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Ecology and biomass production of *Cyperus papyrus* L. on the Nile bank at Damietta, Egypt

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Abstract

An ecological study was carried out to throw light on the associated flora, population parameters (mean height, density, number of sprouts, number of flowering culms/m^2) of *Cyperus papyrus* L in natural and managed stands. Results indicated that papyrus showed a gaint growth form with an average height up to 4 m in June and August in both natural and managed stands, respectively. The peak of density of the plant was recorded in April and June with a gradual decrease during autumn and winter.
The pH of the water where papyrus grows varied from 6.2 to 7.6 with a mean value of 7.5 and from 6.4 to 7.8 with a mean value of 7.3 for both natural and managed stands, respectively. Conductivity of water ranged from 340 to 480 µS/cm with a mean value of 398 µS/cm for the natural stand and from 280 to 520 µS/cm with a mean value of 475 µS/cm for the managed one.
The soil of papyrus is rich in nutrients in particular total phosphorus and nitrogen. Total-P varied from 1.3 to 8.5 mg/100 g dry soil with a mean value of 5.7 mg/100 g dry soil for the natural stand. For the managed stand the total-P ranged from 3.5 to 8.9 mg/100 g dry soil with mean value of 6.3 mg/100 g dry soil. The hydrosoil support the growth of papyrus contained total-N ranged from 5.2 to 9.5 mg/100 g dry soil and 3.7 to 9.9 mg/100 g dry soil with a mean value of 7.6 mg/100 g dry soil for both natural and managed stands, respectively.
The maximum of about 30 kg/m^2 fresh biomass was recorded in June for the above-ground parts for the natural and managed stands. The biomass of papyrus gradually decreased and the minimum values were obtained in winter. During late autumn and winter the aerial culms of the sedge die and fall off. During December, in both studied stands, below-ground-biomass exhibited an opposite trend than the above-ground culms. The peak of biomass was obtained in June for above-ground parts, however the peak was obtained for below-ground parts in December.

Introduction

Cyperus papyrus L. is one of the largest emergent aquatic sedges found growing in both lentic and lotic environments (Kaggwa *et al*., 2001). It was the symbol of lower ancient Egypt (Sculthorpe, 1967). The importance of this plant to the ancient cultures is demonstrated in the paintings and carvings on ancient Egyptian tombs (Tackholm, 1976; Rzoska, 1976). Papyrus has become almost extinct from Egypt more than 150 years earlier. The last traveler to notice papyrus was Baroness V. Minutoli who recorded it at Damietta and the shore of Lake Manzala during 1820-1821 (Tackholm, and Drar, 1950). On July 1968, El-Hadidi (1971) discovered a stand of 20 plants of *Cyperus papyrus* L. growing among other reeds close to Umm Risha Lake, Wadi El- Natrun Depression, it was identified as *C. papyrus* subsp. *antiquorum*. At that time, it was believed to be the only known locality in Egypt and eventually in North Africa. In 1872, twelve *Cyperus papyrus* L. specimens were brought to Egypt from Luxembourg, Paris and planted at gardens in Cairo (Tackholm & Drar, (1950). In 1969, the engineer and doplimate Hassan Ragab decided to revive the art and industry of making papyrus. He imported plants from Sudan and Ethiopia and by 1973 had developed four large papyrus plantations along the banks of the Nile and nearby canals. An agroindustrial study was made to use papyrus for paper prodction and product for tourists (Ragab, 1978; 1979). In July 2000, the author discovered a flourished *C. papyrus* L. stand at Sharabas, on the bank of Damietta Nile branch, 24 km south of Damietta (Serag, 2000).

However, *Cyperus papyrus* L. is almost extinct from Egypt. It forms vast stands in swamps in shallow lakes and along stream banks throughout Africa. Many African swamps known as the Sudd in Central Africa are dominated by papyrus thickets, which totally block navigation. It is considered a weed in the Sudan, Ethiopia and Uganda. It has been also recorded in Sicily, Syria and Palestine. *Cyperus papyrus* L. was first introduced to Sicily and a historical study has been carried out, based on documentary material available, to throw light on its origin and particularly of the papyrus of the River Caine (Basile, 1994; Basile and Di Natale, 1997). The plant was introduced to Syria and Palestine (*C. papyrus* subsp. *palaestina*) where many tropical swamp plants, among them papyrus reach their northern limit of distribution in the swamps of the Upper Jordan Valley (Huleh Plain), in spite of the fact that similar conditions are available further north (Zohary, 1962). In North America, the Praire Pothole region includes several millions of freshwater marshes, some of are dominated by papyrus (Dugan, 1993).

At present an attention has been directed towards the capacity of papyrus to control water pollution and to treat wastewater (Abe *et al.*, 1997; Abe & Ozaki, 1998; Mizuta *et al.*, 1998; Okurut *et al.*, 1999; Azza *et al.*, 2000; Kansiime & van Bruggen, 2001). In Uganda, Denny *et. al.* (1995) proved that papyrus is useful in preventing the heavy metal pollution to reach the Lake George. Thus, in turn it prevents the accumulation of heavy metals in the biota through the food web.

Understanding the ecology and biomass yield of *Cyperus papyrus* under the Egyptian conditions is a prerequisite for using this important sedge for paper production and wastewater treatment and pollution control. Therefore, the objective of the present paper is to describe the ecological relations and evaluate the biomass of papyrus in the Nile delta, Egypt.

Materials and Methods

Study sites

The study was conducted in two stands dominated by *Cyperus papyrus*, in the Nile Delta (Fig. 1). The first one is a natural rediscovered wild growth on the eastern bank of the Damietta Nile branch at Sharabas village, Damietta Governate, Egypt by the author on July, 2000. The second stand is located at Kafr El-Batikh, Damietta Governate, is a managed stand cultivated by rootstocks of papyrus collected from the natural stand at the bank of the Nile.

The climate of Damietta is typically Mediterranean and belongs to the arid province characterized by a short dry period. The mean annual rainfall was 102.3 mm compared to 66.3 mm at Port Said. The mean evaporation rate varies between 2.6 mm/day and 8.1 mm/day. Air temperature varies from a minimum of 13.3 °C to a maximum of 27.4 °C, with warm summers (27-31 °C) and mild winters (8.2-24 °C). Relative humidity varies from a minimum of 69% during summer to a maximum of 84% during winter (Serag, 1991).

Floristic Composition

The associated wild flora with *Cyperus papyrus* was collected and voucher specimens were prepared and are kept in the Herbarium of the Department of Botany, Faculty of Science at Damietta. A duplicate series is also kept in Cairo University Herbarium. Plant names reported here are according to Tackholm (1974) and Boulos (1995, 2000).

Population Parameters

Plant height (vertically from the substrate to the tallest parts of the plant) were also recorded. Number of sprouts and the flowering culms were also counted in each quadrat for both the natural and managed stands. The density of plants was determined by counting the number of culms using a quadtrat (1m^2 in area). Cover values were recorded by visual estimates and are expressed as percentages (Greig-Smith, 1964).

Cultivation of Papyrus at the managed stand

On March 2001, rootstocks of *Cyperus papyrus* were collected from its the natural stand, soil from the bank of the Nile was used for the transplantation experiment at the managed stand (10x10 m in area). Irrigation was made to keep the stand completely flooded to about 25 cm water depth using water from El-Balmoon irrigation canal, it is principally from the Nile water. The procedures of harvesting were applied as in the field trial of the natural stand.

Soiland and water analyses

Twenty four composite soil samples were collected from the rhizoshere of papyrus from both natural and managed stands (12 samples from each stand). Soil texture was determined by sieve method (Jackson, 1962), the mud soil samples were analyzed using the hydrometer method (Palmer & Troeh, 1995). The pH of the soil was determined using a digital pH-meter Model 6209. Conductivity (µS/cm.) was measured at 20 °C using a digital conductivity meter YSI Model 35. Oxidizable organic carbon was determined using Walkely and Black rapid titration method (Black ,1979) whereas, calcium carbonate was determined by titration against hydrochloric acid (Jackson, 1962). Total nitrogen of the soil was estimated using the persulphate method by semi- automatic Kjeldhal Model Pro-NitroI and the absorbance was measured using Spectrophotometer Model 340 (Adams, 1990). Total phosphorus of the soil was estimated using the ignition method applied by Andresen (1976). The samples were diluted and analyzed according to Murphey & Riley (1962). Cations (Na^+, K^+, Ca^{++} and Mg^{++}) were extracted using ammonium acetate at pH 7 and estimated using an Eppendorf Flame Photometer Model PFP7 (Na^+ and K^+) . Ca^{++} and Mg^{++} were estimated using an Atomic Absorption Perkin-Elmer Model 560 (Allen, 1989).

Samples of water were collected from the two stands (natural & managed) dominated by *Cyperus papyrus* from the surface (0-25 cm). Dissolved oxygen was determined using

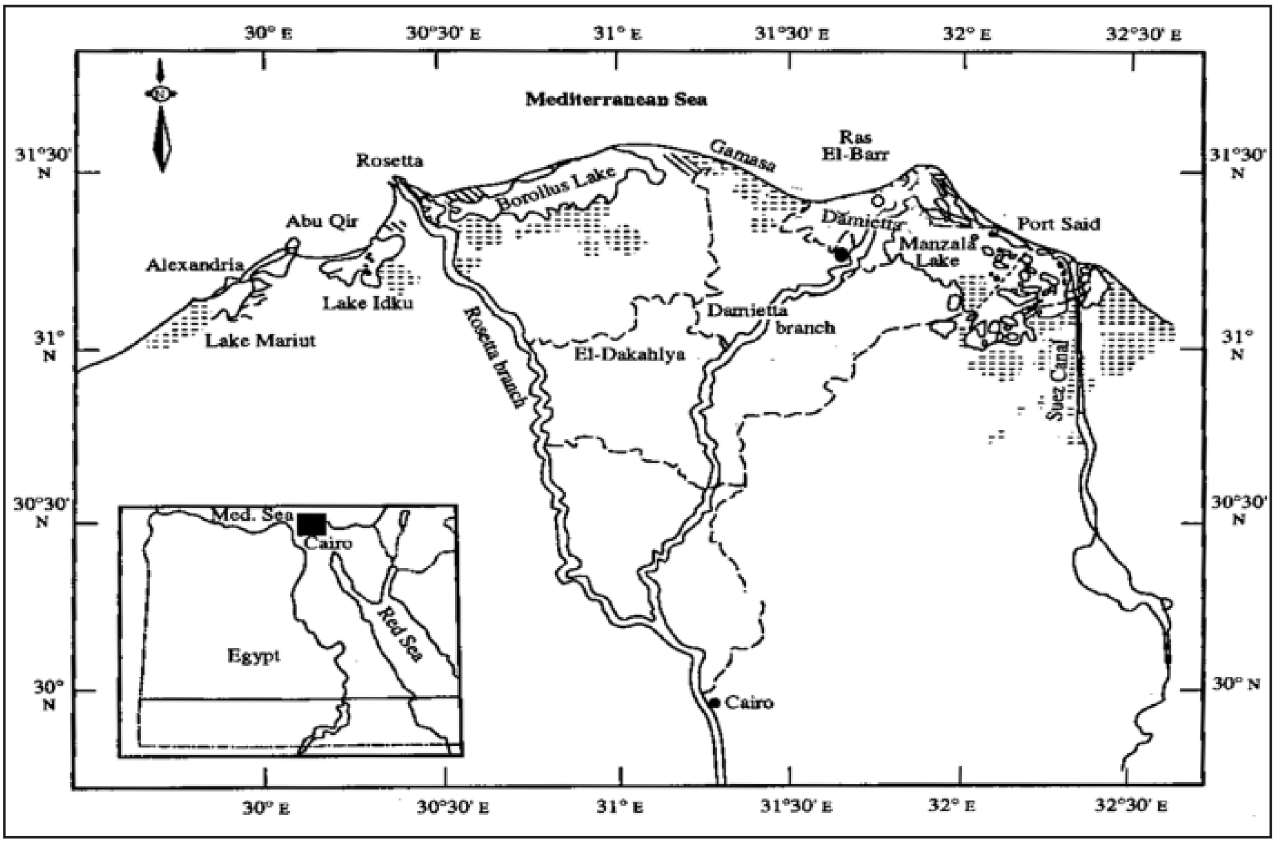

Figure 1 - Location map showing the natural stand (•) of papyrus at Shrabas, the bank of the Nile and the managed stand (o) at Kafr El-Batikh, Nile Delta.

Table 1. The most common associated plant species with *Cyperus papyrus* at the rediscovered stand at the bank of the Nile at Shrabas, Nile delta. Ann: annual, Per: perennial, He: helophytes, Hy: hydrophytes, G: geophytes, Th: therophytes, L: Lianas.

Species	Family	Life form	% of Cover
Zone I: Bank of the Nile:			
Chenopodium murale L. (Ann)	Chenopodiaceae	Th	8
Convolvulus arvensis L. (Per)	Convolvulaceae	L	5
Cyperus rotundus L. (Per)	Cyperaceae	G	10
Imperata cylindrica L. Raeusch. (Per)	Gramineae	G	60
Malva parviflora L. (Ann)	Malvaceae	Th	12
Portulaca oleraceae L. (Ann)	Portulacaceae	Th	5
Zone II: Edge of the Stand:			
Cyperus alopecuroides Rottb.(Per)	Cyperaceae	He	15
Echinochloa stagnina (Retz.) P. Beauv. (Per)	Gramineae	G,He	10
Perscaria tomentosa Willd (Per)	Polygonaceae	G, He	25
Phragmites australis (Cav.) Trin. Ex. Steud (Per)	Gramineae	G, He	5
Saccharum spontaneum (L.) (Per)	Gramineae	G, He	25
Typha domingensis (Pers.) Poir. ex. Steud. (Per)	Typhaceae	He	7
Zone III: Inland Open Water:			
Ceratophyllum demersum (L.) (Per)	Ceratophyllaceae	Hy	5
Eichhornia crassipes (C. Mart) Solms (Per)	Pontederiaceae	Hy	15
Myriophyllum spicatum (L.) (Per)	Haloragidaceae	Hy	5

the modified Winkler method (Wood, 1975). Ammonia-N is measured using the distillation Kjeldahl method. Photometric readings were measured at wavelengths of 430 nm. (Dewis & Freitas, 1970). The method applied by Taras (1950) was used in the determination of nitrate-N while, nitrite-N was measured according to Barnes & Folkard (1951). Readings of the digital spectrophotometer were made at wavelengths of 540 nm. for both nitrate and nitrite-N.

Biomass determination

Biomass of papyrus was determined by harvesting three quadrats (0.5 m x 0.5 m) each two months interval during April to December 2001. Culms were cut level with the sediment and below-ground parts was harvested from the entire 0.5x0.5m quadrat. This quadrat was dug to about one meter down and care was taken to collect all rhizomes (vertical and horizontal) and roots. Rhizomes with their attached roots were washed by continuous water and then air-dried. Fresh weight was determined for the harvested materials (both above- and below-ground parts) separately then were oven dried to a constant weight at 80 °C and dry weight was determined.

Results

Floristic composition

Table 1. shows the most common species recorded in the stand at Sharabas. Three major zones are described as follows:

ZONE I: The bank of the Nile

The most common species growing in this zone are: *Imperata cylindrica* (60% cover), *Malva parviflora* (12% cover), *Cyperus rotundus* (10% cover), *Chenopodium murale* (8% cover), *Convolvulus arvensis* (5% cover) and *Portulaca oleraceae* (5% cover).

ZONE II: Edge of the stand

On the borders of the stand, some helophytes and geophytes were recorded such as: *Persicaria tomentosa* Willd. (35% cover), *Saccharum spontaneum* v. *aegyptium* (25% cover), *Echinochloa stagnina* (10% cover), *Cyperus alopecuroides* (15% cover), *Phragmites australis* (8% cover) and *Typha domingensis* (7% cover).

ZONE III: Inland open water

Sparse mats of *Eichhornia crassipes* cover the open water (60% cover). These mats are drifted due to fishing activities in the area. The most common associated species include: *Ceratophyllum demersum* (20% cover) and *Myriophyllum spicatum* (new invader to the area) (20% cover).

Population parameters

The population paramters such as the average height (cm), density, number of sprouts/m² and number of flowering culms/ m² are presented (Fig.2). The sedge showed vigorous growth with an average height up to 4 m in June and August in both natural and managed stands. The minimum mean height up to 1m was obtained in December. The peak of density of papyrus was recorded in April and June and gradual decrease during autumn and winter.

It was interesting to note that papyrus plants produce new sprouts all year round (see Fig.2). The maximum number of sprouts/m² equal 60 sprouts was obtained in April for the managed stand. Lower number of sprouts 40 /m² was recorded for the natural stand. During the other seasons the number not exceed than 20 sprouts/m². These results may be useful for the transplantation of papyrus vegetatively by using rootstocks under the Egyptian con-

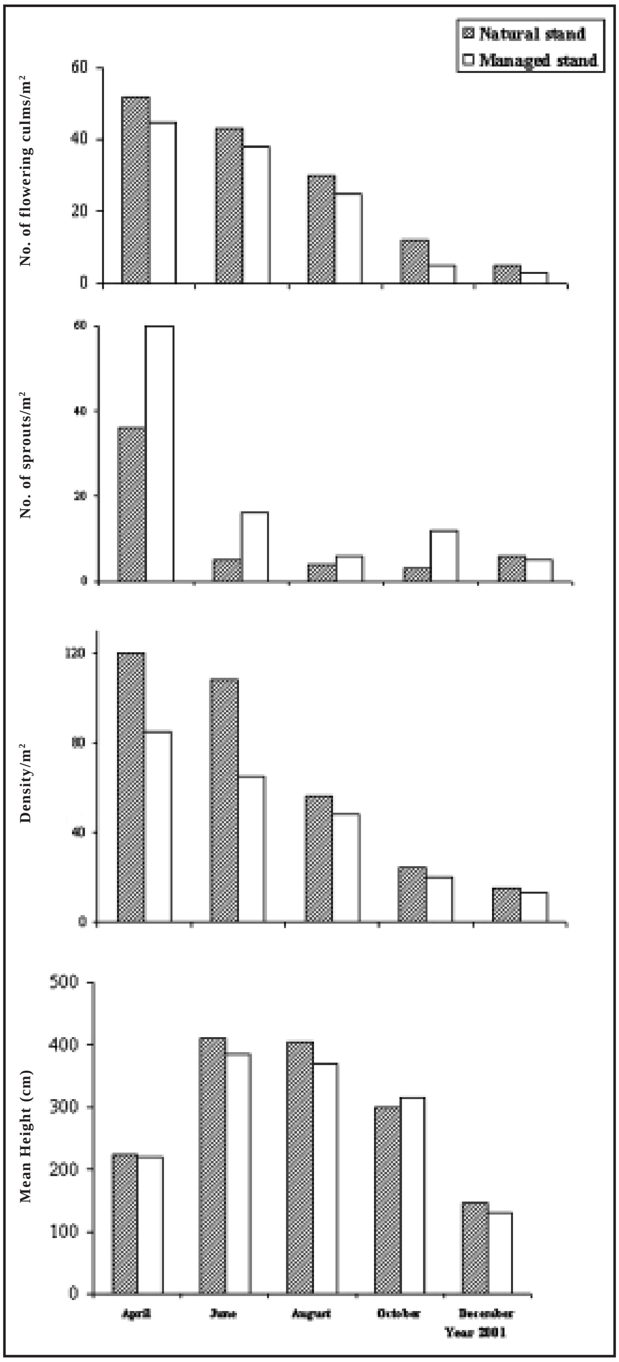

Figure 2 - Monthly variations in mean height (cm), density, number of sprouts/m² and number of flowering cilms/m² of Cyperus papyrus for both natural and managed stands

ditions. Results indicated that the optimum period for the successful transplantation is March-April.

Field observations indicated that papyrus is flowering all year round with the peak of flowering during spring and summer. A gradual decrease in the number of flowering culms was obtained during autumn and winter (Fig.2).

Water properties

Table 2 shows the chemical properties of the water samples collected from the natural and the managed stands of papyrus in the Nile delta. The pH of the water varied from 6.2 to 7.6 with a mean value of 7.5 and from 6.4 to 7.8 with a mean value of 7.3 for both natural and managed stands, respectively. Conductivity of water ranged from 340 to 480 µS/cm with a mean value of 398 µS/cm for the natural stand in the Nile. A range from 280 to 520 µS/cm with a mean value of 475 µS/cm for the managed stand. Dissolved oxygen varied from 5.8 to 9.0 mg/l (mean equal to 8.2 mg/l) for water samples collected from the natural stand. Dissolved oxygen of the managed stand varied from 4.3 to 7.6 mg/l with a mean value equal to 6.9. Low concentrations of nutrients e.g. NO_2-N, NO_3-N, NH_4-N and PO_4-P were obtained in the water samples collected from both natural and managed stands (see Table 2). Total-N varied from o.3 to 7.1 mg/l with a mean value of 1.99 mg/l and from 0.08 to 2.3 mg/l with a mean value equal to 1.48 for the water samples collected from the natural and managed stands, respectively. Total-P ranged from 0.08 to 0.3 mg/l with a mean value of 1.99 for the natural stand and from 0.06 to 0.5 mg/l with a mean equal to 0.18 mg/l for water samples were collected from the managed stand. The concentration of K^+ in the water of the natural stand in the Nile ranged from 7.0 to 15.5 mg/l (mean value equal 8.7). In the managed stand, K in the water samples varied from 1.3 to 30 mg/l with a mean equal to 27 mg/l. The Concentration of Na^+ was slightly higher than K^+, it ranged from 23.6 to 59.0 mg/l with a

Table 2. Chemical analyses of water and hydrosoil samples are collected from both natural and managed stands of Cyperus papyrus in the Nile delta, Egypt.

Paramter		Natural stand			Managed stand	
	Range	Mean	SD ±	Range	Mean	SD ±
A. Water:						
PH	6.2-7.6	7.5	0.46	6.4-7.8	7.3	0.36
(EC (µS/cm	340-480	398	51.1	280-520	475	69.7
(DO (mg/l	5.8-9	8.2	1.73	4.3-7.6	6.9	0.78
NO_2-N (µg/l)	0.5-7.0	3.92	2.51	0.3-6.0	3.6	2.71
NO_3-N (µg/l)	400-727	444	56.2	369-657	436	46.3
NH4- N (µg/l)	253-680	458	69.9	249-670	453	57.8
PO_4-P (µg/l)	20-30.7	24.9	5.19	19-31.2	26.1	6.01
Total - P (mg/l)	0.08-0.3	0.1	0.01	0.06-0.5	0.18	0.02
Total - N (mg/l)	0.3-7.1	1.99	3	0.08-2.3	1.48	0.06
	7.0-15.5	8.7	1.5	1.3-30	27	8.1
	23.6-59.0	55	16.1	21.2-40	35.1	19.8
	15.2-56	40	36.2	31.6-50	45.1	20.2
	13.1-25	18	6.2	12.0-36.0	23.5	7.4
B. Hydrosoil:						
Fine fractions %	16.3-20.3	18.3	1.41	8.3-20.3	13.9	4.55
Coarse fractions %	83.7-97.7	81.7	1.41	79.7-91.7	86	4.52
PH	6.8-7.5	7.03	0.29	6.6-7.0	6.9	0.16
(EC (mS/cm	404-550	547	21.2	280-600	458	14.3
$CaCO_3$ %	0.5-3.0	1.6	1.14	2.0-2.5	2.3	0.27
OC %	3.8-4.5	3.9	0.3	3.5-3.8	3.6	0.13
Chlorides %	0.03-0.10	0.05	0.03	0.02-0.12	0.05	0.04
Total-phosphorus (mg/l)	1.3-8.5	5.7	3.7	3.5-8.9	6.27	2.52
Total-nitrogen (mg/l)	5.2-9.5	7.2	1.62	3.7-9.9	7.6	2.36
K^+ (mg/l)	1.2-7.3	4.2	2.98	1.02-2.32	1.91	0.53
Na^+ (mg/l)	1.7-8.7	3.7	2.83	1.16-5.8	3.43	1.76
Ca^{++} (mg/l)	1.7-7.7	4.2	2.21	0.50-3.8	2.32	1.33
Mg^{++} (mg/l)	1.5-2.63	2.01	0.53	1.10-6.9	2.68	2.45

mean equal to 55 mg/l and from 21.2 to 40 mg/l with a mean equal to 35.1 mg/l for the water of both natural and managed stands, respectively (see Table 2).

Hydrosoil properties

The physical and chemical characteristics of the hydrosoil samples collected from both the natural and managed stands are presented (Table 2). Fine fractions (size of particles less than 0.02 mm) varied from 16.3 to 20.3 % with a mean value of 18.3 for the soil of the natural stand at the Nile. A range of 8.3-20.3 % with a mean value of 13.9 %. Coarse fractions (size of particles from 0.02 to 2 mm) ranged from 83.7 to 97.7 % with a mean value of 81.7% for the soil collected from the natural stand. These fractions varied from 79.7 to 91.7 % with a mean value of 86 % for the hydrosoil was collected from the managed stand. The pH of the soil varied from 6.8 to 7.5 with a mean value of 7.03 for the soil of the natural stand. For the managed stand the pH ranged from 6.6 to 7.0 with a mean value of 6.9. The soil conductivity of both the natural and the managed stands is relatively low, it varied from 404 to 550 µS/cm and from 280 to 600 µS/cm for the hydrosoil of these stands, respectively (Table 2).

The hydrosoil of the rhizoshere of papyrus containing relatively low amount of calcium carbonate but is rich in organic matter. This might be due to the death and decay of old culms of papyrus. Culms grow about three months and after that complete death of culms was observed in the field and also in the managed stand. This may be correlated with the fact that papyrus grows at different stages of growth. At the same stand different ages of culms with different heights were determined. Chlorides in the hydrosoil of both natural and managed stands are relatively low, they varied from 0.03 to 0.1% with a mean value of 0.05% for the natural stand. A range from 0.02 to 0.12% (mean value= 0.05%) was obtained for the managed stand.

The soil of papyrus is rich in nutrients in particular total phosphorus and nitrogen. Total-P varied from 1.3 to 8.5 mg/100 g dry soil with a mean value of 5.7 mg/100 g dry soil for the natural stand. For the managed stand, total-P varied from 3.5 to 8.9 mg/100 g dry soil with mean value of 6.3 mg/100 g dry soil. The hydrosoil support the growth of papyrus contained total-N ranged from 5.2 to 9.5 mg/100 g dry soil and 3.7 to 9.9 mg/100 g dry soil with a mean value of 7.6 mg/100 g dry soil for both natural and managed stands, respectively.

Monovalent (K^+ & Na^+), and bivalent (Ca^{++} & Mg^{++}) showed low values for both studied stands (see Table 2).

Biomass production

Figure 3. shows the monthly variations in above- and below-ground biomass (on fresh &dry weight bases) for papyrus in the studied natural and managed stands. The maximum of about 30 kg/m^2 fresh biomass was recorded in June for the above-ground parts for the natural and managed stands. The biomass gradually decreased and the minimum values were obtained in winter. During late autumn and winter the aerial culms of the sedge die and fall off. The fresh biomass dropped up to a minimum value of 10.1 kg/m^2 in January. Generally, the managed stand produced lower biomass than the natural wild population in the Nile. During December, in both studied stands, below-ground-biomass exhibited an opposite trend than the above-ground culms. The peak of biomass was obtained in June for above-ground parts, however the peak was obtained for below-ground parts in December. (see Fig.3).

Discussion

In Africa although much of its lands are arid, it supports vast areas of freshwater swamps. A large area of these permanent swamps in Africa consists of monospecific stands of papyrus (*Cyperus papyrus* L.). The most extensive papyrus swamps are found around the perimeter of Lake Victoria, in Uganda and Sudan associated with the river Nile basin. In Uganda, the largest papyrus swamps are recorded in the littoral zone of Lake Albert, George, Kioga and Victoria as well as other small lakes (Beadle, 1981). The Bulk of permanent swamps along the Nile lies within the Sudd region of Sudan (Migahed, 1948, Rzo Nska, 1974). In Kenya and Tanzania, lake, river and valley swamps are common and pure populations of papyrus are recorded (Muthuri *et al.*, 1989). Large swamps also occur in Zaire where papyrus swamps are best developed in the Upemba region (Thompson *et al.*, 1979). Many tropical hydrophytes from which papyrus reach their northern limit of distribution in Palestine, where they form isolated outposts widely separated from their main area (Zohary, 1962). Papyrus does not grow in Europe except for the valley of the Anapo (Basile, 1994). The botanical site of the Ciane is today certainly the most extensive colony of papyrus in all Europe, of great naturalistic and historical interest.

In Egypt, the disappearance of papyrus may be due to extended cultivation and perennial irrigation of the Nile banks, and may be also due to the fact that papyrus is no longer needed for paper manufacturing. The physical conditions of the river Nile in particular the periodical rise and fall of its water, not enabling it to hold its ground without human intervention (Tackholm & Drar, 1950). During this study, it was noted that the harvesting for biomass determination activate the growth of the sedge. This may be one of the reasons explain why papyrus disappeared and extinct from Egypt where papyrus is neglected and autotoxicity was occurred. Reports of autotoxicity in aquatic systems have been cited for *Cyperus* (Elakovich & Wooten, 1995). Such reports are important because many of these higher aquatic plants are clonal in nature and rely heavily upon vegetative growth for maintaining large populations (Eriksson, 1997).

The habitat conditions at Sharabas site on the eastern bank of the Damietta Branch of The Nile at Damietta were favourable for the flourishing of papyrus. The substratum is easily penetrable, water supply is adequate and stagnant, light is intense, and air is humid. Furthermore, the presence of rich nutrients is plentiful and flourishing for papyrus. Field study indicated that the plant forms a dense mass of clumps. The aerial branches are at different stages of development. Old branches dry out continually and are replaced by new sprouts. The rhizomes of papyrus are layered and the uppermost layer is the latest formed, and bears the green culms. The lower rhizome layers bear

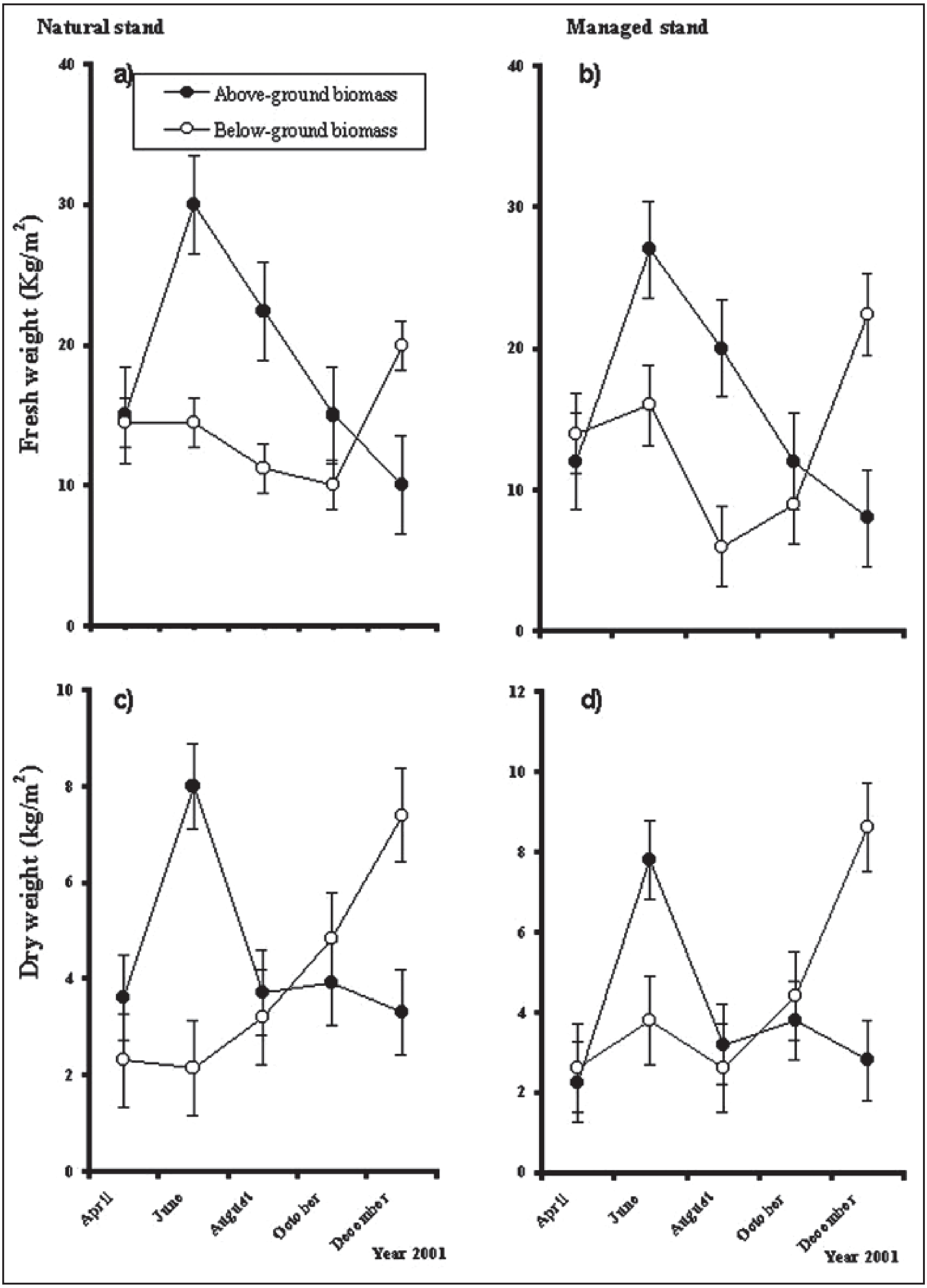

Figure 3 - Monthly variations in Cyperus papyrus biomass for both natural and managed stand, above-ground (solid circles), below-ground (open circles), a,b=fresh weight (Kg/m^2), c,d=dry weight (Kg/m^2)

remnants of dry branches and are at different stages of decay. The rhizome mass is rising to a height of one meter above the level of the substratum. Field observations indicated that C. *papyrus* cleared that the optimum conditions for the papyrus growth is the presence of adequate fresh water current, and continuous flooding of the root system. These field observation was supported with the early mentioned by Tackholm & Drar (1950) about the reasons for papyrus extinction from Egypt they mentioned that the complete disappearance of certain branches of the Nile in the Delta by the silting process within the Christian and early Islamic periods, while the Nile changed its course and subsequent drying of the older channels, marshes and pools which were immediately fed by the Nile flood. The resulted stagnant water soon become of marked salinity and subsequently papyrus become extinct. *C. Papyrus* is a sensitive plant to biotic factors (Serag, 2000), the dominance of *Phragmites australis* (Cav.) Trin. Ex. Steud. and *Typha domingensis* Pers., *Saccharum spontaneum* L. v. *aegyptacum* (Willd.) Hack. and *Vossia cusipdata* Griff. may explain the role of these plants to grow and stress papyrus. Grasses like *Saccharum spontaneum* L. v. *aegyptacum* (Willd.) Hack., *Vossia cusipdata* Griff. and *Phragmites australis* (Cav.) Trin. Ex. Steud. have much more flexible rhizomes than papyrus, and can thus better withstand high current velocities and wave action. Migahid (1952) also referred to this interaction between flow-rate and swamp vegetation type in the Sudan swamps. Holm *et al.* (1977) reported that *Phragmites australis* (Cav.) Trin. ex. Steud. and *Vossia cusipdata* Griff. quickly suppress *C. papyrus* L.

Limnological studies have been carried out directly on water and hydrosoil taken from the papyrus swamps in Uganda, Kenya and Sudan, where the water lay under the floating mat or the border of the stand, unlike the open water, this water should have been more or less stratified. Carter (1955), and Gaudet (1979) provide us with examples of such work on standing water in papyrus swamps. The general trend of water quality in most cases follows a similar pattern i.e. decrease in pH, O_2, rise in CO_2 and decrease in inorganic constituents in particular after the periods of flooding. In case of our study, no flooding any more after the construction of the High Dam at Aswan. The change in the hydrological regime especially water current and the flooding may be one of the reasons of disappearance of papyrus from the Lower Egypt. The present study indicate that the pH within papyrus stand accounts for very high free-CO_2 concentrations can develop in an organic ‘soup’ under anaerobic conditions and at high temperatures. Such conditions may gave an evidence why papyrus is tolerant of a wider pH range than are the other major swamp emergents. The pH is usually 6 to 7.5, but papyrus grows satisfactory between pH 4 and 8.0 (Thompson, 1976). In the papyrus site organic matter accumulates and forms layers under the mat. This facilitates the plant uptake capacity since sorption reactions occur on the colloidal surfaces. Papyrus has a considerable absorbing surfaces of the floating mats, large amounts of nutrients are incorporated in the plant (Gaudet, 1979). The floating root mat of papyrus would easily extract nutrients from wastewater underneath and offer effective treatment of water (Azza *et al*., 2000).

The productivity (kg DM/m^2) of *Cyperus papyrus* under the Egyptian conditions in comparison to the other parts of Africa (Table 3). Production of aquatic plants is regulated by climatic factors such as temperature, day length of growing season as well as nutrients, pH, salinity, wind, sky cover and humidity (Serag, 1996). In the papyrus swamps of Upemba Basin, Zaire and the freshwater marshes of Uganda, Thompson (1975, 1976) reported a value of 12.5 Kg DM/m^2 for the above-ground parts of papyrus. Studies were carried out in the swamps of Lake Naivasha, Kenya and the productivity of papyrus was evaluated. In these swamps *Cyperus papyrus* grows in dense and prolific stands. Jones (1983) reported a harvestable standing crop of 30 tonnes per hectare compared with only 10 tonnes per hectare of grass from the finest European pastures. After harvest, this amount of papyrus biomass was replaced in about nine months. Typically over 95% of the biomass of a papyrus swamps is attributed to the dominant papyrus itself. The interwoven roots and older buried portions of rhizomes form a compact floating mat up to 2 meters thick which, together with its living vegetation, typically weights over 100 Kg (wet weight) per square meter (Thompson, 1976). The productivity of papyrus ranged from 6.61 to 11.54 Kg DM/m^2 (Muthuri *et al*. 1989, Jones and Muthuri, 1997 and Boar *et al*. 1999). In Bahr El Gebel, the Upper Nile, papyrus popula-

Table 3. Productivity of Cyperus papyrus in the different localities of Africa in comparison to the present study.

Location	Above-ground biomass (Kg DM m^{-2})	Below-ground biomass (Kg DM m^{-2})	References
Upemba Basin, Zaire	12.5	_	Thompson (1975)
Fresh water marshes, Uganda	12.5	_	Thompson (1976)
Gaba swamp. southeast of Kampala, Uganda (Managed stand)	3.88	_	Kaggwa (2001)
Lake Naivasha, Kenya	6.61	_	Muthuri (1989)
Lake Naivasha, Kenya	7.8	_	Jones and Muthuri (1997)
Lake Naivasha, Kenya	11.54	_	Boar et al. (1999)
Bahr El Gebel, the Upper Nile	11.81	_	Migahid (1952)
Central Africa	9-15	_	Westlake (1975)
Rediscovered stand, the Nile delta	5-8	2.14-7.2	The present study
Managed stand, the Nile delta	2.8-4.4	4.4-9.6	The present study

tion was studied by Migahed (1952) who reported a value of 11.81 Kg DM/m^2 for the above-ground aerial culms. In central Africa, the above-ground biomass of papyrus ranged from 9 to 15 kg DM/m^2 (Westlake, 1975). The present study indicated that papyrus produced 5-8 kg DM/ m^2 for the above-ground culms of papyrus for the natural stand in the Nile. Lower range of 2.8-4.4 kg DM/ m^2 was recorded for above-ground parts for the managed stand.

Unfortunately, little data are published on the below-ground biomass of emergent aquatic plants because of the difficulties of sampling. Results indicate that papyrus below-ground biomass ranged from 2.14 to 7.2 kg DM/ m^2 and 4.4 to 9.6 kg DM/ m^2 for both the natural and managed stands, respectively.

The high productivity of papyrus may be attributed to: 1) papyrus plants with C4-carbon metabolism and are generally more productive than C3 species, 2) storage of carbohydrates in rhizomes overwinter, 3) water and nutrients availability, 4) relative hot climate prevails in subtropical and tropical zones.

Conclusion

On the basis of the above results, one may conclude that the ecological relations and biomass yield will be useful for credible management of the papyrus and its conservation as important sedge from ancient times. The above-ground culms are a good source for paper production. The below-ground biomass are a potential source of nutrients and oxygen for the associated biota. It is hoped that the obtained results will help in the formulation of suitable strategy for sustainable management of papyrus yield for paper production as well as its use for wastewater treatment and pollution control under the Egyptian conditions.

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