

# STUDIES ON THE USE OF *SESUVIUM PORTULACASTRUM* — PART III: PHYTOREMEDIATION OF SALT CONTAMINATED SOILS OF TANNERY WASTEWATER DISCHARGED LANDS

by

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## ABSTRACT

The leather processing industry is known to be associated with the generation of liquid waste with high total dissolved solids (TDS), in particular salinity. In part I of the present study, *S. portulacastrum* was used for accumulation of NaCl present in tannery wastewater and in part II of the work, the harvest plant was reused for preservation of hides and skins. In the present investigation, *S. portulacastrum* is being used as a phytoremediant for the removal of NaCl in tannery wastewater discharged open lands containing TDS levels of 12,300 ppm for a period of 15 months (April 2008 – June 2009), at pilot scale in a commercial site in Tamilnadu state of India. The TDS levels of the soil in terms of NaCl were reduced from 12,300 to 2700 ppm by harvesting *Sesuvium portulacastrum* for 15 months. An average of 77% of Na<sup>+</sup> and 63% of Cl<sup>-</sup> was absorbed by the plants during the fifteen months of harvesting. Maximum accumulation of Na<sup>+</sup> and Cl<sup>-</sup> was observed during the month of August'08 and minimum level of absorption resulted during the period September'08 to December'08. The phytoremediation capacity of the plant was dependent on the climatic conditions. The lower values of salt absorption are attributed to heavy rainfall in these regions resulting in lower availability of salt for accumulation by the plant. The results of the present work indicate that *S. portulacastrum* can be used for phytoremediation of sodium chloride contaminated soils of tannery wastewater treated lands.

## RESUMEN

La industria del cuero es conocida por estar asociada con la generación de residuos líquidos con alto contenido de sólidos totales disueltos (STD), en particular, la salinidad. En la parte I del presente estudio *S. portulacastrum* fue utilizado para la acumulación de NaCl presente en el efluente de curtiembre y en la parte II de la obra, la planta cosechada fue reutilizada para la conservación de cueros y pieles. En la presente investigación, *S. portulacastrum* está siendo utilizado como una Fito-remediación para la eliminación de NaCl en el efluente de curtiembres, vertidas en espacios abiertos que contienen niveles de STD de 12.300 ppm por un período de 15 meses (Abril 2008-Junio 2009), a escala piloto en un sitio comercial en el estado de Tamil Nadu en la India. Los niveles de STD de la tierra en términos de NaCl se redujeron de 12.300 a 2.700 ppm por la cosecha de *Sesuvium portulacastrum* en 15 meses. Un promedio de 77% Na<sup>+</sup> y 63% Cl<sup>-</sup> fue absorbido por las plantas durante los quince meses de cosecha. La máxima acumulación de Na<sup>+</sup> and Cl<sup>-</sup> se observó durante el mes de Agosto'08 y el nivel mínimo de absorción durante el período de Septiembre'08 a Diciembre'08. La capacidad de Fito-remediación de la planta depende de las condiciones climáticas. Los valores más bajos de la absorción de la sal se atribuyen a las fuertes lluvias en estas regiones que resultan en una menor disponibilidad de sal para la acumulación por la planta. Los resultados del presente trabajo indican que *S. portulacastrum* puede ser utilizado para la Fito-remediación de suelos contaminados por cloruro de sodio de tierras regadas con aguas residuales de curtiembres.

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## INTRODUCTION

The treated effluents from the tanning industries that contain high TDS are discharged inadvertently into natural water bodies or open lands, resulting in contamination of the surface and ground waters as well as the soil flora and fauna,<sup>1</sup> as the effluent contains large concentration of sodium, sulphates, chlorides and chromium.<sup>2</sup> Removal of TDS present in tannery wastewater is necessary for environmental and economic reasons. Most of the well established treatment methods suffer from drawbacks such as high capital or operational costs. Therefore, there is a need for the development of a methodology with low-cost, easily adaptable systems based on zero discharge concepts. Phytoremediation is an emerging low-cost cleanup technology to remove harmless environmental contaminants such as heavy metals, trace elements and organic compounds from the contaminated wastewater or lands.<sup>3</sup> *S. portulacastrum* is known to grow under the conditions of severe salinity and low nutrient availability.<sup>4</sup> The distribution of *S. portulacastrum* is highly correlated with saline habitats. Factors such as soil salinity, soil water potential, precipitation pattern and level of the water table influence the growth and distribution of *S. portulacastrum*. Intraspecific and interspecific competition may also influence the behavior of this species under field conditions.<sup>5</sup> Several studies were dealt with making field measurements of ion content in halophytes. Correlations were found between Na<sup>+</sup> content in plants such as *Glaux maritime*, *Salicornia europaea* and soils in which they were grown and found that Na<sup>+</sup> increased with increase in external NaCl concentration.<sup>6</sup> Malik et al have pointed out that these relationships might be mediated by water availability in saline habitats.<sup>7</sup> Soil moisture and soil salinity are co-determinants of soil water potential, which is the parameter determining the water relations of plant cells. Many species of high drought resistance are also resistant to high salinities, but a plant which survives under conditions of high osmotic stress for example, to Na<sup>+</sup> and Cl<sup>-</sup> concentrations may not be tolerant to similar water potentials due to drought stress.<sup>6</sup> This is because the salt inducing the osmotic stress may be taken up by plants in varying quantities, depending on the species, allowing for complete osmotic adjustment.<sup>8</sup> The present study describes the phytoremediation capacity of *Sesuvium portulacastrum* of TDS in tannery wastewater contaminated soils at field level in Tamil Nadu. The effect of TDS from the contaminated soil on the growth and changing ion balance was studied and an attempt is made to relate these findings to the characteristics of the plant. The extent of removal of TDS from tannery wastewater treated open lands by *S. portulacastrum* has been presented.

## MATERIALS AND METHODS

### On site field conditions

Treated tannery wastewater discharge lands in Chennai, Tamil Nadu state of India were chosen for the study (long. 80° 17'E, lat. 13° 04'N). The land regions of plant growth were a mixture of sandy with red soil. The ambient temperature range during the measuring period varied between 15°C to 37°C. Based on the growth characteristics three different regions were considered for experimental and named as tall, edge and submerged *S. portulacastrum* under field level condition. Approximately, 1500 vegetative fragments of the apical regions of *S. portulacastrum* were grown at interplant distance of 10 cm in an area of 1200 square feet of land in each region for a period of 15 months (April 2008 – June 2009).

### Water delivery system

Ground water (~2.5 L per square meter) was delivered to plants in rows and furrows of experimental lands through electrical motor pump. The plants were watered on alternative days or whenever required, as there was heavy rainfall during some period of the study.

### Plant growth and sampling

Plants were collected monthly from the three selected regions and analyzed for growth characteristics. The plants were washed with commercial usage water twice to remove sand and other unwanted materials followed by washing with distilled water. After washing, plants were quickly and carefully blotted dry with tissue paper for removing the water and then the leaves, stems and roots were separated for the analysis of Na<sup>+</sup> and Cl<sup>-</sup>.

### Determination of Na<sup>+</sup> and Cl<sup>-</sup> ions in plants

The separated leaves, stems and roots were oven dried at 60°C for 48 hrs. Five oven-dried samples from each area were ashed in a muffle furnace for 24 h at 450°C. To the ashed material 10 ml of distilled water was added and diluted accordingly. The Na<sup>+</sup> and Cl<sup>-</sup> of the solution were assayed by flame photometry and argentometric method, respectively.<sup>9</sup> The results presented in this study the average value of five random samples.

### Soil sampling

Five number of soil samples were obtained monthly from each selected region and analyzed for the reduction of NaCl in terms of TDS in soil. The soil samples were taken from corners and middle regions of the selected regions to obtain random sampling of the experimental area for each month of growing seasons. The samples were air dried at room temperature.

### Determination of Na<sup>+</sup> and Cl<sup>-</sup> ions in soil

The soil samples were restricted to particles less than 2 mm diameter by passing them through a 2mm sieve. The air dried soil samples were mixed with double distilled water in the ratio of 1:1 and agitated for 2h on a shaker. This mixture was vacuum-filtered through one layer each of Whatman No.2 and No.42 filter papers in a Buchner funnel. The filtrate was analyzed for concentrations of Na<sup>+</sup> and Cl<sup>-</sup> using standard methods.<sup>9</sup> The results presented in this study the average values of five random samples.

### Determination of % absorption of Na<sup>+</sup>, Cl<sup>-</sup> and TDS in plants and soil

The percentage absorption of Na<sup>+</sup> and Cl<sup>-</sup> absorbed by the plant was estimated in each part of the plant at every month as follows:

$$\% \text{ absorption of Na}^+/\text{Cl}^-/\text{TDS} =$$

$$\frac{[(\text{Final}-\text{Initial}) \text{Na}^+/\text{Cl}^-/\text{TDS concentration in plants}] \times 100}{\text{Total ions offered from wastewater in 30 days}}$$

The sodium and chloride content of the plants from tannery wastewater treated lands were measured during the growth of the plants every month for a period of six months. The percentage absorption of ions by the plant in field conditions was calculated as follows:

$$\% \text{ absorption of Na}^+/\text{Cl}^-/\text{TDS} =$$

$$\frac{[(\text{Initial}-\text{Final}) \text{Na}^+/\text{Cl}^-/\text{TDS concentration in soils}] \times 100}{\text{Initial Na}^+ / \text{Cl}^- / \text{TDS Concentration in soil}}$$

## RESULTS AND DISCUSSION

### Reduction of Na<sup>+</sup>, Cl<sup>-</sup> and TDS from tannery wastewater discharged lands

The removal of salts from the soil with respect to Na<sup>+</sup> and Cl<sup>-</sup> is given in Figure 1. A total of 77% of Na<sup>+</sup> and 63% of Cl<sup>-</sup> were absorbed by plants during the fifteen months of harvesting in on-site field conditions. Harvesting *S. portulacastrum* in tannery wastewater treated lands resulted in the reduction of Na<sup>+</sup> and Cl<sup>-</sup> with variation in absorption capacity in the entire study of harvesting as seen in Figure 1. During the study period, maximum amount of salt was absorbed in the month of August'08, after which, there was a significant reduction in the absorption of salt up to the month of December'08 by the plant. This can be attributed to the percolation of water due to heavy rains in the region of Tamil Nadu in India. From the present study and the results of all the experiments it was observed that aerial portion of plants resulted in maximum removal of Na<sup>+</sup> and Cl<sup>-</sup> from the soil during phytoremediation. Earlier studies on phytoremediation by *Salicornia rubra*, it was found that

predominant ion accumulation of Na<sup>+</sup> and Cl<sup>-</sup> were observed in tissue.<sup>6</sup> Another halophyte, *Suaeda maritima* also exhibited greater accumulation of salts in their tissues and resulted in removal of 504 kg of sodium chloride from 1 hectare in 4 months time.<sup>10</sup> *Atriplex* species of plant species grown in normal conditions have leaf ash contents in the range of 130–270 g/kg<sup>11</sup> and if grown in saline soils, the species had leaf ash contents as high as 390 g/kg.<sup>12-15</sup> Hence, like other halophytes *S. portulacastrum* grown on salt-affected tannery waste water soils removed significant amount of salt and Na<sup>+</sup> through their aerial parts. However, considering the use of such plants as salt and Na<sup>+</sup> accumulators would result in very slow amelioration of salt-affected soils under irrigated agriculture. Sequestering salt from photosynthetic active tissues and cell compartments is a general phenomenon common in all plants.<sup>16</sup>

The removal of salt in terms of TDS from tannery wastewater discharged lands is presented in Table I. In the first month of the harvest, *S. portulacastrum* was able to remove 6% TDS from the tannery wastewater discharged lands containing TDS levels of 12,300 ppm. There was an increase in the removal of TDS up to 8% in the month of August of the phytoremediation period. The increase in Na<sup>+</sup> and Cl<sup>-</sup> absorption in the plants is due to increased level of proline in halophytes that help to maintain the intracellular osmotic potential. The presence of proline also acts as a protective substance against the adverse effects of salinity in glycophyte. However, the phytoremediation capacity of the plant reduced during the period October'08 to December'08, which can be correlated to heavy rainfall as well as availability of ions for accumulation by the plants. The phytoremediation capacity of the plant was later on improved and resulted in an incremental increase of TDS levels from January'09 to June'09. *S. portulacastrum* was able to remove 28% of TDS from the tannery wastewater offered to the plant in the first quarter (April'08 to July'08) of the growing period, after which, there was an increase in the removal of TDS up to 41% in the second quarter (August'08 to November'08) of the growing period. A total of 77% reduction in TDS in terms of NaCl by *S. portulacastrum* was observed at the end of 15 months from tannery wastewater discharged open lands. The TDS levels of the lands were reduced from 12,300 ppm to 2,700 ppm at the end of 15 months by the growth of *S. portulacastrum*. It is estimated from these results that *S. portulacastrum* could remove about 968 kg of sodium chloride from 1 hectare land in 15 months period. Hence, from the above observations it can be accomplished that *S. portulacastrum* can be used for phytoremediation of tannery wastewater treated open lands and a detailed study on the accumulation of Na<sup>+</sup> and Cl<sup>-</sup> by the plant with respect to climatic variations and influence of soil conditions was carried out.

TABLE I

**Removal of NaCl in terms of TDS by *S. portulacastrum* grown at tannery wastewater discharged lands during the period April 2008 to June 2009**

Month of Harvest	TDS Level in Soil		TDS Reduction (%)
	Initial (ppm)	Final (ppm)	
April '08	12300	11600	5.69
May '08	11600	10800	6.50
June '08	10800	9900	7.31
July '08	9900	8950	7.72
August '08	8950	7950	8.13
September '08	7950	7700	2.03
October '08	7700	7400	2.43
November '08	7400	7100	2.43
December '08	7100	6700	3.25
January '09	6700	6200	4.06
February '09	6200	5700	4.06
March '09	5700	5000	5.69
April '09	5000	4200	6.50
May '09	4200	3300	7.31
June '09	3200	2700	4.06
<b>April '08 – June '09</b>	<b>12300</b>	<b>2700</b>	<b>77.17</b>

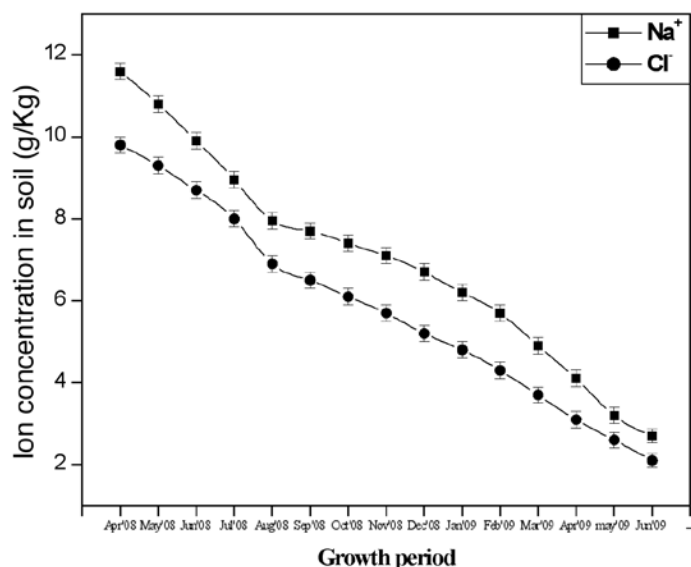


Figure 1. – Removal of NaCl from soil by *S. portulacastrum* under field conditions at tannery wastewater discharged lands.

#### Accumulation of Na<sup>+</sup> and Cl<sup>-</sup> by *S. portulacastrum* – Influence of Soil conditions

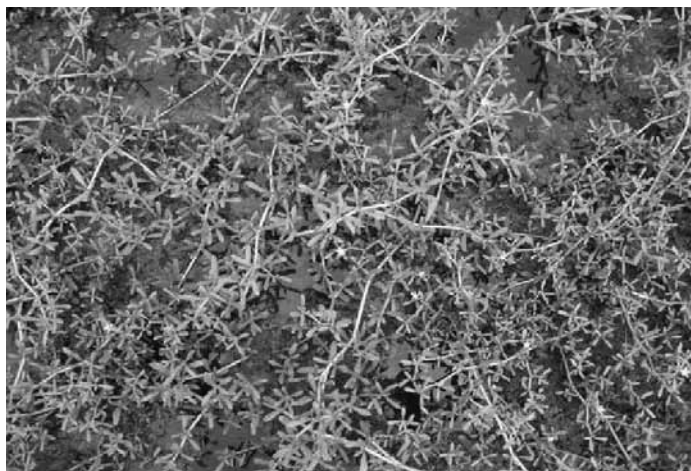
Three regions were designated as Tall, Edge and Submerged *S. portulacastrum* region based on the growth and accumulation of Na<sup>+</sup> and Cl<sup>-</sup> in *S. portulacastrum* in the tannery wastewater treated lands. The accumulation of salt was low in tall region followed by edge and submerged *S. portulacastrum* region as seen in Figure 2a-c. The accumulation capacity of *S. portulacastrum* can be directly correlated with the growth of these plants in these regions. The lands with higher growth of *S. portulacastrum* resulted lower Na<sup>+</sup> and Cl<sup>-</sup> accumulation as seen in Figure 2a. Moreover, as given in Figures 3a-c, absorption of salt was lower in the harvest period from September'08 to December'08. This can be correlated to heavy rains and concentration of ions available for accumulation was lower during this period. *S. portulacastrum* resulted in lower accumulation of Na<sup>+</sup> and Cl<sup>-</sup> of 24 and 21 mM in roots, 205 and 192 mM in leaves and 31 and 23 mM in stem of the plant in the month of December'08. Hence, from the above correlation it can be established that availability of ions for accumulation and climatic conditions are essential for reducing the TDS levels during phytoremediation of tannery



a) Tall *S. portulacastrum* region

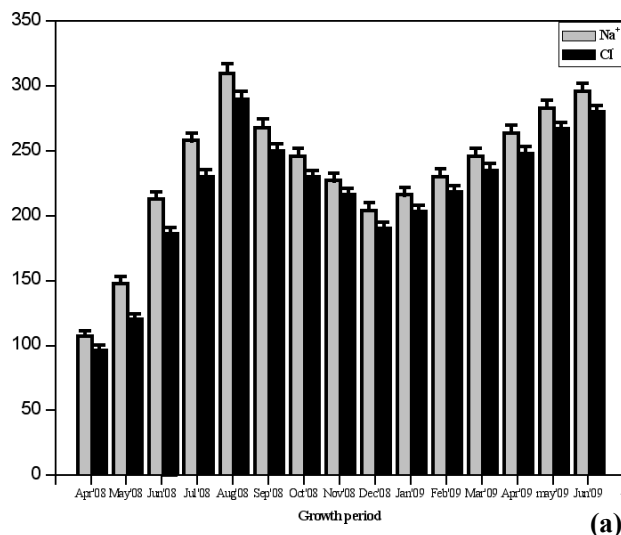


b) Edge *S. portulacastrum* region

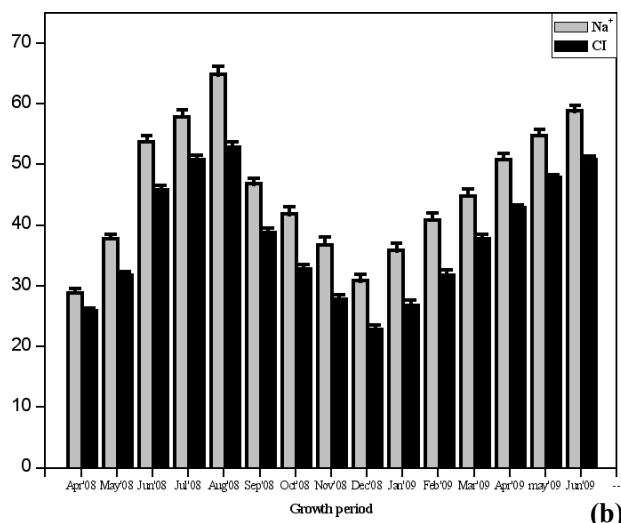


c) Submerged *S. portulacastrum* region

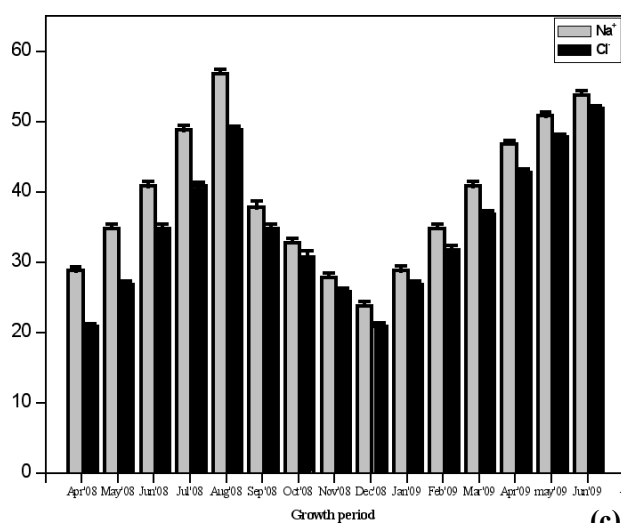
Figure 2a-c. – *S. portulacastrum* plant grown at three different regions of tannery wastewater discharged lands. (Editor Note: For a copy of original figures in color contact the editor or author).



(a)



(b)



(c)

Figure 3a-c. – Monthly fluctuations of ions in a) leaves b) stems and c) roots of *S. portulacastrum* at three different regions of tannery wastewater discharged lands.

wastewater treated lands by *S. portulacastrum*. The absorption of Na<sup>+</sup> and Cl<sup>-</sup> was medium in the region of edge *S. portulacastrum*. The lands with medium growth of *S. portulacastrum* with moderate Na<sup>+</sup> and Cl<sup>-</sup> accumulation are seen in Figure 2b. Figures 3a-c indicates absorption of salt as moderate during the harvest period from January'09 to June'09. This can be correlated to lower rainfall and moderate concentration of ions available for accumulation. The average temperature condition in during this period was 20-31°C. Hence, *S. portulacastrum* resulted in moderate accumulation of Na<sup>+</sup> and Cl<sup>-</sup> of 54 and 49 mM in roots, 297 and 281 mM in leaves and 59 and 51mM in stem of the plant in the month of June'09. The absorption of Na<sup>+</sup> and Cl<sup>-</sup> was high in the regions of submerged *S. portulacastrum* when compared to tall and edge *S. portulacastrum*. Maximum amount of sodium (311 mM) and chloride (291 mM) in submerged *S. portulacastrum* region was recorded in the month of August'08 (Figure 3a-c). Highest accumulation of Na<sup>+</sup> and Cl<sup>-</sup> of 57 and 49 mM in roots, 311 and 291 mM in leaves and 65 and 53 mM in stem of the plant in was observed in the same month. Figures 3a-c shows that maximum absorption of salt in the harvest period from April'08 to August'08. The average temperature condition in during this period was 25-37°C. The land with lower growth of *S. portulacastrum* with highest Na<sup>+</sup> and Cl<sup>-</sup> accumulation is seen in Figure 2c. *S. portulacastrum* appears to withstand higher NaCl salinities in summer season conditions with low water holding capacity in these lands. Plants can withstand different degrees of stress depend upon the ion they are exposed to and are generally more tolerant of mixtures of salts which are found under field conditions.<sup>17</sup>

### CONCLUSIONS

Phytoremediation of tannery waste water treated lands resulted in 77% TDS reduction in terms of NaCl by *S. portulacastrum*. The accumulation of Na<sup>+</sup> and Cl<sup>-</sup> was highly dependent on the presence of ions in the soil and climatic conditions. Maximum uptake of salt was observed in summer up to the month of August'08 and incrementally reduced in rainy season till December'08. Soon after, there was a steady increase in accumulation of salt in winter from January to April. The results of this study indicate that *S. portulacastrum* is able to remove about 968 kg of sodium chloride from 1 hectare land in 15 months period. The present study establishes that *S. portulacastrum* can be used for the removal of NaCl from tannery wastewater treated lands and requires 1½ to 2 years to remediate the salt contaminated lands from 12,300 ppm to acceptable TDS levels. Hence, this low cost clean-up technology offers a potential, economical and greener method of removing TDS from tannery wastewater discharged lands using plant-soil system.

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## CORRIGENDUM

### ***Corrigendum* for manuscript “Ultrasound Assisted Enhancement in Wattle Bark (*Acacia Mollissima*) Vegetable Tanning Extraction for Leather Processing” in *JALCA* 104(11), 375-383, 2009**

The corrections for this manuscript “Ultrasound Assisted Enhancement in Wattle Bark (*Acacia Mollissima*) Vegetable Tanning Extraction for Leather Processing” are as follows;

**Page 379:** in the sub-section ‘Quantitative analysis of wattle tannin’, the word “atechin” should be read as “*catechin*”

**Page 380:** Figure 4a x-axis title is Time (h); y-axis title is Amount total extract (g/ g of wattle), Figure 4b x-axis title is Time (h); y-axis title is Tannin content (mg/ g of wattle)

**Page 380:** under the sub-heading ‘Effect of ultrasound on extraction efficiency’ the sentence, “Effect of ultrasound on percentage yield ( $\eta_{temp}$ ) of extraction for different set of temperature is shown in Table II” should be read as “Effect of control process on percentage yield ( $\eta_{temp}$ ) of extraction for different set of temperature is shown in Table II.”

*JALCA* Editor

11/16/09

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