

Dynamics of carbohydrate translocation between the above- and under-ground organs of *Phragmites australis* (Cav.) Trin. ex Steudel in Lake Burullus, Egypt

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Abstract

The present study aims to test the hypothesis that carbohydrate translocation patterns between the rhizomes and the above-ground organs of *Phragmites australis* (Cav.) Trin. ex Steudel in Lake Burullus (North Egypt) depend not only on the season but also on the site and stand age. Total non-structural carbohydrate (TNC) of above-ground organs and rhizomes of *Phragmites australis* were analyzed along a north-south transect in Lake Burullus at bimonthly intervals from February 2009 to October 2009. Changes in dry weight and TNC per unit area were used to describe the seasonal patterns in growth and translocation as well as the movement of assimilates on an aerial basis. Concentrations of TNC differed between young and old stands ($P < 0.01$) and between plant organs ($P < 0.001$). On the other hand, TNC concentrations were site independent ($P > 0.05$). Significant interactions were detected between the stands age versus plant organ ($P < 0.001$), while those between stand age and plant organ versus site were insignificant ($P > 0.05$). From the present study it can be concluded that, the rhizomes have supplied most of the storage carbohydrate before the leaves are developed, and that the concentration of carbohydrate in the rhizome is low during the period of rapid shoot growth and intensive photosynthesis. When the growth of the shoot is finished, allocation of assimilates to the rhizome starts.

Keywords: carbohydrate, common reed, Lake Burullus, Nile Delta, stand age, wetlands.

1. Introduction

Common reed, *Phragmites australis* (Cav.) Trin. ex Steudel, has been intensively studied for more than four decades and hence its morphological life cycle is now fairly well understood (e.g., Shaltout *et al.* 2006, Asaeda *et al.* 2008, Eid 2009, Eid *et al.* 2010a, b). Quantitative studies that determine material budgets and carbohydrate allocation patterns across the growing season are of crucial importance to understand the life cycle of emergent macrophytes (Westlake 1982, Asaeda & Karunaratne 2000, Asaeda *et al.* 2005a, 2006a). These results can be effectively used in investigation of nutrient and carbon cycling in aquatic ecosystems (Asaeda *et al.* 2000, 2005a, b, Sharma *et al.* 2006, Asaeda & Siong 2008), and the benefits will also provide insight into the management and sequestration of these elements in treatment wetlands (Findlay *et al.* 2003, Asaeda *et al.* 2006b, Eid *et al.* 2010b). Apart from such practical applications, quantitative evaluations of carbohydrate allocation patterns and material budgets are necessary to develop and validate mathematical models that describe the growth and decomposition patterns of such emergent plants

(Asaeda & Karunaratne 2000, Karunaratne & Asaeda 2000, Soetaert *et al.* 2004, Eid *et al.* 2010b).

P. australis is a cosmopolitan angiosperm believed to be one of the most widely distributed species in the world (Holm *et al.* 1977). In Egypt, *P. australis* occurs in all phytogeographical regions (Täckholm 1974, Boulos 2005, Zahran & Willis 2009). It occurs in the main habitats of Lake Burullus such as: salt marshes, sand sheets, lands cut from the lake, terraces, slopes, water edges, open water zones of the drains, lake shores, open water of the lake and islets (Shaltout & Al-Sodany 2008). As a consequence of human alteration (construction of Aswan High Dam, waste water from drains and fish farms which enter Lake Burullus from the south), fertility varies along the north-south direction of Lake Burullus (Eid *et al.* 2010a).

In the present study, two different morphotypes of *P. australis* had been distinguished: more than 10 years old, high reed with thick stems (old stands), and less than one year old, short reed with thin stems (young stands). The main aim was to test the hypothesis that resource translocation patterns between the rhizomes and the above-ground organs depend not only on the season but also on the site and stand age of *P. australis*

in Lake Burullus. The determination of carbohydrate allocation patterns across the growing season are important to understand the life cycle of *P. australis* and are necessary to develop and validate mathematical models that describe the growth and decomposition patterns of *P. australis* in Lake Burullus.

2. Materials and Methods

2.1. Study area

Lake Burullus is located along the Deltaic Mediterranean coast of Egypt with an arid climate characterized by warm summers (20 – 30°C) and mild

winters (10 – 20°C). It has been registered as a site of the Ramsar Convention (Kassas 2002) because of its importance for wintering, foraging, refuge and breeding of the migrant birds; and as a suitable habitat for fish particularly the fry and juveniles (Khalil & El-Dawy 2002). Lake Burullus is located in the northernmost part of the Nile Delta and connects with the Mediterranean Sea through a natural outlet. The lake with an area of 410 km² and an oblong shape is bordered by agricultural lands in the south, while a sand bar separates it from the Mediterranean Sea in the north (Fig. 1). It is characterized as an alkaline, shallow, brackish and polluted lake (Eid 2009, Table 1).

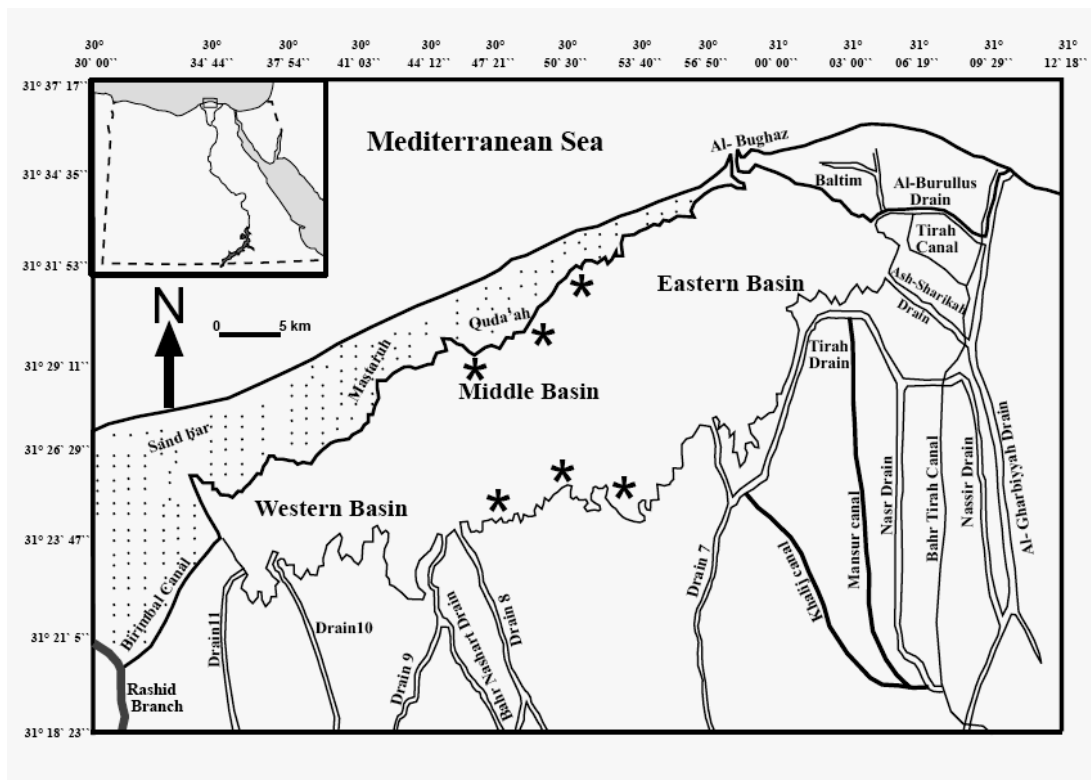


Fig. 1: Map of Lake Burullus indicating the location of the six sampling sites (*).

Table 1: Annual mean ± standard error of the water characteristic of *P. australis* stands in Lake Burullus. F-values represent the one – way ANOVA. * = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant (P > 0.05) (after Eid 2009).

Characteristics	Site		F-value
	North	South	
Water level (cm)	86 ± 4	59 ± 4	23.6***
Transparency (cm)	63 ± 5	56 ± 6	0.9 ^{ns}
pH	8.6 ± 0.05	8.7 ± 0.06	0.7 ^{ns}
Salinity (ppt)	5.3 ± 0.9	5.1 ± 0.7	0.1 ^{ns}
TN	207 ± 21	286 ± 33	4.1*
TP	30 ± 9	106 ± 26	7.7**
Ca	435 ± 19	513 ± 23	6.8*
Mg	157 ± 19	132 ± 17	1.0 ^{ns}
Na	989 ± 101	1151 ± 113	1.2 ^{ns}
K	22 ± 3	26 ± 4	0.8 ^{ns}

2.2. Plant sampling, morphological features and above- and below-ground biomass

Six sites were selected to represent the northern and southern parts of Lake Burullus (Fig. 1). In all the six sampling sites, the above-ground parts of *P. australis* were harvested every two months from February to October 2009 using six randomly distributed quadrates each of 0.5 x 0.5 m to represent the young and old stands. For estimating the above-ground biomass, all *P. australis* shoots within a sample quadrate were cut off at the lake bed; counted and separated into leaves and stems. Rhizomes were excavated from three soil block at each site. Rhizomes were dug out from the sediment surface of 0.5 x 0.5 m down to 0.5 m depth (the deepest point of rhizome penetration) and washed till free from sediment.

In the laboratory, stem height and basal stem diameter (at the first complete internode above the basal cut surface were measured (see Björk 1967) then shoots were cut into 10 cm length and oven-dried to constant weight at 85 °C to give values for dry weight. The average dry weights of the shoots were calculated (g shoot^{-1}) and multiplied by the number of shoots m^{-2} to give the total above-ground biomass (kg DW m^{-2}). Rhizomes biomass was estimated after oven drying the plant material to constant weight at 85°C. Subsequently, material was ground with a Wiley mill into particles less than 0.4 mm for carbohydrate analysis. Total non-structural carbohydrate (TNC) was extracted by diluted sulfuric acid as described by Smith *et al.* (1964) and concentrations were measured by spectrophotometer (CECIL CE 1021) by applying the phenol-sulfuric acid colorimetric method following Graneli *et al.* (1992). The carbohydrate data were subjected to a three-way analysis of variance to test for

differences between sites, stand age and plant organs using Statistica software (Statsoft 2007).

3. Results

Shoot height, diameter, shoot dry weight and above- and below-ground biomass of old stands were significantly higher than young stands, while shoot density of young stands was significantly higher than that of the old stands (Table 2). In addition, shoot height, diameter and shoot dry weight of young and old stands significantly increased from north to south while, shoot density significantly decreased from north to south for both young and old stands. Concentrations of TNC differed between young and old stands ($P < 0.05$) and between plant organs ($P < 0.001$). On the other hand, TNC concentrations were site independent ($P > 0.05$). Significant interactions were detected between age of stand versus plant organ ($P < 0.001$), while those of stand age and plant organ versus site were insignificant ($P > 0.05$).

In February, before the beginning of the vegetative growth, the young and old stands had significantly higher TNC levels in the rhizomes (178 and 188 mg g^{-1} DW). By the end of April, TNC levels of rhizomes dropped to 146 and 164 mg g^{-1} DW for young and old stands (Fig. 2). TNC levels started to increase again in June, reaching 207 mg g^{-1} DW by October for the young stands and 204 mg g^{-1} DW by August for the old stands. The TNC levels of stems showed an increase from February to October for both young and old stands (168 – 201 and 132 – 202 mg g^{-1} DW, respectively). In addition, the TNC levels of leaves showed similar trend for young and old stands (95 – 169 and 113 – 171 mg g^{-1} DW, respectively).

Table 2: Spatial variation and results of two-way ANOVA (F-values) in some morphological and biomass characteristics (mean \pm standard error) of *P. australis* in Lake Burullus. Age: young / old stands, site: north / south sites. * = $P < 0.05$, *** = $P < 0.001$, ns = not significant ($P > 0.05$).

Characteristics	Young stands			Old stands			F-values		
	North	South	Mean	North	South	Mean	Age	Site	Age \times Site
Height (cm)	169 \pm 3	218 \pm 5	189 \pm 3	322 \pm 5	364 \pm 6	343 \pm 4	905.2***	85.6***	0.5 ^{ns}
Diameter (mm)	7 \pm 0.2	9 \pm 0.2	8 \pm 0.1	10 \pm 0.2	13 \pm 0.3	12 \pm 0.2	290.2***	119.4***	2.2 ^{ns}
Density (shoot m^{-2})	171 \pm 6	136 \pm 10	157 \pm 6	147 \pm 7	100 \pm 4	122 \pm 5	19.9***	36.9***	0.8 ^{ns}
Shoot DW (g shoot^{-1})	13 \pm 1	19 \pm 2	16 \pm 1	46 \pm 3	68 \pm 5	58 \pm 3	150.5***	17.2***	5.6*
Above-ground biomass (kg DW m^{-2})	2.2 \pm 0.2	2.3 \pm 0.2	2.3 \pm 0.1	6.3 \pm 0.5	6.1 \pm 0.3	6.2 \pm 0.3	137.6***	0.01 ^{ns}	0.2 ^{ns}
Below-ground biomass (kg DW m^{-2})	0.8 \pm 0.1	0.8 \pm 0.1	0.8 \pm 0.1	2.0 \pm 0.2	1.9 \pm 0.1	2.0 \pm 0.2	19.0***	0.6 ^{ns}	0.9 ^{ns}

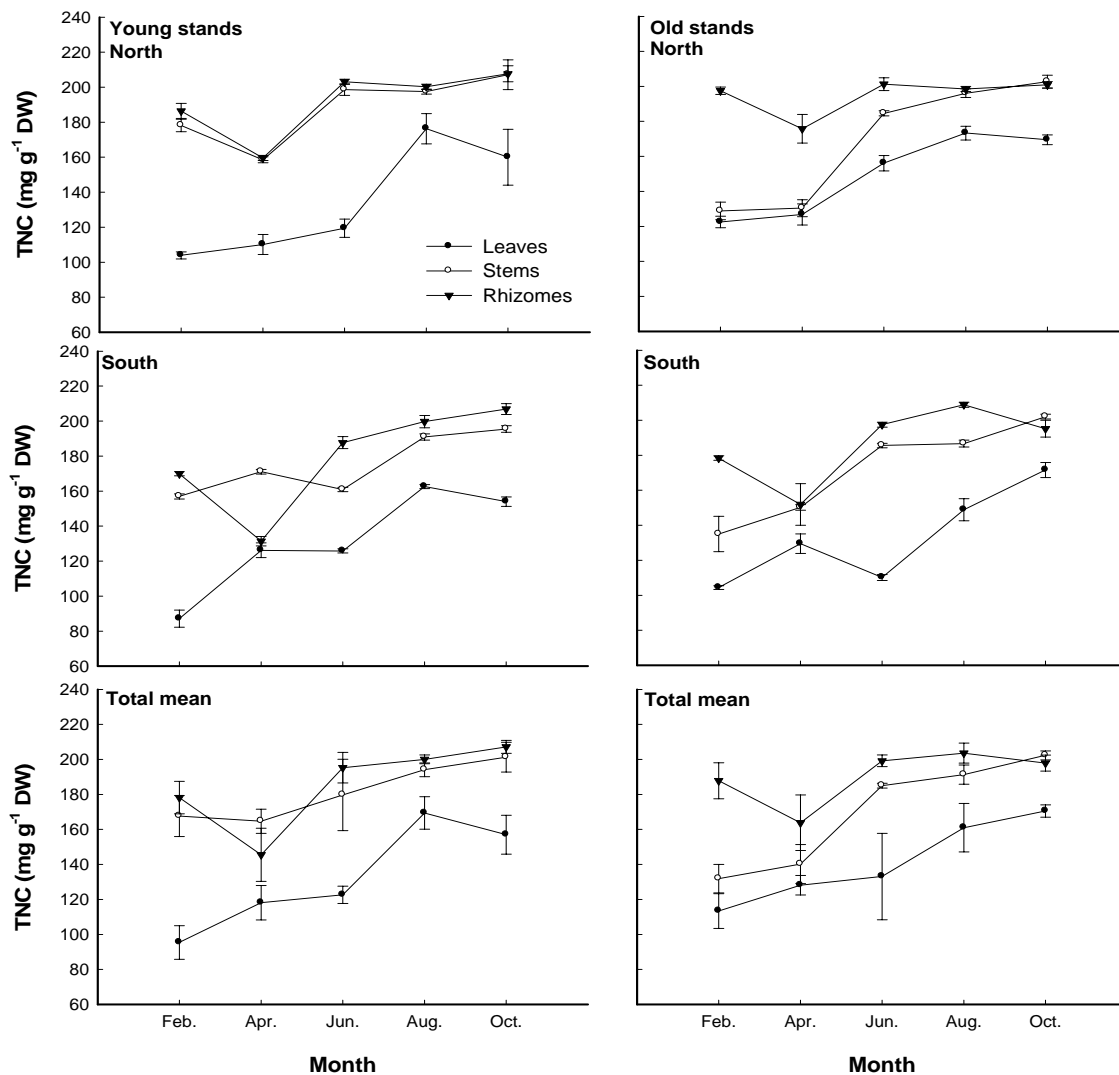


Figure 2: Levels of total non-structural carbohydrates (TNC) (mg g^{-1} DW) of *P. australis* leaves, stems and rhizomes in Lake Burullus from February to October 2009. The vertical bars indicate the standard errors of the means.

4. Discussion

Though the importance of carbohydrate reserves for wetland plant survival has been generally accepted, only few studies bring original data on the seasonal dynamics of reserve carbohydrate in natural reed stands (Granéli *et al.* 1992, Cizkova *et al.* 1996, Cizkova *et al.* 2001). In the present study, two different morphotypes of *P. australis* (young and old stands) were distinguished. It was found that these stand morphotypes differed in all measured morphometric and biomass variables, comparable results was reported by Eid (2009) and Eid *et al.* 2010a. Similar result was also reported for the two different *P. australis*

population types in the Danube Delta (Hanganu *et al.* 1999).

During the outgrowth phase from February to April, the mean rhizome content of TNC decreased with the lowest levels for young and old stands and from June onward the amounts of TNC showed an increase. For leaves and stem, contents of TNC showed an increase from February to October for both young and old stands. Different high rhizome TNC resources were utilized to support spring shoot growth. The rhizomes were reloaded again during summer and autumn through basipetal transport of resources. These staves are needed to ensure establishment of spring shoots the next year (Koppitz 2004). In the present study, the concentrations of TNC differed between plant organs. These differences were probably related to extensive

parenchymatous tissue in stem and rhizome. In addition, rhizome TNC levels drop in October for old stands which can probably be attributed to a coincident growth of new roots, rhizomes and overwintering buds (Cizkova *et al.* 1996). According to Fiala (1976), roots grow intensely in early spring and again in autumn. This growth probably draws on the reserves accumulated in rhizomes.

The seasonal course of TNC concentration in the present study corresponds with the pattern reported by Graneli *et al.* (1992), Guthruf *et al.* (1993) and Cizkova *et al.* (2001). However, when the absolute maximum values of the carbohydrate concentrations in the reed stands of the present study are compared with those of the European reed stands, the Lake Burullus reed stands seem to be among stands with lower values known to date. These are based on the studies of Graneli *et al.* (1992) in Sweden, Guthruf *et al.* (1993) in Swiss, Cizkova *et al.* (1996) in Czech, Kubin & Melzer (1996) in Germany and Cizkova *et al.* (2001) in Hungary. This pattern may be a strategy of *P. australis* to store more assimilates in below-ground rhizomes in the temperate zone compared with the south Mediterranean zone, where photosynthesis is not a limiting factor for biomass production due to high radiation and a longer growth period (Eid *et al.* 2010b).

The comparison of the seasonal decrease in TNC standing stock (217 – 487 and 75 – 230 g TNC m⁻²) with the seasonal maximum TNC standing stock (487 and 230 g TNC.m⁻², respectively) indicates that the carbohydrate pool is depleted by 56 and 68% (as related to the seasonal maximum values for old and young stands). The carbohydrate depleted to a greater degree at Lake Burullus than at most the other European sites e.g., 33% in Sweden (Graneli *et al.* 1992); 30 - 50% in Swiss (Cizkova *et al.* 2001). On the other hand, results of the present study are comparable to those of Cizkova *et al.* (2001) in Hungarian lakes (60 – 80%). The fact that the TNC standing stock was depleted by 56 – 68% at Lake Burullus sites implies that 44 – 32% of the TNC standing stock remain available for possible recovery from a subsequent catastrophic event. Assuming that the same amount is needed for the recovery as was used for spring re-growth, the minimum TNC standing stock would not suffice to support full recovery sites of Lake Burullus. This indicates that the reed stands may be more vulnerable to shoot damage or removal as compared with the reed stands with higher carbohydrate reserves (Cizkova *et al.* 2001).

From the present study it can be concluded that, the rhizomes have supplied most of the storage carbohydrate before the leaves are developed, and that the concentration of carbohydrate in the rhizome is low during the period of rapid shoot growth and intensive photosynthesis. When the growth of the shoot is finished, allocation of assimilates to the rhizome starts. The carbohydrate translocation patterns between rhizomes and the above-ground organs of *P. australis*

depend not only on the season but also on the stand age, while they are site independent.

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ديناميكية انتقال الكربوهيدرات بين الأعضاء فوق و تحت سطح التربة لنبات البوص في بحيرة البرلس (مصر)

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تهدف الدراسة الحالية إلى اختبار فرضية أن انتقال الكربوهيدرات بين الريزومات و أعضاء نبات البوص فوق سطح التربة في بحيرة البرلس (شمال مصر) لا تعتمد فقط على الموسمية، بل أيضا على الموقع و عمر النبات. تم تقدير الكربوهيدرات الكلية في أعضاء نبات البوص فوق و تحت سطح التربة على طول المحور الشمالي، الجنوبي لبحيرة البرلس كل شهرين في الفترة من فبراير حتى أكتوبر 2009. كما تم استخدام التغير في الوزن الجاف للنبات وكمية الكربوهيدرات الكلية في وحدة المساحة لتحديد التغيرات الموسمية في النمو و ديناميكية انتقال الكربوهيدرات. أوضحت الدراسة الحالية أن هناك فروق معنوية في كمية الكربوهيدرات بين أفراد نبات البوص الصغيرة والكبيرة وكذلك بين أعضاء النبات المختلفة، في حين أن الفروق كانت غير معنوية بين أفراد المواقع الشمالية والجنوبية للبحيرة. كما أوضحت الدراسة أيضا أنه في بداية موسم النمو، وقبل تكوين الأوراق، يحدث انتقال للمواد الكربوهيدراتية المخزنة من الريزومات إلي أجزاء النبات المختلفة فوق سطح التربة، في حين أنه عند انتهاء موسم نمو النبات يحدث انتقال عكسي للمواد الكربوهيدراتية المخزنة في الأعضاء فوق سطح التربة لتخزن في الريزومات.