Effects of Saline Soils on Culms and Culm Strands of *Cyperus Corymbosus* Rottb

Patcharaporn Pimchan and Nittaya Saesim*

Department of Chemistry, Faculty of Science and Technology, Rajabhat Maha Sarakham University, Maha Sarakham 44000, Thailand

* Corresponding author. E-mail address: seasim_s@yahoo.co.th

Abstract

The objectives of these studies were to evaluate the chemical compositions of *Cyperus Corymbosus* culms and the tensile strength of the culm strands. The samples were collected at Nong Bo District Maha Sarakham province using plots of Roi Et Saline series and Udon Series. It was found that before planting the electrical conductivity of soil saturation extracted (ECe) from plots of Roi Et Saline series and Udon Series was high and differed extremely. Also the ECe from plots of Roi Et Saline series and Udon Series extremely decreased after harvesting and were not significantly different (0.05). The chemical compositions indicated that the average content of ash, moisture and extractives (ethanol-benzene) of culms of *Cyperus Corymbosus* planted in Roi Et saline series and Udon series plots were not significantly different while the content of the lignin, alpha cellulose and holocellulose were found to differ significantly. The culms of *Cyperus Corymbosus* planted in Roi Et saline plots showed higher lignin, alpha-cellulose and holocellulose than that of planted in Udon series plots. The tensile strengths of the culm strands from Udon and Roi Et saline series plots were not significantly different (0.05). This shows that *Cyperus corymbosus* can decrease the salinity of soil and produce quality products from the culm strands in saline soil.

Keywords: Saline soil, Soil series, *Cyperus corymbosus* Rottb, Tensile strength

Introduction

Cyperus is the largest genus of *Cyperaceae* and comprises about 650-700 species distributed all over the world (Tejavathi & Nijalingappa, 1990; Simpson, Furness, Hodkinson, Muasya, & Chase, 2003) of these, 47 species occur in Thailand (Simpson & Koyama, 1998). *Cyperus corymbosus* Rottb, a rhizomatous sedge, is the major species in both Eastern and Northeastern Thailand. It is found growing in almost all environments, including marshy lands, and those with poor soils. Its culms, which are also known as mat sedge, provide material for making mats and also coarse products such as hand bags, baskets and wall hangings. Ban Phaeng village in Kosum Phisai District, located in Maha Sarakham province in the Northeast, is well known in Thailand for making local mat and coarse products using mat sedge. The culms are sometimes contaminated with soils causing fungi to grow on the products. However Seasim (2013) reported that no A. terreus, A niger and A. fumigates were found on the culm strands of *Cyperus Corymbosus* planted in Roi Et saline series and Udon series plots. This may be the result of adsorption of salt from the saline soil from the plots.

Nong Bo Reservoir, located in Borabur district, Maha Sarakham province, was constructed in 1965. It was originally fresh water and flowed into the Siew Yai River. In 1971 the villagers pumped up underground water near Nong Bo Reservoir for consumption but they found a lot of salt. Consequently, a salt production business was developed which pumped the saline water and dried it by sunlight or boiling. A lot of this was done during 1978-1989 and was expanded into areas around Nong Bo. The saline water in Nong Bo Reserviour affected the area around Nong Bo

Reservoir and Siew Yai River and caused great damage to the crops when it overflowed on agricultural lands. The Prime Minister's order 3/2532 required that salt production cease. After that, the area around Nong Bo was developed, but it was still covered with salt, especially in the dry season.

Rajabat Maha Sarakham University was asked to look at P-2 area at Nong Bo Reservoir in cooperation with the RAJAPRUEK INSTITUTE FOUNDATION to set up the New Theory Demonstration Farming Plot in order to develop the salty area. There are four salty soil series in this 9.6 ha. area, Roi-Et Saline (Re-sa); Udon (Ud); Kula Ronghai (Ki); and; Roi Et Saline and Thick Sandy Soil (Re-sa-tks).

This study is of the *Cyperus corrymbosus* planted at P-2 area located in Nong Bo Reservoir area. If the villagers could expand the plantation of the corrymbosus in salty soils in Nong Bo Reservoir area, it would not only decrease salinity in the soil, but also improve the quality of the mat sedge products.

The resultant data were statistically analyzed by using an independent t-test to compare the mean of the chemical components in Roi-Et Saline and Udon soil series, the chemical components of *Cyperus Corymbosus* planted in Roi Et saline series and Udon series plots and tensile strength of culm strands of *Cyperus Corymbosus* planted in Roi Et saline series and Udon series plots. A significant difference was considered to be a level of $p<0.05$

The objectives of these studies were to evaluate the effect of saline soil on the chemical compositions of *C. corymbosus* and the tensile strength of it's culm strands and the effect of growing *C. corymbosus* on the chemical composition of the soil.

Materials and methods

Study area: The study areas were Roiet-sa saline series plot (S1) and Udon series plot (S2) in P-2 area of Nong Bo Reservoir, as shown in Figure 1.

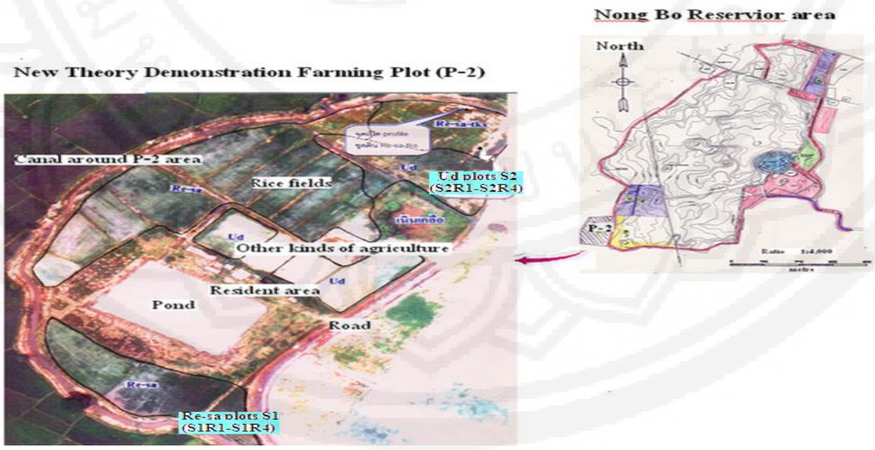


Figure 1 Map of Nong Bo Resevoir area (right) and Aerial Photograph of P-2 area (left)

Soil sampling: Samples from four 4x6 m sampling plots of Re-sa (S1R1-S1R4)) and Ud series (S2R1-S2R4) before and after planting were collected to represent the soil of the experimental area at 0-20 cm depth. The soil samples were air dried and sieved through 2 mm and 0.5 mm sieves, then kept in amber glass bottles.

Soil analysis: Soil pH was measured in a 1:2 soil: water ratio (W/V) using a Metrohm pH meter (model 744). Electrical conductivity of soil saturated solution was measured using a Eutech conductivity meter (model CON 700). Organic matter was determined by oxidation with $K_2Cr_2O_7$ and titration with $Fe_2NH_4SO_4$ (Walkley, 1946). Total nitrogen was determined by Kjeldahl digestion, distillation and titration procedure (Bremner & Mulvaney, 1982). Available phosphorus was determined by the ascorbic acid molybdenum blue method and measured with a Perkin-Elmer spectrometer (model Lambda 12) (Bray & Kurtz, 1945; Murphy & Riley, 1962). Extractable sodium and potassium were extracted from the soil with NH_4OAc at pH 7.0 (w/v) and measured with a Sherwood Flame photometer (Model 410). Extractable calcium and magnesium were extracted in the same way and measured with a Perkin-Elmer atomic absorption spectrophotometer (model 3110) (Horneck, Hart, Topper, & Koepsell, 1998).

Plant material: *Cyperus corrymbosus* culms were collected along with the rhizomes from the swamps of P-2 area, then the tops were cut off 30 cm. from the bottom. These were placed in nursery bags then raised in a nursery for 1 month. Four 4x6 m plots of Roiet-sa saline series were prepared by adding 375 kg/ ha. of sesbania rostata seeds as green manure $6.25x10^3$ kg/ha. of rice husk and $6.25x10^3$ kg/ha of manure. Four plots of Udon series were similarly prepared. Plant spacing between rows and within rows was 40x40 cm. Then the plantings from the nursery bags were planted in the remediate saline soil until the flowers became light brown.

Chemical analysis: *Corrymbosus* culms grown in Roiet-saline soil (C1) and Udon series (C2) were cut off 1.5 cm. from the bottom and taken back to the laboratory. They were initially washed in running tap water for 5 min followed by washing with distilled water and drying in air. The dried culms were ground, then sifted through a 40 mesh sieve and the fine sample of culms from plots of Re-sa (C1R1-C1R4)) and Ud series (C2R1-C2R4) was kept in amber glass bottles. Moisture content was determined by drying the fine sample at 100±5 °C for 4-6 hours in an oven (TAPPI, 1998, T 264 om-88) and ash value was determined by heating the fine sample at 575±25 °C in a muffle furnace (TAPPI, 2000, T 211 om-93). The acid-insoluble lignin (also known as Klason lignin), a constituent of fine sample, which is insoluble in 72 % sulfuric acid, was filtered off, dried and weighed. The extractive free fiber (Benzene-ethanol) was estimated by extraction from the fine sample with ethanol-benzene (1:2, v/v) for 6-8 hours in a Soxhlet extractor followed by extraction with 95 % ethanol for 4 hours. Then it was filtered, dried and weighed (TAPPI, 1997, T 264 om-97). The extractive content was estimated by drying the Soxhlet extraction after rotary vacuum-evaporation and weighing (TAPPI, 1997, T 204 om-97). The holocellulose, was estimated following Zobel and McElwee (1966) using extractive free fibre treated with 10 ml of stock solution A (60 ml glacial acetic acid + 20 g NaOH per litre of distilled water) and 1 ml of stock solution B (200 g $NaClO_2$ per litre of distilled water). To determine α-cellulose content, the holocellulose-containing crucible was placed in a watch glass, containing water to a depth of 1 cm, then treated with 17.5% sulphuric and 10% acetic acid. The α-cellulose remaining was washed with distilled water and acetone, this was then oven-dried to a constant weight at 103±2 °C C (Zobel & McElwee, 1966).

Analysis of tensile strength: The culm strands were prepared by splitting green culms of *corrymbosus* with a sharp knife into 3-4 pieces, removing the pith, and then dried in the hot sun. The dried culm strands (approximately 0.3 cm. diameter) were cut in three portions (upper, middle and lower) to study the tensile strength. Each portion was cut to 20 cm. then placed in the upper and lower grips of the removable cross-head of a tensile machine and load was applied continuously at the rate of 100 mm/sec. until the sample broke. The same procedure was repeated for the middle and bottom portions of the culm strands. The tensile strengths were calculated using the data obtained from the machine.

Results and discussion

Soil chemicals and nutrients: Soil chemicals and nutrients of S1 and S2 before and after have sting are shown in Table 1 and Figure 2.

After harvesting the average pH and ECe of S1 and S2 decreased, especially the ECe which decreased from 54.37 and 536.25 dS/m to 25.85 and 21.85 dS/m, respectively. The average quantity of organic matter, total nitrogen and available phosphorus before planting was low-very low, but after harvesting only the quantity of organic matter and available phosphorus increased. The average quantity of extractable sodium, potassium, calcium and magnesium in S1 and S2 before planting had a significant difference (<0.05).

Sodium was highest followed by calcium, magnesium and potassium, respectively. However, after harvesting the average quantity of extractable sodium and magnesium between S1 and S2 showed no significant difference, and was much lower than before planting. This may be caused by water draining through the sandy coarse soil and leaching out the salinity. This agrees with Arunin and Pongwichin (1993) who found that the irrigating water can remove the salt from sandy soil.

Table 1 Soil chemicals and nutrients of S1 and S2 before and after harvesting

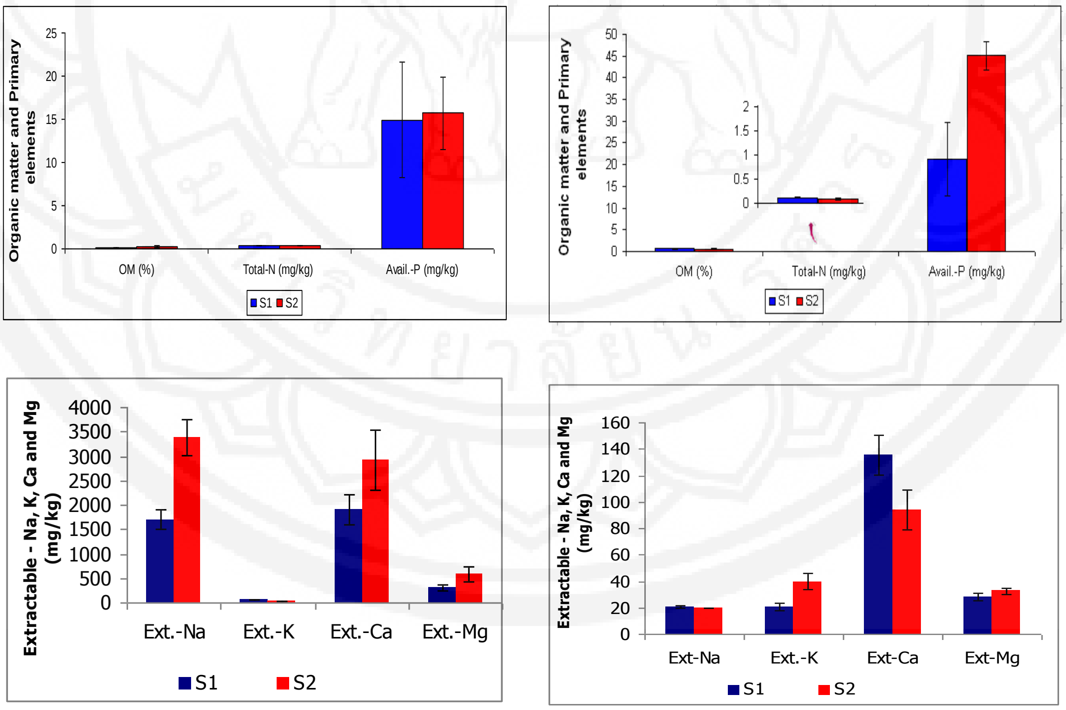
Soils	pH	ECe (dS/m)	OM (%)	Total-N (%)	Avail.-P (mg/kg)	Ext.-Na (mg/kg)	Ext.-K (mg/kg)	Ext.-Ca (mg/kg)	Ext.-Mg (mg/kg)
S1	Before planting								
S1R1	6.93	52.16	0.15	0.36	12.1	1577.46	53.81	1497.62	325.09
S1R2	7.00	44.48	0.19	0.34	16.91	1975.96	53.15	2025.64	197.85
S1R3	6.7	71.26	0.14	0.36	12.78	1724.02	52.98	2223.95	349.12
S1R4	7.16	49.56	0.12	0.35	17.82	1545.75	53.48	1898.45	349.36
Mean	6.95	54.37	0.15	0.35	14.90	1705.80	53.36	1911.42	305.36
%CV	2.75	21.53	19.63	2.72	19.33	11.50	0.69	16.04	23.77
S2	Before planting								
S2R1	6.03	551.33	0.34	0.38	18.93	3095.36	35.32	3746.76	774.59
S2R2	6.5	579	0.17	0.36	13.18	3176.12	35.32	2797.45	624.79
S2R3	6.06	497.66	0.25	0.42	13.10	3325.17	42.88	2922.88	546.42
S2R4	6.13	517	0.22	0.34	17.60	3903.52	36.61	2224.36	424.8
Mean	6.18	536.25	0.25	0.38	15.70	3375.04	37.53	2922.86	592.65
%CV	3.52	6.74	29015	9.11	19.16	10.81	9.64	21.48	24.73
t-test	*	*	**ns**	**ns**	**ns**	*	*	*	*
S1					After harvesting				
S1R1	5.66	27.3	0.80	0.1	19.13	20.21	23.47	151.96	30.39
S1R2	5.7	26.63	0.49	0.11	18.91	20.22	19.81	135.17	27.9
S1R3	5.66	25.06	0.48	0.10	22.4	20.41	17.84	116.11	23.94

Table 1 (Cont.)

Soils	pH	ECe (dS/m)	OM (%)	Total-N (%)	Avail.-P (mg/kg)	Ext.-Na (mg/kg)	Ext.-K (mg/kg)	Ext.-Ca (mg/kg)	Ext.-Mg (mg/kg)
S1R4	5.73	24.4	0.66	0.11	24.3	22.1	23.45	138.44	30.26
Mean	5.69	25.85	0.61	0.11	21.19	20.74	21.14	135.42	28.12
S2					After harvesting				
S2R1	5.43	21.25	0.59	0.10	49.75	19.28	37.69	114.57	33.54
S2R2	4.96	23.51	0.48	0.07	41.97	19.48	39.18	79.95	29.74
S2R3	5.6	21.87	0.74	0.11	44.00	19.91	48.03	88.92	34.68
S2R4	5.2	20.75	0.60	0.09	44.49	20.17	33.68	92.77	31.95
Mean	5.30	21.85	0.60	0.09	45.05	19.71	39.65	94.05	32.48
%CV	5.25	5.50	17.69	18.86	7.36	2.05	15.27	15.62	6.59
t-test	**ns**	*	**ns**	**ns**	*	**ns**	*	*	**ns**

% CV = coefficient of variation, ns = no significant difference, *= significant difference

The average quantity of organic matter, total nitrogen and available phosphorus of S1 and S2 before planting and after harvesting was low-very low with no significant difference (<0.05), but available phosphorus of S2 after have sting increased to 45.05 mg/kg. Similar results were obtained by Arunin and Pongwichian (1993) who reported that after the application of green manure the quantity of organic matter and available phosphorus increased but nitrogen decreased.



Before planting After harvesting

Figure 2 Soil chemicals and nutrients of S1 and S2 before and after harvesting

Chemical components: The chemical components of the *C. corrymbosus's* culms of eight samples grown under 2 different saline soils are shown in Figure 3.

This shows that the moisture, ash, and extractive (alcohol-benzene) of C1 and C2 were 6.29 % and 6.51%; 13.46 % and 14. 3 % and 9.07 % and 10.09 % respectively, and there was no significant difference. The ash content of C1 and C2 was high when compared to results with *Cyperus tegetum* obtained by Bhaduri, Chanda, and Majumdar (1998), which were in the range 9.50±0.85-11.30±1.06 %. It appears that C1 and C2 may have accumulated salt from the saline soil as suggested by Khan, Ungar, and Showalter (2000) and Ebtihal and Mervat Sh (2012), who reported that in soil, salinity leads to an increase in ash content, especially in the leaf. Because of when the salinity was increasing, the water potential and osmotic potential of plants were more negative, so that the inorganic ion were adsorbed for adjustment and facilitates water uptake along a soil-plant gradient. The ash content relative to the inorganic ion. Benazir, Manimekalai, Ravichandran, Suganthi, and Dinesh (2010) found the moisture content of *Cyperus pangorei* to be much higher at 9.2%. This would enhance the growth of fungi. Zheng and Wenjing (2003) reported the extractive content of Yunnanicus and Whangee bamboos to be 5.71 and 7.71 % respectively, which is much lower than C1 and C2. This may be the result of accumulated salts in the culms. However these results of C1 and C2 when compared with other plants were satisfactory.

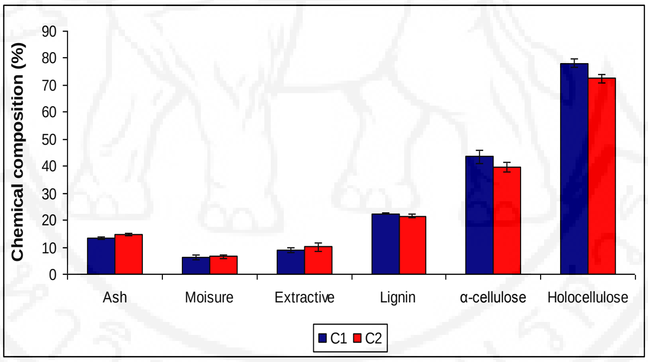


Figure 3 The chemical components of C1 and C2 in different saline soils

The content of the major constituents of *Cyperus corymbosus*, lignin, α-cellulose and holocellulose, in C1 and C2 were (22.47 %, 43.47 % and 78.08 %) and (21.56 %, 39.60 % and 72.42 %) respectively. These results show a significant decrease with high salinity. Ebtihal and Mervat Sh (2012) found a similar decrease for α-cellulose and holocellulose but an increase for lignin. The salt stress were effect to the osmotic and disturbances in water balance of the stressed plants due to the reducing in activity of meristematic tissues. This may be attributed to the synthesis of chlorophyll which is involved in increasing photosynthetic metabolites (Ebtihal & Mervat Sh, 2012). The decrease in content of the 3 major constituents of C1 and C2 was satisfactory when compared with the α-cellulose of *Cyperus Pangorei* (41.79 %) reported by Benazir et al. (2010), and α -cellulose of non-wood (bamboo and kenaf) (26-43 %, 45-63 %), softwood (40-45 %) and hardwood (38-49 %)

respectively, reported by Jahan, Al-Maruf, and Chowdhury (2009). This shows that *C. corrymbosus* growth in saline soils still provides a large amount of fiber which could be used to produce coarse products or support the home paper pulp industry. The data for lignin was not in agreement with that obtained by Ebtihal and Mervat (2012) who suggested that under higher salinity, levels of lignin increased. However the levels of lignin of C1 and C2 were satisfactory when compared to *Cyperus tegetum* (16.62±1.07-17.25 ±1.15 %) reported by Bhaduri et al. (1998). It is well known that lignin gives strength to the plant, and can protect against fungi and insects. The presence of lignin in large quantities would increase the amount of chemicals necessary to remove lignin. Therefore the amount of lignin of the *C. corrymbosus* grown in saline soil is desirable.

Tensile strength: The tensile strength of *C. corrymbosus* measured was that of the culm strands of C1 and C2 as shown in Figure 4. The tensile strength of the C1 and C2 culm strands (upper, middle and lower parts) showed no significant difference at the level 0.05. The tensile strength of the upper, middle and lower parts of C1 was 1293.98 MPa, 849.37 MPa and 670.30. MPa and of C2 were 1288.35 MPa, 1049.89 Mpa and 819.09 MPa respectively. The higher tensile strength of the lower strands may be caused by the greater amount of α-cellulose, lignin and ash in the lower culms. Ververis, Georghiou, Christodoulakis, Santas, and Santas (2004) found that these substances are likely to decline from the lower to the upper parts of the strand. This is expected since mature tissue (at the base) accumulates higher amounts of metabolic products than the younger parts at the top. The average tensile strength of the C1 culm strands (973.88 MPa) is lower than the C2 culm strands (1052.44 MPa), which corresponds to the quantity of moisture, ash and extractives of C1 and C2. The moisture, ash and extractives were related to the inorganic contents that enhance the tensile strength of fiber. However C1 and C2 culms showed higher tensile strength when compared to non-woods: pineapple leaf fiber (654±46 MPa), kenaf fiber (473±46 MPa), abaca leaf fiber (452±34 MPa) and sisal fiber 375±36 MPa), as reported by Munawar, Umemura, and Kawai (2007).

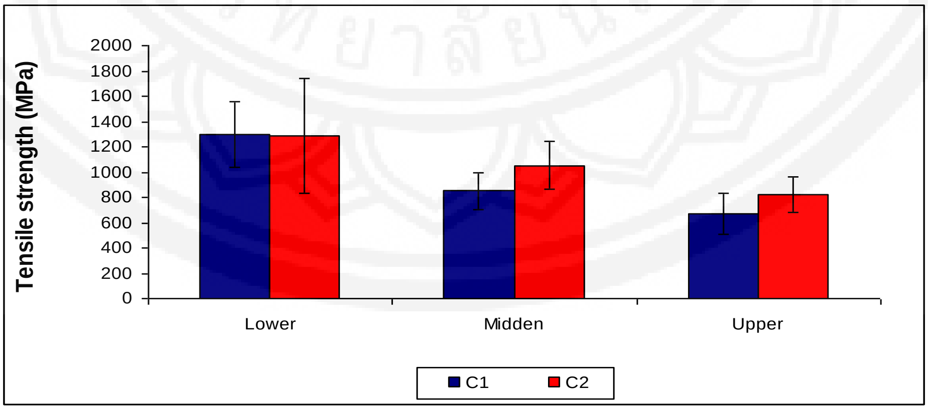


Figure 4 The tensile strength of C1 and C2 culms

Conclusion

The chemical compositions of the soil and culms and the tensile strength of the culm strands of the *Cyperus Corymbosus* planted in plots of Roi Et saline series (C1) and, in plots of Udon series (C2) in P-2 area at Nong Bo District, Maha Sarakham Province were studied

The average quantity of organic matter, total nitrogen and available phosphorus before planting of S1 and S2 was low-very low but after harvesting only organic matter, and available phosphorus increased. Before planting the extractable sodium was the highest, follow by calcium, magnesium and potassium. However, after harvesting the average quantity of extractable sodium and potassium between S1 and S2 showed no significant difference, and was considerably lower than before planting.

The moisture, ash, and extractive (alcohol-benzene) of C1 and C2 were not significantly different. The quantity of lignin, α-cellulose, and holocellulose, the major constituents of *Cyperus corymbosus*, of C1 and C2 showed a significant decrease with high salinity. This shows that *C. corrymbosus* growth in saline soils still provides a large amount of fiber which could be used to produce coarse products or support the paper pulp home industry. The levels of lignin were still satisfactory. The tensile strength of the C1 and C2 culm strands showed no significant difference at the level 0.05.

This research shows that the saline soil did not significantly affect the major constituents of clums but did increase the tensile strength of clum strands of *Cyperus corymbosus*. Consequently higher salinity produced better clum strands's products an additional advantage of planting *Cyperus corymbosus* is the reduction soil salinity.

Acknowledgements

I would like to thank the Office of National Research Council of Thailand for financial support and the Science Center, and the Department of Chemistry, Faculty of Science and Technology, Rajabhat Maha Sarakham University for support in providing instruments and facilities.

References

Arunin, S., & Pongwichian, P. (1993). *Effect of chemical fertilizer and amendments on Sesbania rostrata and succeeding rice crop in saline and non saline soil*. KhonKaen: Office of the Permanent Secretary for Ministry of Agriculture and Cooperatives.

Benazir, J. A. F., Manimekalai, V., Ravichandran, P., Suganthi, R., & Dinesh, D. C. (2010). Properties of fibres/culm strand from mat sedge-cyperus pangorei rottb. *Biore sources*, *5*, 951-967.

Bhaduri, S. K., Chanda, S., & Majumdar, P. (1998). Chemical characterization of the stem of Cyperus tegetum-A semi-aquatic plant of economic importance. *Bioresource Tech*, *63*, 279-281.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soil. *Soil Sci*, *59*, 39-45.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen-Total. In A. L. Page & R. H. Miller (Eds.), *Methods of Soil Analysis* (2nd ed., pp. 595-624). Madison, WI: Agron. Monogr. 9. ASA and SSSA.

Ebtihal, M., & Mervat Sh, S. (2012) Performance of flax cultivars in response to exogenous application of Salicylic Acid under Salinity Stress. *J. Appl. Sci. Res.*, *8*, 5081-5088.

Horneck, D. A., Hart, J. M., Topper, K., & Koepsell, B. (1998). *Methods of soil analysis used in the soil testing laboratory at Oregon State University*. State Oregon, USA: Agr. Exp.

Jahan, M. S., Al-Maruf, A., & Chowdhury, D. A. N. (2009). Pulping of Keora (Sonneratia apetala) a major mangrove species of Bangladesh. *IPPTA J.*, *21*, 51-54.

Khan, M. A., Ungar, I. A., & Showalter, A. M. (2000). Effects of Salinity on Growth, Water Relations and Ion Accumulation of the Subtropical Perennial Halophyte, Atriple griffithii var. stocksii. *Annals of Botany*, *85*, 225-232.

Munawar, S. S., Umemura, K., & Kawai, S. (2007). Characterization of the morphological, physical, and mechanical properties of seven nonwood plant fiber bundles. *J. Wood Sci.*, *53*, 108-113.

Murphy, J., & Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta*, *27*, 31-36.

Seasim, N. (2013). *The Properties of Cyperus corymbosus Rottb and It's Products growth in Saline Soil*. Mahasarakham: Rajabhat Mahasarakham University.

Simpson, D. A., & Koyama, T. (1998). Cyperaceae. In T. Santisuk & K. Larsen (Eds.), *Flora of Thailand* (pp. 34-40). Bangkok: Royal Forest Department.

Simpson, D. A., Furness, C. A., Hodkinson, T. R., Muasya, A. M., & Chase, M. W. (2003). Phylogenetic relationships in Cyperaceae subfamily Mapanioideae inferred from pollen and plastid DNA sequence data. *Am. J. Bot.*, *90*, 1071-1086.

TAPPI (US Technical Association of Pulp and Paper Industry): Preparation of wood for chemical analysis, T 264 om-88. (1988). *Tappi test methods.* Atlanta, GA, USA: Technical Association of the Pulp and Paper Industry.

TAPPI (US Technical Association of Pulp and Paper Industry): Preparation of wood for chemical analysis, TAPPI-T264-om-97. (1997). *Tappi test methods.* Atlanta, GA, USA: Technical Association of the Pulp and Paper Industry.

TAPPI (US Technical Association of Pulp and Paper Industry): Solvent extractives of wood and pulp, TAPPI-T204-om-97. (1997). *Tappi test methods.* Atlanta, GA, USA: Technical Association of the Pulp and Paper Industry.

TAPPI (US Technical Association of Pulp and Paper Industry): Technical association of pulp and paper industry, T 211 om-93. (2000). *Tappi test methods.* Atlanta, GA, USA: Technical Association of the Pulp and Paper Industry.

Tejavathi, D. H., & Nijalingappa, B. H. M. (1990). Cytological studies in some members of Cyperaceae. *Cytologia*, *55*, 363-372.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., & Santas, R. (2004). Fiber dimensions, lignin And cellulose content of various plant materials and their suitability for paper production. *Ind. Crop Prod.*, *19*, 245-254.

Walkley, A. (1946). A critical examination of a rapid method for determination, organic carbon in soils: effects of variations in digestion conditions and organic soils constituents. *Soil Sci.*, *63*, 251-263.

Zheng, W., & Wenjing, G. (2003). *A study on chemical composition and fiber characteristics of two sympodial Bamboos*. Beijing: The Research Institute of Chinese Pulp and paper making.

Zobel, B. J., & McElwee, R. L. (1966). Variation of cellulose in loblolly pine. *Tappi Journal*, *49*, 383-387.