total lipids were estimated according to Bligh and Dyer (1959). The results of the three components were expressed as mg/g dry weight. The detection limit of the spectrophotometer used for measuring the three components was 2.00×10^{-3}.

Measurements of major elements

The second seagrass sub-samples were dried at 60.00 °C to a constant weight, homogenized by crushing each sample in a porcelain pestle and mortar and kept away from metallic materials and dusty conditions to avoid contamination. 1 g dry weight of each sample was subjected to acid digestion in 5.00 mL concentrated HNO_3 in a Teflon-lined vessel by means of a microwave oven in pressure-controlled conditions. Digested samples were filtered through an acid washed filter (Whatman GF/C) and diluted to 25.00 mL with double distilled water (Haritonidis et al., 1983; Mohamed and Khaled, 2005). All the major elements in the digested samples were measured spectrophotometrically and the detection limit of the apparatus was 2.00×10^{-3}.

The measurement of phosphorus was based on the reaction of phosphate with molybdate in strong acidic medium to form a complex. The absorbance of this complex in the near UV is directly proportional to the phosphate concentration (Gamst and Try, 1980).

The method of measurement of sodium is based on modifications of those first described by Trinder (1951) and Maruna (1958) in which sodium is precipitated as the triple salt, sodium magnesium uranyl acetate, the excess uranium reacted with ferrocyanide, producing a chromophore whose absorbance varies inversely as the concentration of sodium in the sample.

The amount of potassium is determined by using sodium tetraphenylboron in a specifically prepared mixture to produce a colloidal suspension. The turbidity of which is proportional to potassium concentration (Terri and Sesin, 1958).

The method of measurement of calcium is based on the formation of a purple–red complex with ortho-cresolphthalein in an alkaline medium. Intensity of the developed color is proportional to the calcium concentration in the sample (Stem and Lewis, 1957).

The results of all major elements were expressed as mg/100 g.

Measurements of trace elements

For measurement of the trace elements copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn), the same steps of measurements of major elements were followed. 1 g dry weight of each sample was digested according to (Haritonidis et al., 1983; Mohamed and Khaled, 2005) and was used for analysis of these elements, which were measured using Wizard software involved with SHIMAZU atomic absorption spectrophotometer AA-6800 where the flame unit was together with autosampler SHIMAZU ASC-6100. The detection limit of the apparatus for Cu was 0.02 μg/g, Ni (0.04 μg/g), Pb (0.10 μg/g) and Zn (4×10^{-3} μg/g). The accuracy of the method was verified using standard reference materials (TORT-2) from National Research Council of Canada and recoveries were above 95% for the measured trace metals. The reported results are mean values of triplicate determinations and expressed as μg/g dry

Table 1 The physico-chemical characteristics of the study area during summer (2006 and 2009), after Hemaida et al. (2008) and personal communication with Abdel Halim and Maiyza.

Stations	Depth (m)	Temp. °C	Salinity	pH	D O. ml/l	NH_4 µM	NO_2 µM	NO_3 µM	PO_4 µM	SiO_4 µM
Zawyet El Shamass (I)	52	16.90	38.40	8.30	5.46	1.90	0.46	7.35	0.56	4.60
Alam El Roum (II)	50	17.50	38.50	8.30	5.28	1.63	0.28	4.83	0.20	5.74
El Dabaa (III)	40	16.62	38.56	–	–	8.21	0.31	1.28	0.28	2.37
Sidi Abdel Rahman (IV)	60	18.50	38.60	–	–	–	–	–	–	–
El Alamein (V)	68	16.92	38.78	–	–	7.69	0.32	2.55	0.59	1.38

Note:
Dissolved oxygen = D.O.
Ammonia = NH_4.
Nitrite = NO_2.
Nitrate = NO_3.
Phosphate = PO_4.
Silicate = SiO_4.

weight. All glass wares, plastic and Teflon devices were thoroughly acid washed.

Evaluation of the economic values of the two seagrass species C. nodosa and P. oceanica

In order to evaluate the nutritive value of the two seagrass species for marine herbivores, the calorific content of the two species was calculated, using the following known conversion values to convert the organic content into calorific values: fats 9.45, carbohydrates 4.10 and protein 5.65 K cal/g (Brody, 1945).

Also for the preliminary investigation of the two species as organic fertilizers and/or compost, the composition of some compounds such as P_2O_5%, K_2O%, N% and the C:N ratio was calculated in the two species. The superphosphate (P_2O_5%) was calculated by multiplying the total average phosphorus content with a converting factor 2.29 and potassium oxide (potash) (K_2O%) was calculated by multiplying the total average potassium content by the converting factor 1.20 (IFDC/UNIDO Fertilizer Manual, 1979).

For measurement of the total organic nitrogen content, the third seagrasses' sub-samples were dried at 40.00 °C to a constant weight. 1.00 g of the dried sub-sample was completely digested by adding 200.00 mg of catalyst (K_2SO_4, Cu SO_4 and SeO in ratio 100:10:1), respectively and 3.00 ml of concentrated sulfuric acid then diluted to 75.00 mL with double distilled water (Grasshof, 1975). The concentration of total nitrogen content in the digested sample was estimated spectrophotometrically at 240 nm with detection limit 2.00×10^{-3} and using ammonium salt as a standard.

For total organic carbon measurement, a portion of the third dried seagrass sub-samples was used for analysis. 5 mL of 1.00 N potassium dichromate solution, followed by 10.00 ml of concentrated sulfuric acid were added to 0.5 g of the dried sample. The formed suspension was filtered and then was titrated against 0.50 N ferrous sulfate, where the amount of ferrous sulfate equivalent to the carbon content was calculated (Grasshof, 1975). The C:N ratio was calculated as average of three replicas for each sample.

Statistical analysis

In order to evaluate the effect of physico-chemical parameters on biochemical components, major elements and trace elements concentrations in the two seagrasses, the correlation coefficient between the physico-chemical parameters including depth, water temperature, salinity, nutrients (NH_4, NO_2, NO_3, PO_4, and SiO_4) and these constituents was calculated at confidence limit 95% ($P \leqslant 0.05$).

T- test was conducted according to the measured constituents in the two seagrass species to detect the difference between them and *F*-test was conducted between the five stations based on the measured constituents in the two species to detect the difference between stations, using the software SPSS (11.5) for *T* test and the Excel program for *F* test.

Results

Physicochemical parameters

The physico-chemical parameters of the study area during summer 2006 and summer 2009 are shown in Table 1.

As the depths of all sites of the study area were below the thermocline zone (Sharaf El-Din et al., 1997), the readings of temperature were relatively low ranging from a minimum of 16.62 °C (St. III) to a maximum of 18.50 °C (St. IV) with a maximum difference of 1.88 °C.

The readings of salinity were uniform in all stations ranging from 38.40 (St. I) to 38.78 (St. V) and exhibited only a narrow variation with a maximum difference of 0.38 during the sampling period. The two recorded pH values at St. I and II were equal (8.30) and that of dissolved oxygen were almost equal at the same stations.

As far as nutrients are concerned, their values showed great differences from one station to another. The lowest concentrations of NH_4 (1.63 µM), NO_2 (0.28 µM) and PO_4 (0.20 µM) were recorded at St. II, whereas, the lowest values of NO_3 (1.28 µM) and SiO_4 (1.38 µM) were recorded at St. III and V, respectively. On the other hand, the highest values of NH_4 (8.21 µM) were recorded at St. III and the highest values of both NO_2 (0.46 µM), NO_3 (7.35 µM) were recorded at St. I, whereas, the highest values of PO_4 (0.59 µM) and SiO_4 (5.74 µM) were recorded at the St. V and II, respectively.

Natural components

Biochemical components (total carbohydrates, total protein and total lipids)

The results of TCH, TPr and TL showed spatial and specific considerable differences. However, the TCH was relatively

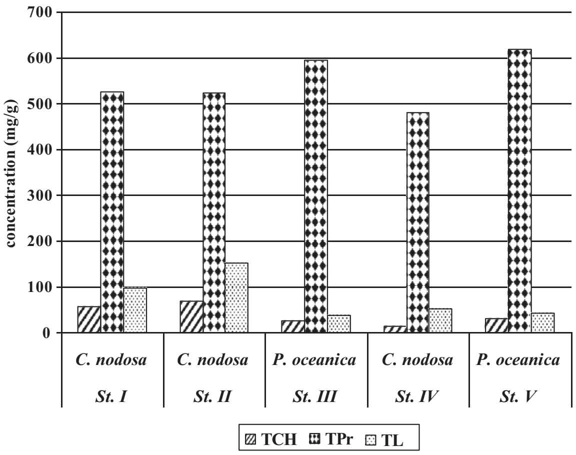

Figure 2 The concentration of biochemical components: (TCH, TPr, TL in mg/g) of the seagrass *Cymodocea nodosa* and *Posidonia oceanica* at western of Alexandria during 2006 and 2009.

low with the minimum value (15.00 ± 4.58 mg/g) recorded at St. IV, whereas the maximum value (70.00 ± 10.00 mg/g) was recorded at St. II (Fig. 2). On the other hand, the TCH content was lower in *P. oceanica* than in *C. nodosa*, attaining a total average of 28.98 mg/g in the former and 47.22 mg/g in the latter (Table 2). In contrast, TPr contents were very high in the two species and at all stations, recording the highest value (620.00 ± 64.55 mg/g) at St. V and the lowest value (481.67 ± 4.73 mg/g) at St. IV (Fig. 2). The TPr content showed an inverse pattern to TCH content where the species *P. oceanica* exhibited a higher value than the species *C. nodosa* (607.50 and 510.44 mg/g), respectively (Table 2). The TL content recorded a minimum value of 37.67 ± 4.16 mg/g at ST. III and a maximum value of 152.00 ± 11.14 mg/g at St. II. Specifically, *C. nodosa* recorded a higher TL content in comparison with *P. oceanica* (100.78 and 40.50 mg/g), respectively (Table 2).

Major elements

Like TCH, TPr and TL, the concentrations of major elements in the two seagrass species showed also great variations spatially and specifically. However, the maximum values of phosphorus (1063.33 ± 56.86 mg/100 g), sodium (3021.67 ± 65.26 mg/100 g) and calcium (6100.00 ± 360.56 mg/100 g) were recorded at St. V, whereas the maximum value of potassium (960.00 ± 26.46 mg/100 g) was recorded at St. II. On the other hand, the minimum values of phosphorus and potassium were recorded at St. IV (376.67 ± 51.32 and 123.00 ± 11.27 mg/100 g), respectively, while the minimum values of the two other elements sodium and calcium were recorded at St. II (716.67 ± 28.87 and 996.67 ± 85.05 mg/100 g), respectively (Fig. 3). On the species level, the total average of the phosphorus, sodium and calcium elements exceeded in *P. oceanica* than those recorded in *C. nodosa* attaining in the former (930.00, 2765.00 and 3890.00 mg/100 g), respectively, and attaining in the latter (530.00, 1044.44 and 2470.00 mg/100 g), respectively. Whereas potassium element showed the inverse pattern attaining in *C. nodosa* a value of 675.44 mg/100 g and in *P. oceanica* a value of 481.67 mg/100 g (Table 3).

The trace elements

Generally, the distribution of the trace elements in the two seagrass species showed varied concentrations. Copper was under the detection limit in both species and at all stations, whereas zinc was higher than lead and nickel. However, *C. nodosa* revealed higher concentrations of the three elements (Ni, Pb, Zn) than those recorded in *P. oceanica*, attaining in the first species (10.65, 27.98 and 42.08 μg/g), respectively and attaining in the second species (9.35, 8.07 and 32.21 μg/g), respectively (Table 4).

On the spatial scale, the lowest concentrations of nickel (5.26 ± 1.49 μg/g), lead (7.83 ± 9.60 μg/g) and Zn (25.00 ± 28.85 μg/g) were recorded at St. III. On the other hand, the highest concentration of Ni (13.44 ± 4.65 μg/g) was recorded at St. V, whereas the highest concentrations of both lead and zinc (29.68 ± 5.58 and 39.10 ± 34.98 μg/g) were recorded at St. II, and IV, respectively (Fig. 4).

Table 2 The concentrations of biochemical components: TCH, TPr, TL in mg/g in seagrass leaves of the present study and the previous studies.

Seagrass species	TCH	TPr	TL	References
Cymodocea nodosa	72.14	130.00	11	In the whole plant (Geneid and El-Hady, 2006)
	130.00	186.00	36.50	In the whole plant (Abdel Hady et al. 2007)
	27.40–105.20	–	–	In the leaves (Mascaro et al., 2009)
	47.22	510.44	100.78	In the leaves (present study)
Posidonia oceanica	28.98	607.50	40.50	In the leaves (present study)
Posidonia australis	–	54.00–61.00	–	In the whole plant (Tobatinejad et al., 2007)
Ruppia cirrhosa	24.75	132.70	5.04	In the whole plant (Geneid and El-Hady, 2006)
	62.00	287.00	15.00	In the whole plant (Abdel Hady et al., 2007)
Thalassia testudinum	30.00–120.00	30.00–120.00	–	In the leaves (Dawes et al., 1979)
Seagrass spp.	–	33.80–115.00	–	In the leaves (Birch, 1975)
	2.00–8.70	0.10–5.90	0.10–32.00	In the leaves (Pradheeba et al., 2011)

Note:
Total carbohydrates = TCH.
Total protein = TPr.
Total lipids = TL.

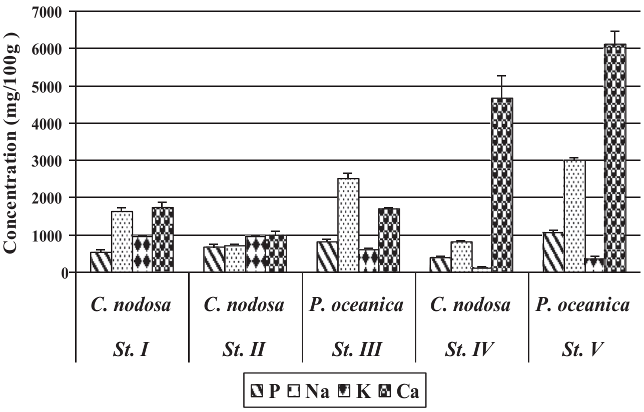

Figure 3 The concentrations of minerals (P, Na, K and Ca, mg/100 g) dry weight in the seagrass *Cymodocea nodosa* and *Posidonia oceanica* at western of Alexandria during 2006 and 2009.

Evaluation of the economic importance of the two seagrass species C. nodosa and P. oceanica

However, the calorific content of *C. nodosa* species was slightly higher than that of *P. oceanica* (4.03 and 3.93 K cal/g), respectively (Table 5).

The calculated P_2O_5% was lower in *C. nodosa* than in *P. oceanica* (1.21% and 2.13%), respectively, whereas the contrary was for K_2O% (0.81% and 0.58%), respectively (Table 6). On the other hand, the concentrations of the total organic nitrogen content in *C. nodosa* were 83.00, 86.00 and 85.00 mg/g and the concentrations of the total organic carbon content were 121.00, 125.00 and 126 mg/g at St. I, II and IV, respectively with a total average of 84.60 mg/g for nitrogen and a total average of 124.00 mg/g for carbon, whereas the concentrations of the total nitrogen in *P. oceanica* were 109.00 and 103.00 mg/g and the concentrations of the total carbon were 134.03 and 130.50 mg/g at St. III and V respectively, with a total average of 106.00 mg/g for nitrogen and a total average of 132.30 mg/g for carbon. From these results, the C:N ratio was calculated for each species, where the ratio in *C. nodosa* was 1.50:1 and in *P. oceanica* was 1.25:1 (Table 6).

Results of statistical analysis

The correlation coefficient between the physico-chemical parameters including depth, water temperature, salinity, nutrients (NH_4, NO_2, NO_3, PO_4, and SiO_4) and biochemical components, major and trace elements at confidence limit 95% ($P \leqslant 0.05$) is shown in (Table 7).

The results of the T-test between the two species based on the measured constituents in the two seagrasses revealed that the mean for *C. nodosa* was 264.19 and for *P. oceanica* was 418.51 at $n = 22$, $p < 0.05$, the value of T-test was 1.535, while the T-critical one-tail was 1.721. The Pearson correlation value was 0.96 which indicates a significant relationship between the two species.

Whereas, the results of the F-test between the five stations based on the measured constituents in the two seagrass species in these stations revealed that there are no significant relationships between them, where the F values were small and between 0.000 and 0.167 at $n = 39$, $p < 0.05$.

Discussion

However, there are few literatures that dealt with biochemical components in *C. nodosa* (Geneid and El-Hady, 2006; Abdel Hady et al., 2007; Mascaro et al., 2009) and other seagrass species (Birch, 1975; Dawes et al., 1979; Tobatinejad et al., 2007; Pradheeba et al., 2011), while there is no available data on biochemical components of *P. oceanica*. Therefore it is important to know more about the chemical composition of the two seagrass species, because of their direct or indirect role in coastal marine food chains (Kikuchi, 1980).

Seagrass community structure, species abundance, growth and productivity are greatly influenced by water quality (CERP, Monitoring and Assessment Plan, 2004). The water quality influences in turn biochemical constituents (Pradheeba et al., 2011), minerals and trace metal contents. These findings are supported by different correlations between physico-chemical parameters and these constituents in the two seagrass species of the present study. The TCH contents were relatively low in the two seagrass species *C. nodosa* and *P. oceanica* compared with those previously recorded (Dawes et al., 1979;

Table 3 The concentrations of major elements: P, Na, K and Ca in mg/100 g in seagrass leaves of the present study and the previous studies.

Seagrass species	P	Na	K	Ca	References
Cymodocea nodosa	135.00–176.00	–	–	–	In the leaves (Mostafa, 1997b)
	100.00–250.00	–	–	–	In the leaves (Mascaro et al., 2009)
	530.00	1044.40	675.44	2470.00	In the leaves (present study)
Posidonia oceanica	114.00–154.00	–	–	–	In the leaves (Mostafa, 1997b)
	122.00–396.00	–	–	–	In the leaves (Delgado et al., 1999)
	50.00	–	–	3527.00	In the whole plant (Masoud et al., 2006)
	930.00	2765.00	481.67	3890.00	In the leaves (present study)
Seagrass spp.	–	69.00	30.09	22.00	In the whole plant (Kannan et al., 2010)
Thalassia testudinum	54.40–629.40	–	–	–	In the leaves (Fourqurean and Cai, 2001)
Zostera marina	–	3330.00	3500.00	1310.00	In the leaves (Brix and Lyngby, 1984)

Note:
Phosphorus = P.
Sodium = Na.
Potassium = K.
Calcium = Ca.

Table 4 The concentrations of trace metals: Cu, Ni, Pb and Zn in µg/g in seagrass leaves of the present study and the previous studies.

Seagrass species	Cu	Ni	Pb	Zn	References
Cymodocea nodosa	6.28	–	2.33	24.16	In the whole plant (Geneid and Mourad, 2007)
	0	10.65	27.98	42.08	In the leaves (present study)
Posidonia oceanica	12.71	–	3.31	106.80	In the leaves (Campanella et al., 2001)
	8.80	–	0.02	119.30	In the whole plant (Sawidis et al., 2001)
	3.80	13.70	–	102.00	In the whole plant (El-Deeb and Aboul-Naga, 2002)
	8.40–15.30	5.80–12.50	–	213.00–676.00	In the leaves (Tranchina et al., 2005)
	11.10	22.90	5.20	109.30	In the leaves (Gosselin et al., 2006)
	23.67	13.00	–	85.33	In the whole plant (Masoud et al., 2006)
	31.88	–	2.29	213.00	In the leaves (Conti et al., 2007)
	14.68	31.64	2.25	134.48	In the leaves (Pergent-Martini et al., 2007)
	11.70	–	1.94	70.90	In the leaves (Conti et al., 2010)
	13.30	31.00	2.30	163.00	In the shoots (Richir et al., 2010)
	10.90	24.50	6.12	133.00	In leaves (Sanz-Lázaro et al., 2012)
	3.91	–	1.45	167.25	In leaves (Dileo et al., 2013)
	0	9.35	8.07	32.21	In leaves (present study)
Ruppia cirrhosa	7.94	–	2.33	31.81	In whole plant (Geneid and Mourad, 2007)
Ruppia maritima	0.50	2.30	2.10	16.90	In whole plant (Riosmena-Rodríguez et al., 2010)
Seagrass spp.	7.80	1.51	2.04	17.59	In whole plant (Kannan et al., 2010)
Zostera marina	4.91	–	1.07	78.00	In the leaves (Brix and Lyngby, 1984)
	1.00	2.95	2.50	15.00	In whole plant (Riosmena-Rodríguez et al., 2010)

Note:
Copper = Cu.
Nickel = Ni.
Lead = Pb.
Zinc = Zn.

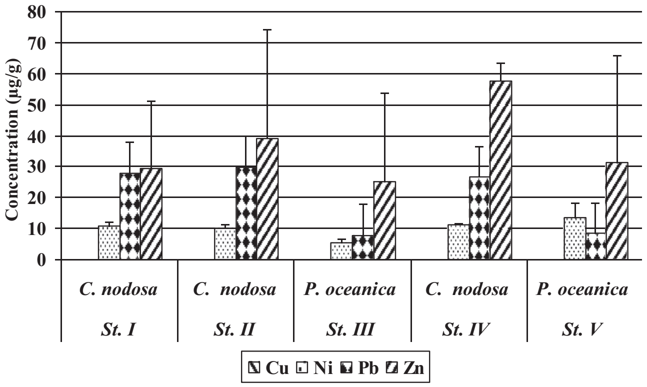

Figure 4 The concentrations of trace elements (Cu, Ni, Pb and Zn) µg/g dry weight in the seagrass *Cymodocea nodosa* and *Posidonia oceanica* at western of Alexandria during 2006 and 2009.

Geneid and El-Hady, 2006; Abdel Hady et al., 2007; Tobatinejad et al., 2007; Mascaro et al., 2009), except those of Pradheeba et al. (2011). In contrast, the concentrations of TPr are markedly higher in the two species especially in *P. oceanica* than the previous studies (Birch, 1975; Dawes et al., 1979; Geneid and El-Hady, 2006; Abdel Hady et al., 2007; Tobatinejad et al., 2007; Pradheeba et al., 2011). This inter-specific and spatial variation in TCH and TPR contents may be related to many factors such as the depth, light intensity, degree of turbidity of water column (Short and Coles, 2001), as well as, nutrient availability in the water column (Pradheeba et al., 2011) and the natural cycle of the plant with different uptake, translocation in different parts of the plant (Geneid and El-Hady, 2006). In the present study, the TCH content was negatively influenced by the salinity and ammonia and was positively influenced by nitrate and silicate. On the other hand, TPr content was negatively affected by temperature, nitrate and silicate and was positively affected by the concentration of ammonia. Like TPr, TL contents were also higher in the two species than those recorded in the previous studies, but inverse to TPr, *C. nodosa* showed higher TL average concentration than *P. oceanica*. The TL content was negatively influenced by the salinity and ammonia and was positively influenced by nitrate and silicate. However, Pirc (1989) attributed variations in the total lipid content of seagrass species to age, stage of growth and ecological variations.

The total average concentrations of phosphorus, sodium and calcium were higher in *P. oceanica* than in *C. nodosa*, while the potassium element showed an inverse pattern. On the other hand, the concentrations of these elements varied greatly in comparison with the available previous studies (Brix and Lyngby, 1984; Mostafa, 1997b; Delgado et al., 1999; Fourqurean and Cai, 2001; Masoud et al., 2006; Mascaro et al., 2009; Kannan et al., 2010). The variations in mineral contents were attributed to metabolic reactions, environmental conditions and seasonal variations and to the different requirements of the plant (Stewart, 1974). Whereas, Barko and Smart (1980) reported that rooted aquatic plants could facilitate mineral uptake by roots from the sediments, which also depend on their concentrations in the interstitial and overlying waters. Mostafa (1997b) and Masoud et al. (2006) stressed on the importance of carbonate sediments as the main source of minerals and Fourqurean and Cai (2001) suggested that mineral content in seagrasses is controlled by freshwater and marine inputs of these elements. In the present study, the major element contents

Table 5 Nutritional composition of some aquatic plants eaten mainly by Dugong and Manatees in comparison with terrestrial angiosperms and seagrasses of the present study (Dawes and Lawrence[1], 1980; Lawrence et al[2]., 1989; Dawes and Guiry[3], 1992; Aketa and Kawamura[4], 2001; Philpott and Bradford[5], 2006).

Seagrasses	Dry matter%	Protein% D.W	Lipids% D.W.	Cellulose% D.W	K cal/gm D.W.
Cymodocea serrulata[4]	16.8	7.5	*	*	2.70
Halophila ovalis[4]	14.3	6.2	*	24	2.10
Halodiule uninervis[4]	19.30	8.1	*	*	2.10
Zostera capricorgni[4]	17.30	5.00	*	42–50	2.90
Halodule wrightii[1] (leaves)	25–32	14–19	1.0–3.2	*	3.11–3.59
Posidonia oceanica[2] (leaves)	18–22	3.7–4.3	1.9–3.2	*	4.30
Syringodium filiforme[1] (leaves)	28–33	8–13	1.7–6.2	*	2.39–3.11
Thalassia testudinium[1] (leaves)	29–44	8–22	0.9–4.0	*	2.39–3.11
Zostera marina[3] (leaves)	24–33	10.14	2.5–3.4	*	3.11–3.59
The present study					
Cymodocea nodosa (leaves)	*	51.04	10.08	*	4.03
Posidonia oceanica (leaves)	*	60.75	4.05	*	3.93
Macroalgae					
Nori[5] (*Porphyra tenera*)	*	35.6	0.6	*	3.49
Dulse[5] (Palmaria palmata)	*	7.90	0.1	*	2.72
Kombu[5] (*Laminaria japonica*)	*	7.30	0.3	*	2.74
Wakame[5] (*Undaria pinnatifida*)	*	17.30	0.7	*	2.32
Hijiki[5] (*Hizikia fusiforme*)	*	10.00	0.1	*	2.60
Macrophytes					
Elodea densa[4]	9.8	20.5	3.3	29.2	3.40
Alternanthera philo[4]	14.5	15.6	2.7	21.3	3.50
Najas guadlupensis[4]	7.3	22.8	3.8	35.6	3.60
Hydrilla sp.[4]	8.0	17	3.5	32	3.50
Eichhomia crassipes[4]	5.9	17	3.5	28	3.80
Myriophyllum spicatum[4]	12.8	9.8	1.8	18.8	2.50
Ceratophyllum demersum[4]	5.2	21.7	6	27.9	3.70
Eleocharis acicularis[4]	11.1	22.5	3.6	27.9	3.90
Salvinia auriculata[4]	5.5	12.2	*	*	3.60
Pistia stratiotus[4]	5.9	13	4	26	3.50
Echinochloa polystachya[4]	17.4	9.2	*	*	3.90
Calomba sp.[4]	7.0	13.1	5.4	26.8	3.80
Plasoplum fasciculatum[4]	25.6	5.8	*	*	4.10
Paspolum repens[4]	16.7	9.8	2.9	*	4.00
Hymenachoe amplexicaulus[4]	13.9	21.3	*	*	3.90
Oryza perennis[4]	16.1	8.1	*	*	3.90
Terrestrial angiosperms					
Alfalfa[4]	18.3	19.5	0.7	3.6	*
Timothy[4]	18.3	13.4	0.7	3.4	4.50
Orchard grass[4]	17.6	15.5	0.9	4.4	*
Lactuca sp.[4]	16	21.6	4.9	8.3	3.00
Dandelian greens[4]	14.4	18.7	4.9	4.9	3.10

Note: The sign * means not available data.

were greatly affected by the measured physico-chemical parameters in the five sites.

However, many literatures dealt with the determination of the trace elements (Cu, Ni, Pb, and Zn) in seagrasses all over the world (Brix and Lyngby, 1984; Kannan et al., 2010; Riosmena-Rodríguez et al., 2010), in Mediterranean Sea (Campanella et al., 2001; Sawidis et al., 2001; Tranchina et al., 2005; Gosselin et al., 2006; Conti et al., 2007; Pergent-Martini et al., 2007; Conti et al., 2010; Richir et al., 2010; Sanz-Lázaro et al., 2012; Dileo et al., 2013) and in Egyptian waters (El-Deeb and Aboul-Naga, 2002; Masoud et al., 2006; Geneid and Mourad, 2007), as they are considered one of the most suitable biological indicators for water quality (Salivas-Decaux et al., 2010). But in the present study, zinc and copper are measured as they are essential for growth but in very low concentrations (Round, 1973), whereas lead and nickel are generally characterized as toxic elements for living organisms (Malea, 1994). The concentration of copper was under the detection limit in both species; while the concentrations of the other measured metals (nickel, lead and zinc) were lower in *P. oceanica* than in *C. nodosa*. The four elements displayed great variations in the two species in comparison with the previous studies. St-Cyr and Campbell (2000) stressed on the important role of the root system in metal uptake. Mohamed (2002) referred the variation in metal contents in plants to the physico-chemical parameters such as temperature, pH, salinity, wave exposure and light, which are also considerable in the present study, where nickel element was positively

Table 6 Approximate nutrient composition of various organic fertilizers (N%, P_2O_5% and K_2O%) according to Rosen et al. (2008) and (C:N ratio) according to (Cochran and Carney, 1996).

Organic material	N (%)	P_2O_5 (%)	K_2O (%)	C:N ratio
Beef	1.20	2.00	2.10	–
Dairy	2.10	3.20	3.00	13.00–18.00
Horse	2.10	3.20	2.00	22.00–50.00
Poultry	3.00	5.00	2.00	3.00–10.00
Rabbit	2.40	1.40	0.60	–
Sheep	1.60	1.20	1.00	13.00–20.00
Swine	2.50	2.10	2.00	9.00–19.00
Alfalfa hay	2.50	0.50	2.50	15.00–19.00
Blood meal	13.00	2.00	1.00	–
Bone meal, raw	3.00	22.00	0.00	3.00–3.50
Bone meal streamed	1.00	15.00	0.00	–
Composted yard waste	1.30	0.40	0.40	–
Cottonseed meal	6.00	3.00	1.50	7.00
Fish meal	10.00	6.00	0.00	2.60–5.00
Grain straw	0.60	0.20	2.10	48.00–150.00
Kelp/seaweed	1.50	1.00	4.90	5.00–27.00
Lawn-clippings	2.50	0.30	2.00	9.00–25.00
Leaves, broad leaves	0.90	0.20	0.80	40.00–80.00
Milogranite	5.00	3.00	2.00	–
sawdust	0.20	0.10	0.20	200.00–750.00
Soybean meal	7.00	1.20	2.00	4.00–6.00
Wood ashes	0.00	2.00	6.00	–
Seagrasses (present study)				
Cymodocea nodosa leaves	8.45	1.21	0.81	1.50
Posidonia oceanica leaves	10.60	2.13	0.58	1.25

*These are total concentrations and only slowly available over weeks, months, or years. Many materials will vary in composition due to methods of handling and moisture content.

*The composition of rabbit manure is on a fresh weight basis.

*Milogranite is not recommended for fertilizing fruit or vegetables.

Table 7 The correlation coefficient between the physico-chemical parameters and the biochemical components, major and trace elements in the seagrass *Cymodocea nodosa* and *Posidonia oceanica* measured in the study area during summer (2006) and summer (2009).

	Depth	Temp.	Salinity	NH_4	NO_2	NO_3	PO_4	SiO_4
TCH	−0.23	−0.25	**−0.53**	**−0.86**	0.13	**0.69**	−0.26	**0.84**
TPr	0.03	**−0.60**	0.43	**0.63**	−0.23	**−0.54**	0.21	**−0.64**
TL	−0.20	0.12	**−0.59**	**−0.91**	−0.02	**0.66**	−0.43	**0.94**
P	0.20	**−0.66**	**0.63**	**0.76**	**−0.52**	**−0.73**	0.25	**−0.80**
Na	0.14	**−0.75**	**0.57**	**0.90**	−0.02	**−0.64**	**0.55**	**−0.99**
K	**−0.53**	−0.50	**−0.72**	**−0.92**	0.33	**0.77**	−0.38	**0.96**
Ca	**0.87**	0.27	**0.85**	**0.58**	−0.09	−0.36	**0.69**	**−0.78**
Ni	**0.77**	0.27	0.32	−0.19	0.17	0.32	**0.55**	−0.04
Pb	−0.02	**0.52**	**−0.59**	**−0.86**	0.29	**0.76**	−0.17	**0.83**
Zn	0.09	**0.65**	−0.16	−0.44	−0.01	0.31	−0.26	0.48
n (The number of replica in the five stations) =	**15**	**15**	**15**	**12**	**12**	**12**	**12**	**12**
$r \geqslant$	**0.51**	**0.51**	**0.51**	**0.56**	**0.56**	**0.56**	**0.56**	**0.56**

Note: The bold values are significant.

influenced by water depth and phosphorus concentration. The concentration of lead synergized with temperature readings, nitrate and silicate, while antagonized with salinity and concentration of ammonia, whereas, the zinc element was affected only by temperature. On the other hand, Geneid and Mourad (2007) attributed these variations to biological conditions, which influence the bioavailability of trace metals and was attributed also to inter-specific differences. According to FAO (1992) the limits of Cu, Pb, and Zn in the biota should not exceed 30, 2.00 and 1000 μg/g respectively, whereas there is no available literature about the limit of nickel in biota but Oliveira et al. (2009) has considered the recorded values (2.60 μg/g) in edible seaweeds as high values. Accordingly, the concentrations of zinc and copper were lower in the two seagrass species of the present study than these limits, whereas nickel and Pb are higher, indicating that the two metals incorporated in the diet of many herbivorous animals can be bioaccumulated in their bodies with severe consequences in their health and also magnified in the next trophic level in the marine food chain (Gardner et al., 2006). Thus, the surrounding environmental conditions of the seagrasses species should be controlled to avoid any heavy metal pollution effect.

On the Basis of the measured constituents in the two seagrass species, the *t*-test between the two species indicates a significant relationship between them, which can be expected since they are from two related families evolved from the same origin (Short and Coles, 2001). Whereas, the *F*-test between the five stations revealed that there are no significant relationships between them, indicating different ecological conditions in these stations. This result was confirmed by the different physico-chemical conditions of these stations.

For all these measured important constituents, seagrasses are of great nutritive value for marine organisms, namely; sea urchins, sea turtles, sea dugong, sea manatees (Nagelkerken et al., 2000). However, Heck and Valentine (1995) found that the sea urchin *Lytechinus ariegates* consumes from 50% to 100% of the aboveground seagrass biomass produced in the eastern Gulf of Mexico and Caribbean Sea. Similarly, *Tripneustes ventricosus* and *Diadema antillarum* consume large quantities of seagrass in some Caribbean settings (Keller, 1983). The same findings were reported by Jernakoff et al. (1996). On the other hand, in the Egyptian Mediterranean Sea there is no recorded data either about the amount of seagrasses consumed by the sparid fish *Sarpa salpa*, the sea urchins *Paracentrotus lividus*, *Arbacia lixula*, *Psammechinus microtuberculatus*, the sea turtles *Chelonia mydas* and *Caretta caretta* or the calorific value that seagrasses can provide to these animals, despite their great economic values and their importance in the food chain. Accordingly, the present study calculated the calorific content for the two species *C. nodosa* and *P. oceanica*, which showed considerable values in comparison with the previous recorded values of the other seagrass species, common edible algae, some macrophytes and common terrestrial angiosperms (Dawes and Lawrence, 1980; Lawrence et al., 1989; Dawes and Guiry, 1992; Aketa and Kawamura, 2001; Philpott and Bradford, 2006), indicating their essential role in the marine ecosystem for these organisms.

On the other hand, organic fertilizer and/or compost are advantageous over chemical fertilizer because they contain nutrients as well as organic matter, where their presence in the soil is fundamental in maintaining the soil fertility and decreasing nutrient losses (Inckel et al., 2005). The use of mineral fertilizer alone has not been helpful under intensive agriculture because it is often associated with reduced yield, soil acidity and nutrient imbalance (Kang and Juo, 1980). The need to use renewable forms of energy has revived the use of organic fertilizers worldwide (Titilola, 2006). Improvement of environmental conditions and public health as well as the need to reduce costs of fertilizing crops are also important reasons for advocating increased use of organic materials (Hossain and Singh, 2000).

The primary nutrients required by the microorganisms involved in composting are namely the carbon, nitrogen, phosphorus and potassium whose concentrations determine the value of the compost. Excessive or insufficient carbon or nitrogen will affect the process. Carbon provides microorganisms with both energy and growth while nitrogen is essential for protein and reproduction. Thus, the C:N ratio is a useful guide to formulate composting recipes and the rate at which the carbon compounds decompose must also be considered (Cochran and Carney, 1996). However, a C:N ratio of 25:1–30:1 is ideal for active composting, although initial ratios of 20:1 up to 40:1 consistently give good results and in some applications, C:N ratios of 50:1 and higher are acceptable (Cochran and Carney, 1996). However, if the C:N ratio is too low ($<$14:1) the raw material will be rich in nitrogen and the limiting nutrient will be carbon and in this case excess nitrogen may be released as gaseous ammonia, accumulate within the pile in toxic amounts, or leach out of the pile and potentially contaminate ground or surface water. In contrast, high C:N ratios means that carbon is present in excessive amounts relative to nitrogen so that the C:N ratio is above the optimal range, and nitrogen availability is the limiting factor, resulting in longer time for micro-organisms to use the excess carbon (Graves et al., 2000). In order to manage composting process, straw or another additive material may be added to compost resulting in a mix compost, taking into account in such case that the mix of raw materials should have a proper C:N ratio and that the nutrients in this mix should be in available forms (National Engineering Handbook, 2000).

In the present study we investigate the potential use of seagrasses as organic fertilizer and/or compost, based on the percentage of the main constituents (N%, P_2O_5% and K_2O%) (Inckel et al., 2005; Rosen et al., 2008), C:N ratio (Cochran and Carney, 1996), major and trace elements concentrations. The two seagrass species were higher in total nitrogen percentage than the other organic fertilizers except that of blood meal and comparable to almost of them in respect with P_2O_5% and K_2O% (Kang and Juo, 1980). A soil test determines which nutrients are needed and the amount of fertilizer required meeting a nutrient recommendation according to Koenig and Johnson (2011).

The calculated C:N ratio for *C. nodosa* was 1.50:1 and for *Posidonia* 1.25:1, which was lower in comparison with C:N ratio of some other organic materials (Cochran and Carney, 1996). Thus, another additive material rich in carbon such as straw, sawdust or bark should be added to the plant material to increase the C:N ratio at composting, taking also in account oxygen supply, moisture content, temperature, and pH of the compost pile (Cochran and Carney, 1996).

On the other hand, the concentrations of the trace metals in the two seagrass species were much lower than their limiting ranges in composts recently proposed by the European States (Cu: 70 µg/g; Ni: 25 µg/g; Pb: 75 µg/g and Zn: 200 µg/g) (EEC Organic Rule #2092/91 Brussels, 1998), while the concentrations of major elements in the seagrass *C. nodosa* coincided with the typical concentration in composts proposed in Compost Management Program (2012) (Ca: 3000, P: 250 and Na: 1000 mg/100 g). Actually, the concentration of these elements in *P. oceanica* is higher than these permissible concentrations, especially the sodium element which is critical at higher concentration than 1%, where it can damage the root tissue, causing germination and emergence problems for a number of plants. According to all these criteria and guidelines for typical composition of compost, the seagrass *C. nodosa* only can be potentially used like seaweeds as supplementary powdered organic fertilizer and/or additive compost.

Conclusion

The leaves of the two seagrass species *C. nodosa* and *P. oceanica* are a rich source of biochemical components, major and essential trace elements, giving the two seagrasses spp. a great nutritive value for marine organisms and an essential role in marine food chain. In fact, further studies on the other parts of the plant should be taken into consideration to give the chance to benefit from the whole plant. On the other hand, the surrounding environment of the two species growth should be controlled to avoid any pollution effect. Thus, further studies on controlling factors such as light intensity, water turbidity, concentrations of major and minor elements in water, etc.... should be carried out. The usage of the two seagrass species as organic fertilizer and/or compost must be applied under the criteria and guidelines for typical compost. It is noteworthy to investigate the other economic values of these two common species in the Mediterranean Sea. However, further work should be carried out on the usage of *C. nodosa* as additive compost and the species should be experienced in the field on different crops.

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