Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

JEB
Journal of Environmental Biology

ISSN: 0254-8704
CODEN: JEBIDP

# The effect of salinity on chlorophyll, proline and mineral nutrients in common weeds of coastal rice fields in Malaysia

**M. A. Hakim[1,2]*, Abdul Shukor Juraimi[3], M.M. Hanafi[1], Mohd Razi Ismail[1], M.Y. Rafii[1], Fazad Aslani[3] and A. Selamat[3]**

[1]Institute of Tropical Agriculture, University Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

[2]Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh

[3]Department of Crop Science, University Putra Malaysia 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

*Corresponding Authors Email : ahakimupm@gmail.com

**Publication Info**

*Paper received:*
06 June 2013

*Revised received:*
30 December 2013

*Accepted:*
25 January 2014

**Abstract**

Six weed species (*Leptochola chinensis, Echinochloa crus-galli, Echinochloa colona, Jussiaea linifolia*, *Oryza sativa* (weedy rice) and *Cyperus iria*) were tested for their salt tolerant traits in terms of chlorophyll, proline and mineral nutrients accumulation against different salinity levels (0, 4, 8, 16, 24, 32, and 40 dS $m^{-1}$). Chlorophyll a, b and total chlorophyll content, proline and mineral nutrients accumulation were determined. Salt stress showed prominent effect on all the parameters investigated and there were significant variations between the all weed species. Chlorophyll content, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ ions in both shoots and roots significantly decreased; while proline and $Na^+$ accumulation significantly increased with increasing salinity up to 40 dS $m^{-1}$. In terms of overall performance, *Cyperus iria* and *E. crus-galli* were relatively more tolerant; *E. colona* and *J. linifolia* were tolerant; *L. chinensis* and *O. sativa* L were salt sensitive, respectively.

**Key words**

Common weeds, Mineral nutrients, Salinity, Rice

## Introduction

Rice (*Oryza sativa* L.) is the staple food for more than half of the world population with at least two billion people in Asia, especially in South and Southeast Asia and Latin America (Khush, 2005; Rao *et al*., 2007). It is the third most important crop in Malaysia, grown mainly in eight granaries in Peninsular Malaysia covering an area of about 205,548 ha (MOA, 2007). Self sufficiency of rice in Malaysia is about 70% (Bernama, 2008). However, as the population is predicted to reach 66.4 million in 2056, it calls for more research and technological advancement to increase rice production to meet consumption within the nation (Selamat and Ismail, 2008).

Global warming is one of the greatest threats facing the planet. With global warming, the sea level rise is expected to increase, thus causing salt water intrusion into coastal areas affecting crop production (Peng *et al*., 2004). The oceans which cover 71% of the Earth's surface, is currently rising at a rate of about 0.25 cm per year due to global warming (BACC, 2008). Rising sea-levels result in changes in salinity which could adversely affect tropical agriculture. It has been estimated that worldwide more than 2 million acres of agricultural land is affected by salinity per year (Summart *et al*., 2010). Increasing population growth in developing countries of Asia, Africa and Latin America indicates that agricultural salinization will become a life-threatening problem (Flowers and Yeo, 1995). Though salinity has not yet become a crucial problem in Malaysia, but it is predicted to affect productivity in 100,000 ha of rice growing areas that would be salt affected by the year 2056 (Selamat and Ismail, 2008). Continuous intrusion of saline water will result in decreasing areas for rice production and lead to food shortages.

Globally, weeds are a serious pest of rice. They are a major constraint in rice production. Beside allopathic effects, weed plants compete with rice for water, light, physical space and

Online Copy

nutrient thus reducing yields, while weed seeds contaminate harvested rice grains and lower grain quality and cash value of the crop (Florkowski and Landry, 2002). Worldwide, the annual rice yield loss due to weed infestation is about 15-21% (Karim *et al.*, 2004). Annual loss of 10 million metric ton rice due to weed competition has been reported in China (Zhang, 2001). In fields without any weed control, the yield loss in rice due to weeds in Malaysia is estimated to be 41-70% (Azmi, 1990). In general, weeds are more salt tolerant than rice, however, weeds are also affected but salt tolerant weed species become less affected by salt stress. Salt exclusion, ion balance and synthesis/ accumulation of organic solutes are main salt tolerant mechanisms adapted by crop plants as well as weeds and the salt tolerant mechanisms vary between species. Barnyard grass (*Echinochloa crusgalli* L.) showed more salt tolerance as compared to rice under saline conditions due to elevated proline and other biochemical constituents accumulation and not with restricted sodium uptake (Yamamoto *et al*., 2003). However, the most important mechanism of salt tolerance of *E. oryzicola* was the ability to limit $Na^+$ accumulation and maintenance of a high $K^+/Na^+$ ratio in leaves (Nguyen *et al*., 2005).

Therefore, researchers and policy makers need to consider economic and efficient use of salinity management options in salt affected areas. Among the options, salt tolerant rice variety with their appropriate weed management technology is the best approach for optimizing the use of saline soils, while at the same time, meeting the increasing demand for food. The weed management techniques may differ under different saline environments, therefore, appropriate location specific weed control measures are essential for successful rice production in specific salt affected areas. Although much work has been done on the influence of saline habitats on seed germination, growth, reproduction and population dynamics of crop plants (Khan *et al*., 2002), not much attention has been paid to study the response of weeds to salinity. There is, therefore, an urgent need to identify tolerance level of major weed species in order to develop successful weed management practices in rice fields under saline environments. The present study was undertaken to investigate the stress of salinity on chlorophyll content, proline and mineral nutrient accumulation of some major weeds in coastal rice fields of Peninsular Malaysia.

## Materials and Methods

The study was conducted in pots (14 cm diameter × 15 cm depth) in glasshouse of the Universiti Putra Malaysia, during March to June 2011, in Randomized Completely Block Design with four replicates. Six weed species (*Leptochola chinensis, Echinochloa crus-galli, Echinochloa colona, Jussiaea linifolia*, *Oryza sativa* and *Cyperus iria*) were selected for this study based on the results of laboratory experiment in which *Cyperus iria*, *E. colona* and *E. crus-galli* were categorized as tolerant to salinity and *J. linifolia L. chinensis* and *O. sativa* (weedy rice) as moderately tolerant (Hakim *et al*., 2011). These species were treated with seven different salinity levels (distilled water as control, 4, 8, 16, 24, 32, and 40 dS $m^{-1}$). The rice field soil was collected for this study from Tangjung Karang, Selangor, Malaysia. The soil was pulverized and inert materials, visible insect pest and plant debris were removed. The soil was then crushed, mixed thoroughly, and dried in the sun. Two kilogram of prepared clean soil was put in each pot. The pre-stored weed seeds were soaked in water for 24 hrs, washed thoroughly in distilled water, and incubated in wet seed beds. After 3 weeks of incubation, three seedlings were transplanted into each pot. The transplantation weeds were irrigated twice daily with water to allow rooting and recovery from transplanting. After 2 weeks of transplantation when the plants were fully established, the salt treatments were initiated. To avoid osmotic shock, one liter salt solutions were added in three equal proportions on alternate days according to the salt treatments until the expected conductivity was reached. Water was provided to each pot to maintain optimum moisture. Leachates of salt solutions were collected daily from each pot and electrical conductivity (EC) was measured using a conductivity meter (model: Z 865/SCHOTT Instruments, Germany) and necessary adjustments were made.

Chlorophyll content in leaf samples were determined by the method of Coombs *et al.* (1987). While proline content was estimated according to the method of Bates (1973).

**Mineral nutrients :** After harvest, dried root and shoot samples were ground using a Wiley Hammer Mill, passed through 40 mesh screens, mixed well and stored in plastic vials until analysis. The samples were analyzed separately to determine the Na, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ content. All elemental analyses were conducted on acid digested materials by micro-Kjeldahl digestion system (Thomas *et al*., 1967). $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ content were estimated by Atomic Absorption Spectrophotometer (AAS) (Clesceri *et al*., 1988).

**Statistical analysis :** All the data were analyzed using analysis of variance (ANOVA) and the means were compared by least significant difference (LSD) using Statistical Analysis System software (SAS, version 9.0).

## Results and Discussion

Chlorophyll content significantly differed among weed species due to salinity (Fig. 1). The highest values of chlorophyll a and chlorophyll *b* were observed in *O. sativa* under control conditions, while lowest was observed in *L. chinensis* and *O. sativa* at higher salinity levels (32 dS $m^{-1}$ above). Chlorophyll a and b decreased least in *E. crus-galli* and *C. iria* while highest decrease was recorded in *O. sativa* followed by *L. chinensis.* Chlorophyll b content was least affected up to 16 dS $m^{-1}$, however, sharply decreased thereafter. Chlorophyll a content in some weed species were not affected at 4 dS $m^{-1}$ and then gradually decreased with increasing salinity levels. In general, reduction in chlorophyll b was more than chlorophyll a due to salinity effect (Fig. 2).



Online Copy

A linear relationship was observed between leaf chlorophyll content and salinity level (Fig. 3). The leaf chlorophyll content was negatively corelated (R=-0.996) with increasing the salinity levels. Total chlorophyll content decreased with increasing salinity level however, the rate of decrease varied among weed species (Table 1). *Oryza sativa, C. iria* had higher total chlorophyll under control conditions, but *C. iria*, *E. crus-galli* and *E. colona* maintained comparatively higher amount of total chlorophyll under salt stress with minimal reduction as compared to other weed species. At 4 dS $m^{-1}$, the least affected species were C*. iria* and *E. crus-galli* (1% reduction)and the most affected species was *O. sativa* (14 % reduction) relative to control. At 8 dS $m^{-1}$, *E. crus-galli* produced highest amount of chlorophyll followed by *C. iria* and *E. colona* with ≥90%, while the lowest value was observed in *O. sativa* with respect to control. Similar trends were observed at 16 dS $m^{-1}$. However, above 16 dS $m^{-1}$, salt effects were more prominent with least chlorophyll reduction in *C. iria* followed by *E. colona,* while the highest total chlorophyll reduction was found in *O. sativa* followed by *L. chinensis* (Table 1).

Decrease in chlorophyll content under saline conditions is a commonly reported phenomenon (Ashraf and Bhatti, 2000). Reduction in chlorophyll concentration in leaf might be due to loss of photosynthetic capacity and the inhibitory effect of accumulated ions on biosynthesis of chlorophyll fraction. Salinity-induced chlorophyll reduction may also be either related to $Mg^{2+}$ deficiency (as an integral part of chlorophyll) and/or chlorophyll oxidation in salinity stressed conditions (Moradi and Ismail, 2007). NaCl-induced decrease in chlorophyll level has widely been reported in glycophytes and halophytes (Abdullah *et al*., 2001). Dhanapackiam and Ilyas (2010) reported that chlorophyll a and b of *Sesbania grandiflora* seedlings were influenced by increase in the salt concentrations and decreased at higher salinity levels.

Proline accumulation increased significantly with increasing salinity (Table 2). Proline accumulation increased 1.8, 2.9, 4.3, 6.2, 8.9 and 13-fold, respectively at 4, 8, 16, 24, 32 and 40 dS $m^{-1}$ salinity. In all weed species, proline accumulation increased gradually up to 24 dS $m^{-1}$, but increased abruptly at 32 and 40 $dSm^{-1}$. At 40 dS $m^{-1}$, significantly higher accumulation (15.6-fold) of proline was observed in *J. linifolia*, while lowest accumulation was seen in *O. sativa* (9.4-fold). At 4 dS $m^{-1}$, the change in proline content ranged from 1.5-fold (*C. iria*) to 2.2-fold (*E. crus-galli*) as compared to control. At 8 dS $m^{-1}$, maximum increase in proline accumulation was seen in *J. linifolia* (3.8-fold), followed by *E. colona* and *E. crus-galli* with over 3-fold increase. At 16 dS $m^{-1}$ salinity, proline accumulation was higher in *J. linifolia* (5.4-fold) followed by *C. iria* (5.3-fold). At 24 dS $m^{-1}$, the highest proline accumulation was seen in *E. colona* (7.2-fold) followed by *J. linifolia* (7-fold), while the least accumulation was found in *L. chinensis* (4.3-fold). There were significant differences between the grasses with respect to proline accumulation at 32 and 40 dS $m^{-1}$ salinity level. There was a significant positive correlation (R=0.9983) between leaf proline content and salt concentration (Fig. 3). This result mentioned that proline content increased with increasing salinity levels.

Proline accumulation is a common characteristic observed in sesame cultivars under saline conditions (Koca *et al*., 2007). The most important mechanism in higher plants under salt-stress is accumulation of compatible solutes such as proline. P5CS has been reported as the main responsible gene in proline biosynthesis. The mechanism of proline decomposition by proline dehydrogenase enzyme, which is a mitochondrial enzyme, is a mechanism that increases the proline content. Many researchers have reported the significant role of proline in osmotic adjustment, cell structure protection, turgor maintenance and its role in salt-tolerant and salt-sensitive cultivars of *E. crus-galli*, sweet fennel, cotton, foxtail millet (Yamamoto *et al*., 2003; Ashraf and Akhtar, 2004; Desingh and Kanagaraj, 2007; Veeranagamallaiah *et al*., 2007) which are in agreement with the present results.

There were significant differences in $Na^{+}$ concentration in weed shoots at different salinity levels observed (Table 3); a significant positive correlation both in shoot and root (R=0.9982, 0.996) between sodium contents and salt concentration (Fig. 3) was observed. At 4 dS $m^{-1}$, the highest increase (2-fold) was found in *C. iria* followed by *E. crus-galli* and *O. sativa* with a 1.5 fold increase. Subsequently, *C. iria* showed an increasing trend up to

**Table 1 :** Effect of salinity on total chlorophyll content (mg $g^{-1}$ f.wt.) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $4.67^{c}$ | $4.32^{b}$ (93) | $3.82^{b}$ (82) | $3.09^{c}$ (66) | $2.50^{c}$ (54) | $1.88^{c}$ (40) | $1.38^{d}$ (30) |
| *E. crus-galli* | $4.81^{bc}$ | $4.79^{a}$ (99) | $4.52^{a}$ (94) | $3.94^{a}$ (81) | $3.21^{ab}$ (67) | $2.61^{b}$ (55) | $2.10^{b}$ (44) |
| *E. colona* | $4.34^{d}$ | $4.15^{b}$ (96) | $3.90^{b}$ (90) | $3.43^{b}$ (80) | $3.08^{b}$ (71) | $2.73^{ab}$ (62) | $1.99^{b}$ (46) |
| *C. iria* | $5.01^{b}$ | $4.95^{a}$ (99) | $4.56^{a}$ (91) | $4.12^{a}$ (83) | $3.46^{a}$ (69) | $3.10^{a}$ (62) | $2.50^{a}$ (50) |
| *O. sativa* L. | $5.75^{a}$ | $4.93^{a}$ (86) | $4.05^{b}$ (70) | $2.55^{d}$ (44) | $2.06^{d}$ (36) | $1.41^{d}$ (25) | $1.29^{d}$ (22) |
| *J. linifolia* | $3.89^{e}$ | $3.62^{c}$ (98) | $3.37^{c}$ (87) | $2.86^{c}$ (74) | $2.46^{c}$ (63) | $2.02^{c}$ (52) | $1.60^{c}$ (41) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate values as percent relative to the control

**Table 2 :** Effect of salinity on proline accumulation (µmol $g^{-1}$ f.wt.) in six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | 3.25$^{b}$ | 5.29$^{c}$ (1.6) | 7.74$^{c}$ (2.4) | 10.89$^{d}$ (3.4) | 14.01$^{e}$ (4.3) | 26.43$^{c}$ (8.1) | 41.08$^{c}$ (12.6) |
| *E. crus-galli* | 3.36$^{b}$ | 7.54$^{b}$ (2.2) | 10.20$^{b}$ (3) | 13.21$^{c}$ (4) | 22.02$^{c}$ (6.5) | 27.08$^{c}$ (8) | 45.25$^{b}$ (13.5) |
| *E. colona* | 4.45$^{a}$ | 8.83$^{a}$ (2) | 14.95$^{a}$ (3.4) | 18.47$^{b}$ (4) | 30.50$^{a}$ (7.2) | 35.12$^{b}$ (8) | 55.76$^{a}$ (12.5) |
| *C. iria* | 3.85$^{ab}$ | 5.72$^{c}$ (1.5) | 9.81$^{b}$ (2.5) | 20.59$^{a}$ (5.3) | 26.64$^{b}$ (6.9) | 43.63$^{a}$ (11.3) | 55.35$^{a}$ (14.4) |
| *O. sativa* L. | 3.45$^{b}$ | 6.02$^{c}$ (1.7) | 9.53$^{b}$ (2.7) | 14.13$^{c}$ (4) | 18.62$^{d}$ (5.4) | 26.71$^{c}$ (7.7) | 32.55$^{d}$ (9.4) |
| *J. linifolia* | 2.15$^{c}$ | 4.19$^{d}$ (2) | 8.11$^{c}$ (3.8) | 11.73$^{d}$ (5.4) | 15.59$^{e}$ (7) | 22.22$^{d}$ (10.3) | 33.47$^{d}$ (15.6) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate x-fold increase relative to the control

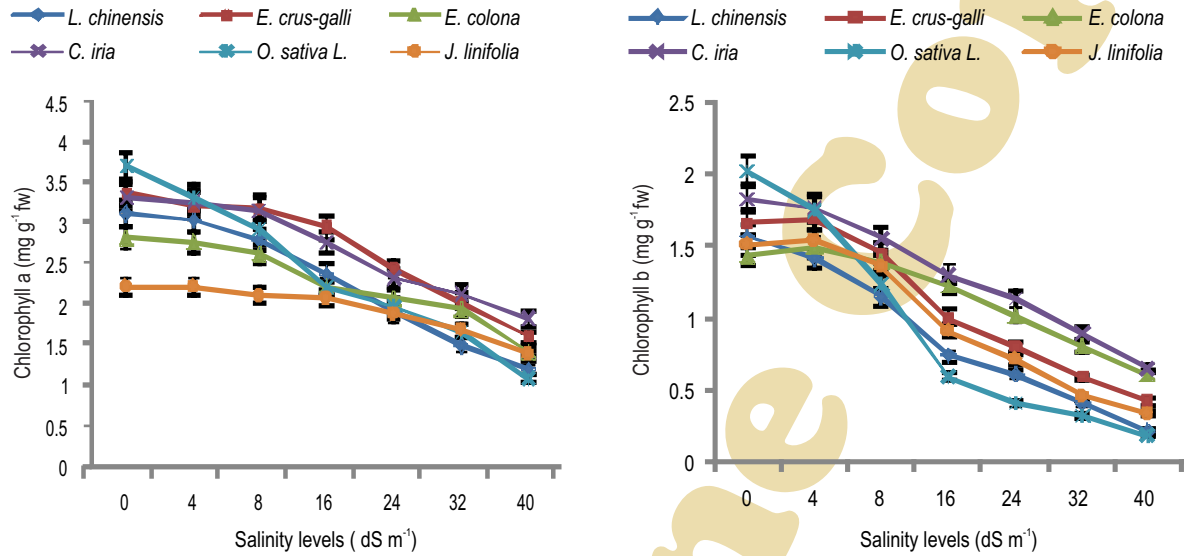


**Fig. 1 :** Effect on salinity on chlorophyll a and chlorophyll b of six weed species

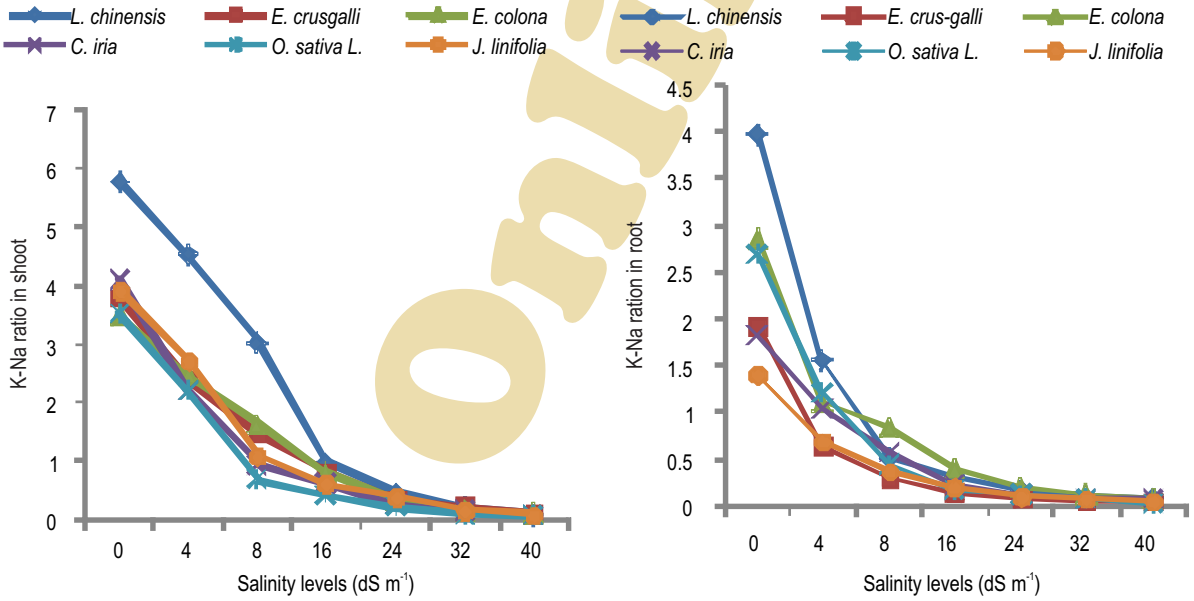


**Fig. 2 :** Relationship between salinity levels and $K^{+}$ /$Na^{+}$ ratio in shoot and root of six weed species

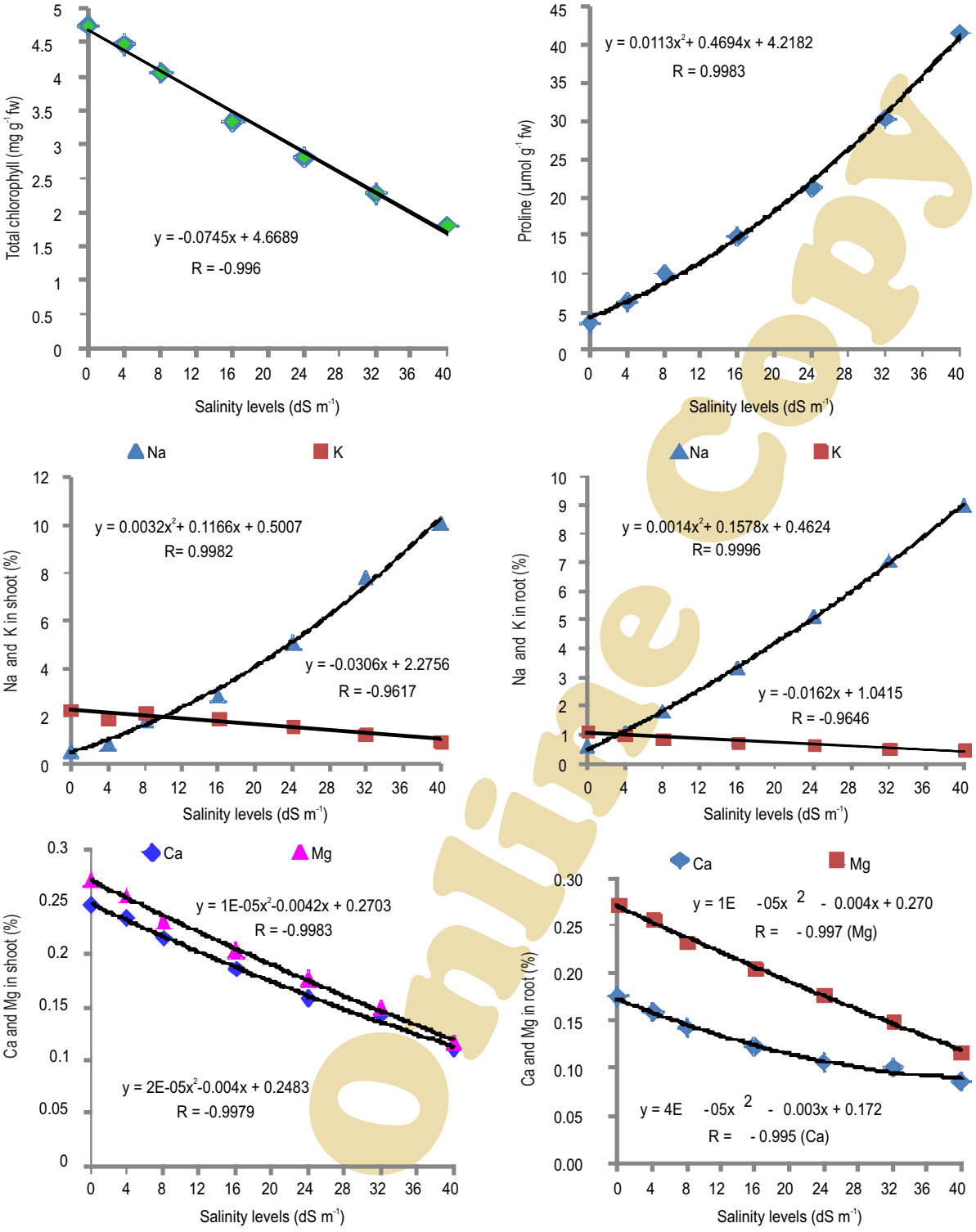


**Fig. 3 :** Responses to salinity levels on (a) Total chlorophyll; (b) Proline; (c) $Na^+$ and $K^+$ in shoot; (d) $Na^+$ and $K^+$ in root; (e) $Ca^{2+}$ and $Mg^{2+}$ in shoot and (f) $Ca^{2+}$ and $Mg^{2+}$ in root (Pooled data across to six weed species)

Online Copy

32 dS $m^{-1}$, while lowest value was found in *E. colona*. At 40 dS $m^{-1}$, the increasing trend somehow changed, and highest $Na^+$ concentration was observed in *L. chinensis* (23-fold) followed by *C. iria* and *J. linifolia* with an 18-fold increase, while lowest value (14-fold) was recorded in *O. sativa* and *E. colona* (15-fold), respectively.

$Na^+$ content in roots of six selected weed species were observed to increase progressively with increasing salinity levels (Table 4). In control, $Na^+$ content in different weed species ranged between 0.31 to 0.88% of the total dry matter. However, at 4, 8, 16, 24, 32 and 40 dS $m^{-1}$ salinity level, $Na^+$ ions in roots increased on an average respectively by 2, 3, 6, 9, 13 and 17-fold. $Na^+$ ions accumulation gradually increased up to 16 dS $m^{-1}$ salinity level, thereafter increased sharply (Table 4). At 40 dS $m^{-1}$, least $Na^+$ accumulation was recorded in *J. linifolia* (12-fold) followed by *C. iria* (13-fold) and *E. colona* (14-fold), while highest accumulation was recorded in *L. chinensis* (25-fold) followed by *O. sativa* (22-fold). *E. colona* was the least $Na^+$ accumulating species at all salinity levels followed by *J. linifolia* and *C. iria*, while *L. chinensis* was the highest $Na^+$ accumulating species followed by *O. sativa* and *E. crus-galli*, respectively.

Massive influx of $Na^+$ into the cells through non-selective cation channels (NSCCs) occur in the presence of excess Na in typical saline environments (Wilson *et al*., 2000; Rahman *et al*., 2008). Similar findings were also reported by Yamamoto *et al.* (2003) who observed increased $Na^+$ content in leaves of *E. crus-*

**Table 3 :** Effect of salinity on $Na^+$ content in shoots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $0.39^{b}$ | $0.49^{d}$ (1) | $0.68^{c}$ (2) | $1.88^{c}$ (5) | $3.10^{d}$ (8) | $5.35^{c}$ (14) | $8.89^{c}$ (23) |
| *E. crus-galli* | $0.67^{a}$ | $0.99^{ab}$ (1.5) | $1.57^{b}$ (3) | $2.74^{b}$ (4) | $6.40^{ab}$ (10) | $8.74^{a}$ (13) | $11.43^{a}$ (17) |
| *E. colona* | $0.66^{a}$ | $0.87^{bc}$ (1) | $1.29^{b}$ (2) | $2.28^{bc}$ (3) | $4.62^{c}$ (7) | $8.13^{ab}$ (12) | $9.59^{bc}$ (15) |
| *C. iria* | $0.62^{a}$ | $1.14^{a}$ (2) | $2.76^{a}$ (4) | $3.77^{a}$ (6) | $6.86^{a}$ (11) | $8.87^{a}$ (14) | $11.30^{a}$ (18) |
| *O. sativa* L. | $0.70^{a}$ | $0.99^{ab}$ (1.5) | $3.06^{a}$ (4) | $4.23^{a}$ (6) | $5.79^{b}$ (8) | $9.08^{a}$ (13) | $9.97^{b}$ (14) |
| *J. linifolia* | $0.52^{b}$ | $0.71^{c}$ (1) | $1.63^{b}$ (3) | $2.66^{b}$ (5) | $3.86^{cd}$ (7) | $7.42^{b}$ (14) | $9.28^{b}$ (18) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate x-fold increase relative to the control

**Table 4 :** Effect of salinity on $Na^+$ content in roots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $0.31^{c}$ | $0.68^{b}$ (2) | $1.82^{bc}$ (6) | $2.33^{cd}$ (8) | $3.41^{cd}$ (11) | $6.11^{d}$ (20) | $7.69^{d}$ (25) |
| *E. crus-galli* | $0.60^{b}$ | $1.24^{a}$ (2) | $2.61^{a}$ (4) | $4.80^{a}$ (8) | $7.07^{a}$ (12) | $9.07^{b}$ (15) | $10.66^{ab}$ (18) |
| *E. colona* | $0.39^{c}$ | $0.80^{b}$ (2) | $0.87^{d}$ (2) | $1.65^{d}$ (4) | $2.79^{d}$ (7) | $3.65^{e}$ (9) | $5.44^{e}$ (14) |
| *C. iria* | $0.88^{a}$ | $1.18^{a}$ (1) | $1.87^{bc}$ (2) | $4.33^{ab}$ (5) | $7.41^{a}$ (8) | $10.45^{a}$ (12) | $11.26^{a}$ (13) |
| *O. sativa* L. | $0.42^{bc}$ | $0.83^{b}$ (2) | $1.35^{c}$ (3) | $2.69^{c}$ (6) | $4.02^{c}$ (10) | $5.56^{d}$ (13) | $9.15^{c}$ (22) |
| *J. linifolia* | $0.82^{a}$ | $1.41^{a}$ (2) | $2.12^{b}$ (3) | $4.01^{b}$ (5) | $6.05^{b}$ (7) | $7.47^{c}$ (9) | $9.72^{bc}$ (12) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate x-fold increase relative to control

**Table 5 :** Effect of salinity on $K^+$ content in shoots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $2.26^{bc}$ (100) | $2.19^{b}$ (97) | $2.01^{bc}$ (89) | $1.81^{bc}$ (80) | $1.50^{c}$ (66) | $1.06^{c}$ (47) | $0.73^{cd}$ (32) |
| *E. crus-galli* | $2.44^{ab}$ (100) | $2.35^{ab}$ (96) | $2.30^{b}$ (94) | $2.23^{a}$ (91) | $2.08^{a}$ (85) | $1.94^{a}$ (80) | $1.50^{a}$ (61) |
| *E. colona* | $2.28^{bc}$ (100) | $2.13^{bc}$ (93) | $1.99^{bc}$ (87) | $1.84^{b}$ (81) | $1.45^{c}$ (64) | $1.24^{b}$ (54) | $1.02^{b}$ (45) |
| *C. iria* | $2.54^{a}$ (100) | $2.51^{a}$ (99) | $2.70^{a}$ (106) | $2.21^{a}$ (87) | $1.87^{b}$ (74) | $1.30^{b}$ (51) | $1.04^{b}$ (41) |
| *O. sativa* L. | $2.25^{c}$ (100) | $2.15^{bc}$ (96) | $2.09^{bc}$ (93) | $1.73^{cd}$ (77) | $1.30^{d}$ (58) | $0.84^{d}$ (37) | $0.65^{d}$ (29) |
| *J. linifolia* | $2.03^{d}$ (100) | $1.88^{c}$ (93) | $1.77^{c}$ (87) | $1.63^{d}$ (81) | $1.52^{c}$ (75) | $1.24^{b}$ (61) | $0.90^{bc}$ (44) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate values in percent relative to the control



Online Copy

*galli* with NaCl treatment. Similarly, Nguyen *et al.* (2005) observed increased $Na^+$ content in *Echinochloa oryzicola* seedlings with the application of salt solution.

Potassium ($K^+$) concentration in weed species, based on percent dry matter, ranged from 2.03 to 2.54% in control plants and were found to decrease significantly with increasing salinity levels (Table 5). There was significant correlation (R=-0.9617, -0.9646) observed between potassium content and salt concentration in both shoot and root *i.e.*, K content significantly decreased both in shoot and root with increasing salinity levels (Fig. 3). $K^+$ concentration decreased with increase in salinity levels and the effect was severe at highest salinity level (40 dS $m^{-1}$). At salinity levels up to 16 dS $m^{-1}$, *C. iria* maintained higher $K^+$ content, but above 16 dS $m^{-1}$ salinity level, *E. crus-galli* showed a higher $K^+$ content (1.5%) compared to others, while lowest value (0.65) was found in *O. sativa* followed by *L. chinensis*. At 4 dS $m^{-1}$, reduction in $K^+$ content was marginal in all species.

$K^+$ ions content in roots of weed species varied significantly due to salinity treatments (Table 6). Root $K^+$ level ranged from 0.93 to 1.37% in control treatment. On average, $K^+$ ion uptake by weed species was 90, 75, 62, 54, 48 and 35% relative to control at 4, 8, 16, 24, 32 and 40 dS $m^{-1}$, respectively. At 8 dS $m^{-1}$, least reduction (20%) in $K^+$ content occurred in *E. colona*, *C. iria* and *J. linifolia* relative to control but reduced greatly (40%) in *O. sativa*. At 16 and 24 dS $m^{-1}$, minimum reduction was recorded in *J. linifolia* followed by *E. colona* with relative value greater than 70 and 55 %, respectively. At higher salinity levels, highest $K^+$ ion uptake was observed in *C. iria* followed by *E. colona,* while minimum uptake was recorded in *O. sativa* followed by *L. chinensis*.

The results showed that $K^+$ content decreased with increasing salinity levels probably due to high external $Na^+$ negatively affecting $K^+$ acquisition due to similar physico-chemical properties of $Na^+$ and K; KUP (potassium uptake permease) / HAK (High Affinity $K^+$) transporters are extremely selective for $K^+$ and are blocked by $Na^+$ present in high salt concentrations (Gierth *et al*., 2005). Yamamoto *et al.* (2003) observed that $K^+$ content in the leaves and root of *E. crus-galli* decreased with increasing salt concentration. Kumar *et al.* (2008) found that $K^+$ content declined in *Jatropha curcas* due to effect of NaCl. Similar result was also reported by Nguyen *et al.* (2005) who found that $K^+$ content of *Echinochloa oryzicola* seedlings increased under salt stress which is in accordance with the present study.

$K^+$ /$Na^+$ ratio decreased with increasing salinity levels in shoots and significantly varied among weed species (Fig. 2). The highest $K^+$ /$Na^+$ ratio was found in *L. chinensis* (5.78) and lowest in *E. colona* (3.49) with no salinity stress. Up to 32 dS $m^{-1}$ salinity,

**Table 6 :** Effect of salinity on $K^+$ content in roots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $1.21^{b}$ (100) | $1.05^{b}$ (87) | $0.88^{ab}$ (73) | $0.75^{b}$ (62) | $0.59^{bc}$ (49) | $0.54^{b}$ (45) | $0.42^{b}$ (35) |
| *E. crus-galli* | $1.15^{b}$ (100) | $1.09^{b}$ (95) | $0.83^{b}$ (72) | $0.70^{bc}$ (61) | $0.67^{b}$ (58) | $0.51^{b}$ (45) | $0.43^{b}$ (37) |
| *E. colona* | $0.93^{c}$ (100) | $0.84^{c}$ (90) | $0.76^{bc}$ (82) | $0.65^{c}$ (70) | $0.52^{c}$ (56) | $0.49^{b}$ (53) | $0.45^{b}$ (48) |
| *C. iria* | $1.37^{a}$ (100) | $1.29^{a}$ (94) | $1.11^{a}$ (81) | $0.90^{a}$ (66) | $0.79^{a}$ (58) | $0.75^{a}$ (55) | $0.70^{a}$ (51) |
| *O. sativa* L. | $1.06^{bc}$ (100) | $0.86^{c}$ (81) | $0.64^{c}$ (60) | $0.46^{d}$ (43) | $0.43^{d}$ (41) | $0.37^{c}$ (35) | $0.30^{c}$ (28) |
| *J. linifolia* | $1.05^{bc}$ (100) | $0.95^{bc}$ (91) | $0.84^{b}$ (80) | $0.75^{b}$ (71) | $0.62^{b}$ (59) | $0.53^{b}$ (51) | $0.43^{b}$ (41) |

Means within columns with the same letters are not significantly different (LSD, p> 0.05); Values in parentheses indicate values in percent relative to the control

**Table 7 :** Effect of salinity on $Ca^{2+}$ content in shoots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $0.208^{c}$ (100) | $0.199^{c}$ (96) | $0.193^{b}$ (93) | $0.161^{d}$ (77) | $0.130^{c}$ (62) | $0.112^{b}$ (54) | $0.083^{e}$ (40) |
| *E. crus-galli* | $0.276^{a}$ (100) | $0.269^{a}$ (98) | $0.225^{a}$ (89) | $0.195^{bc}$ (71) | $0.183^{ab}$ (66) | $0.168^{a}$ (61) | $0.127^{b}$ (46) |
| *E. colona* | $0.237^{b}$ (100) | $0.223^{b}$ (94) | $0.220^{b}$ (93) | $0.184^{c}$ (78) | $0.149^{bc}$ (63) | $0.126^{b}$ (53) | $0.112^{c}$ (47) |
| *C. iria* | $0.277^{a}$ (100) | $0.270^{a}$ (98) | $0.256^{a}$ (93) | $0.213^{ab}$ (77) | $0.171^{b}$ (62) | $0.168^{a}$ (61) | $0.139^{a}$ (50) |
| *O. sativa* L. | $0.209^{c}$ (100) | $0.181^{c}$ (87) | $0.163^{c}$ (80) | $0.142^{d}$ (68) | $0.121^{d}$ (58) | $0.113^{b}$ (54) | $0.090^{d}$ (43) |
| *J. linifolia* | $0.276^{a}$ (100) | $0.273^{a}$ (99) | $0.242^{a}$ (88) | $0.224^{a}$ (85) | $0.198^{a}$ (72) | $0.166^{a}$ (60) | $0.113^{c}$ (41) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate values as percent relative to the control

highest $K^+$ /$Na^+$ ratio was recorded in *L. chinensis* followed by *E. crus-galli* and *E. colona* while lowest value was recorded in *O. sativa* followed by *C. iria.* However, at 40 dS $m^{-1}$, the highest value was recorded in *E. crus-galli* and lowest in *O. sativa.*

$K^+$/$Na^+$ ratio in roots also decreased with increasing salinity in all species however, decrease was found to be more than shoots (Fig. 2). The highest $K^+$ /$Na^+$ ratio was found in control treatment for *L. chinensis* (3.97) and lowest in *J. linifolia* (1.41). At 4 dS $m^{-1}$, the highest $K^+$ /$Na^+$ ratio (1.55) was recorded in *L. chinensis* followed by *O. sativa* (1.22) and *E. colona* (1.11) while the lowest (0.63) was found in *E. crus-galli.* At 8 dS $m^{-1}$ and above, maximum $K^+$ /$Na^+$ ratio was recorded in *E. colona* followed *by L. chinensis* and *C. iria,* while the lowest value was recorded in *E. crus-galli* followed by *J. linifolia.*

The results showed that $K^+$ /$Na^+$ ratio decreased both in shoot and root under salt stress due to increased $Na^+$ and decreased $K^+$ ion uptake, with increasing salinity levels. Hence, $K^+$ /$Na^+$ ratio in weed species studied may be explained due to the following reasons : NSCC (non-selective cation channel) allows both $Na^+$ and $K^+$ to enter; HKT (High Potassium Transporters) is a selective transporter of K; but presence of NaCl in apoplast inhibits $K^+$ uptake and accelerates $Na^+$ influx. The results are in

**Table 8 :** Effect of salinity on $Ca^{2+}$content in roots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $0.16^{b}$ (100) | $0.13^{c}$ (81) | $0.11^{d}$ (69) | $0.11^{c}$ (69) | $0.09^{b}$ (56) | $0.09^{b}$ (56) | $0.08^{b}$ (50) |
| *E. crus-galli* | $0.17^{b}$ (100) | $0.16^{b}$ (94) | $0.14^{c}$ (82) | $0.11^{c}$ (65) | $0.09^{b}$ (53) | $0.09^{b}$ (53) | $0.08^{b}$ (47) |
| *E. colona* | $0.14^{c}$ (100) | $0.13^{c}$(93) | $0.12^{d}$ (86) | $0.11^{c}$ (79) | $0.09^{b}$ (64) | $0.09^{b}$ (64) | $0.08^{b}$ (57) |
| *C. iria* | $0.21^{a}$ (100) | $0.19^{a}$ (91) | $0.17^{b}$ (81) | $0.15^{b}$ (72) | $0.14^{a}$ (67) | $0.13^{a}$ (62) | $0.11^{a}$ (52) |
| *O. sativa* L. | $0.16^{b}$ (100) | $0.15^{b}$ (94) | $0.13^{c}$ (81) | 0.09 (56) | $0.08^{c}$ (50) | $0.07^{c}$ (44) | $0.06^{c}$ (38) |
| *J. linifolia* | $0.21^{a}$ (100) | $0.19^{a}$ (91) | $0.18^{a}$ (86) | $0.17^{a}$ (81) | $0.15^{a}$ (71) | $0.13^{a}$ (62) | $0.11^{a}$ (52) |

Means within columns with the same letters are not significantly different (LSD, p>0.05). Values in parentheses indicate values in percent relative to the control

**Table 9 :** Effect of salinity on $Mg^{2+}$ content in shoots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $0.256^{bcd}$ (100) | $0.230^{cd}$ (90) | $0.195^{b}$ (75) | $0.160^{b}$ (63) | $0.137^{b}$ (54) | $0.110^{d}$ (43) | $0.073^{b}$ (29) |
| *E. crus-galli* | $0.311^{a}$ (100) | $0.297^{a}$ (96) | $0.251^{a}$ (81) | $0.221^{a}$ (71) | $0.208^{a}$ (63) | $0.172^{ab}$ (55) | $0.131^{a}$ (42) |
| *E. colona* | $0.286^{ab}$ (100) | $0.271^{ab}$ (95) | $0.259^{a}$ (91) | $0.234^{a}$ (82) | $0.199^{a}$ (70) | $0.190^{a}$ (67) | $0.148^{a}$ (52) |
| *C. iria* | $0.248^{cd}$ (100) | $0.245^{bcd}$ (99) | $0.238^{a}$ (96) | $0.210^{a}$ (85) | $0.183^{a}$ (74) | $0.149^{bc}$ (60) | $0.126^{ab}$ (51) |
| *O. sativa* L. | $0.249^{cd}$ (100) | $0.225^{d}$ (90) | $0.192^{b}$ (77) | $0.171^{b}$ (69) | $0.134^{b}$ (54) | $0.116^{cd}$ (47) | $0.097^{ab}$ (36) |
| *J. linifolia* | $0.282^{ab}$ (100) | $0.268^{abc}$ (95) | $0.257^{a}$ (91) | $0.229^{a}$ (81) | $0.207^{a}$ (73) | $0.163^{ab}$ (58) | $0.126^{ab}$ (45) |

Means within columns with the same letters are not significantly different (LSD, p>0.05); Values in parentheses indicate value in percent relative to the control

**Table 10 :** Effect of salinity on $Mg^{2+}$ content in roots (% dry matter) of six weed species

| Species | Salinity level (dS $m^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 16 | 24 | 32 | 40 |
| *L. chinensis* | $0.24^{b}$ (100) | $0.22^{d}$ (92) | $0.20^{c}$ (83) | $0.17^{c}$ (71) | $0.16^{b}$ (67) | $0.15^{b}$ (63) | $0.12^{a}$ (50) |
| *E. crus-galli* | $0.32^{a}$ (100) | $0.31^{ab}$ (97) | $0.30^{a}$ (94) | $0.27^{a}$ (84) | $0.24^{a}$ (75) | $0.23^{a}$ (72) | $0.17^{a}$ (53) |
| *E. colona* | $0.25^{b}$ (100) | $0.25^{cd}$ (100) | $0.23^{bc}$ (92) | $0.20^{bc}$ (80) | $0.21^{ab}$ (84) | $0.15^{b}$ (60) | $0.14^{a}$ (56) |
| *C. iria* | $0.33^{a}$ (100) | $0.32^{ab}$ (97) | $0.30^{a}$ (91) | $0.27^{a}$ (82) | $0.24^{a}$ (73) | $0.21^{ab}$ (64) | $0.17^{a}$ (52) |
| *O. sativa* L. | $0.30^{ab}$ (100) | $0.28^{bc}$ (93) | $0.26^{ab}$ (87) | $0.22^{abc}$ (73) | $0.20^{ab}$ (67) | $0.16^{b}$ (53) | $0.12^{a}$ (40) |
| *J. linifolia* | $0.34^{a}$ (100) | $0.34^{a}$ (100) | $0.28^{ab}$ (82) | $0.25^{ab}$ (74) | $0.23^{a}$ (68) | $0.17^{ab}$ (50) | $0.16^{a}$ (46) |

Means within columns with the same letters are not significantly different (LSD, p>0.05). Values in parentheses indicate values in percent relative to the control



Online Copy

confirmation with the earlier reports of Munns (2002). Saleque *et al.* (2005) also observed that the molar ratio of $K^+$ /$Na^+$ of rice was greater at low-saline site than at high-saline site. Ashraf and Akhtar (2004) found that $K^+$ /$Na^+$ in sweet funnel decreased due to the effect of salinity. Al-Abdoulhadi *et al.* (2012) showed $K^+$ /$Na^+$ content in stem and roots of date palm (*(Phoenix dactylifera L)* decreased with increasing salinity level.

The results showed that there were significant differences in $Ca^{2+}$ content among weed species and different salinity levels (Table 7). There was a significant negative correlation (R=-0.9979) between shoot $Ca^{2+}$ content and salt concentration *i.e.*, the calcium content declined with increasing salinity levels (Fig. 3). The highest calcium content was found in *C. iria* (0.277 %) in control treatment, while lowest in *L. chinensis* (0.083 %). At 4, 8, 16, 24, 32 and 40 dS $m^{-1}$ salinity, average $Ca^{2+}$ contents in shoots of the weed species reduced to about 95, 89, 76, 64, 59 and 45%, respectively. At 4 dS $m^{-1}$ salinity, $Ca^{2+}$ content decreased marginally in all species. At 8 dS $m^{-1}$, $Ca^{2+}$ content decreased in all species. *Jussiaea linifolia, O. sativa* and *E. crusgalli* showed higher decrease (< 90%) relative to control; while *L. chinensis*, *E. colona* and *C. iria* showed less decrease ( >90%) relative to control. *Leptochloa chinensis* and *J. linifolia* exhibited lesser decreases in $Ca^{2+}$ content at 16 dS $m^{-1}$ with >85% as compared to control. *Echinochloa crus-galli* and *C. iria* performed better with minimum decrease of >60 and 45%, respectively. Compared to the respective controls, the percentage decrease in $Ca^{2+}$ content was found in the following order: *C. Iria* > *J. linifolia* > *E. crus-galli* > *E. Colona* > *L. chinensis* > *O. sativa.*

$Ca^{2+}$ content in roots of six selected weed species decreased significantly with increasing salinity levels (Table 8). A significant negative correlation (R=-0.995) between root $Ca^{2+}$ content and different salinity concentration root $Ca^{2+}$ content declined with increasing salinity levels (Fig. 3). Results showed that the highest $Ca^{2+}$ concentration (0.21%) was observed in *C. iria* under control treatment, while lowest value was found in *O. sativa* (0.06%) at 40 dS $m^{-1}$. On an average, relative values of $Ca^{2+}$ content over control was 91, 81, 70, 60, 57 and 49% in 4, 8, 16, 24, 32 and 40 dS $m^{-1}$ salinity treatments, respectively. At 4 dS $m^{-1}$, there was a very minor decrease in all species, but greater decrease occurred with increasing salinity levels. At higher salinity levels (32 and 40 dS $m^{-1}$), $Ca^{2+}$ content showed highest decrease in *O. sativa*, while least decrease was recorded in *E. colona* followed by *C. iria* and *J. linifolia. The* overall decrease in $Ca^{2+}$ content was as follows: *E. colona* > *J. linifolia* > *C. iria* > *E. crus-galli* > *L. chinensis* > *O. sativa.* In the present study, $Ca^{2+}$ decreased with increasing salinity levels. Kumar *et al.* (2008) found reduction in $Ca^{2+}$content in *Jatropha curcas* due to the effect of NaCl salt**,** which might be due to damaged cell membrane permeability under salt stress which in turn caused displacement of $Ca^{2+}$ by increasing $Na^+$ from the binding sites of phospholipids of membranes (Munns, 2005).

$Mg^{2+}$ content in six selected weed species were significantly influenced by increasing salinity levels, and differences were distinct between control and saline treatments (Table 9). A significant negative correlation (R=-0.9983) between shoot $Mg^{2+}$ content and salt concentration *i.e.,* shoot $Mg^{2+}$ content declined with increasing salinity levels (Fig 3). The results indicated that the highest $Mg^{2+}$ content was observed in *E. crus-galli* (0.311 %), while lowest (0.073 %) was *seen* in *L. chinensis* under control conditions. At 4 dS $m^{-1}$, $Mg^{2+}$ content reduced marginally (<10%) in all species and did not decrease markedly as salinity level increased from 8 to 24 dS $m^{-1}$. *Echinochloa colona, C. iria* and *J. linifolia* showed minimum $Mg^{2+}$ reduction at these salinity levels. At higher salinity levels, *E. colona and C. iria* performed better than other species with relative $Mg^{2+}$ values >60 and 50%, respectively, while *L. chinensis* and *O. sativa* showed more reduction in $Mg^{2+}$ content. The percentage decrease in $Mg^{2+}$ content in shoots was in the following order: *C. iria* > *E. colona* > *J. linifolia* > *E. crus-galli* > *O. sativa* > *L. chinensis.*

$Mg^{2+}$ content in roots of six selected weed species also differed significantly due salinity (Table 10). The results indicate that the highest $Mg^{2+}$ content was found in *J. linifolia* (0.34%) under control (0 dS $m^{-1}$) conditions, while *L. chinensis* had the lowest content (0.12%) at 40 dS $m^{-1}$. At 4 dS $m^{-1}$, there was no significant change in all selected weed species as compared to control. At a glance, decrease in $Mg^{2+}$ content with 4, 8, 16, 24, 32 and 40 dS $m^{-1}$ salinity treatments were 3, 12, 23, 28, 40 and 50%, respectively. At highest salinity level (40 dS $m^{-1}$), maximum reduction was observed in *O. sativa* (60%) followed by *J. linifolia* (54%), while maximum reduction was recorded in *E. colona* (44%) followed by *E. crus-galli* (47%). A significant negative correlation (R=-0.995) between shoot $Mg^{2+}$ content and salt concentration *i.e.* root $Mg^{2+}$ content decreased with increasing salinity level (Fig 3).

The results showed that $Mg^{2+}$ content decreased with increasing salinity levels both in shoots and roots of all species studied but the level of decrease varied among species. Al-Abdoulhadi *et al.* (2012) reported that $Mg^{2+}$ content in stem and roots of date palm (*Phoenix dactylifera L)* decreased with increasing levels of salinity. Kumar *et al.* (2008) also found a declining tendency in $Mg^{2+}$ content in *Jatropha curcas* due to NaCl stress.

The findings of the present study revealed that *C. iria* and *E. crus-galli* were least affected by salt stress followed by *E. colona* and *J. linifolia*, considering effects on biochemical constituents and mineral composition. In terms of overall performance, it was found that *C. iria* and *E. crus-galli* were relatively more tolerant, while *E. colona* and *J. linifolia* were tolerant; *L. chinensis* and *O. sativa* L were salt sensitive. The presence of salt-tolerant weed species in rice ecosystems requires appropriate weed control methods to be applied. Hence, special management should be paid to *Echinochloa* spp. and *C. iria* under saline environment.

**Acknowledgments**

The authors would like to acknowledge the Universiti Putra Malaysia and Long Term Research Grant Scheme (LRGS) in Food Security – Enhance Sustainable Rice Production under the Ministry of High Education, Malaysia for Technical and financial support of this project.

**References**

Abdullah, Z., M.A. Khan and T.J. Flowers: Causes of sterility in seed set of rice under salinity stress. *J.Agron. Crop Sci.,* **187**, 25–32 (2001).

Al-Abdoulhadi, A., H.A. Dinar, G. Ebert and C. Büttner: Influence of salinity levels on nutrient content in leaf, stem and root of major date palm (Phoenix dactylifera L) cultivars. *Int. Res. J. Agric. Sci. Soil Sci.,* **2**, 341-346 (2012).

Ashraf, M.Y. and A.S. Bhatti: Effect of salinity on growth and chlorophyll content of rice. *Pak. J. Sci. Industr. Res.,* **43**,130–131(2000).

Ashraf, M. and N. Akhtar: Influence of salt stress on growth, ion accumulation and seed oil content in sweet fennel. *Biol. Plant,* **48**, 461–464(2004).

Baltex: Assessment of Climate Change ( BACC): Assesment of climate change for the Baltic Sea basin. Springer Berlin, Heidelberg, p.139 (2008)

Bates, L.S., R.P. Waldren and L.D. Teare: Rapid determination of free proline for water-stress studies. *Plant Soil*, **39**, 205–207(1973).

Bernama Malaysia's rice industry: A revamp needed? FAMA Link, FAMA, Ministry of Agriculture and Agro-based Industry, Malaysia (2008).

Clesceri, L.S., A.E. Greenberg and R.R. Trussel: Standard methods for the examination of water and waste water. 17th Edn. American Public Health Association, Washington D.C., pp. 100–175 (1988).

Coombs, J., D.O. Hall, S.P. Long and S.M.O. Scurlock: Chlorophyll determination.Techniques in bioproductivity and photosynthesis. Pergamon Press, Oxford, p. 223(1987).

Desingh, R. and G. Kanagaraj: Influence of salinity stress on photosynthesis and antioxidative systems in two cotton varieties. *Appl. Plant Physiol.,* **33**, 221–234(2007).

Dhanapackiam, S. and M.H. Muhammad Ilyas: Effect of salinity on chlorophyll and carbohydrate contents of *Sesbania grandiflora* seedlings. *Indian J. Sci. Technol.*, **3**, 64–66(2010).

Florkowski, W.J. and G. Landry: An economic profile of golf courses in Georgia: course and landscape maintenance, University of Georgia, Griffin, GA, p. 681 (2002).

Flowers, T.J. and Yeo A.R.: Breeding for salinity resistance in crop plants; where next. *Aust. J. Plant Physiol.,* **22**, 875–884(1995).

Gierth, M., P. Maser and J.I. Schroeder: The potassium transporter at HAK5 functions in $K^+$ deprivation-induced high-affinity $K^+$ uptake and AKT1 $K^+$ channel contribution to $K^+$ uptake kinetics in *Arabidopsis* roots. *Plant Physiol.*, **137**, 1105–1114 (2005).

Hakim, M.A., A.S Juraimi, M.M. Hanafi, A. Selamat, M.R. Ismail and R.S.M. Karim: Studies on seed germination and growth in weed species of rice field under salinity stress. *J. Environ. Biol.*, **32**, 529-536 (2011).

Karim, S.M.R., B.M. Azmi and B.S. Ismail: Weed problems and their management in rice fields of Malaysia: An overview. *Biol. Manan.,* **4**, 177–186(2004).

Khan, M.A., B. Gul and D.J. Weber: Seed germination in the Great Basin halophyte *Salsola iberica*. *Canad. J. Bot.,* **80**, 650–655 (2002)

Khush, G.S.: What it will take to feed 5.0 billion rice consumers in 2030? *Plant Mol. Biol.*, **59**, 1–6 (2005).

Koca, H., M. Bor, F. Ozdemir and I. Türkan: The effect of salt stress on lipid peroxidation, antioxidative enzymes and proline content of sesame cultivars. *Environ. Exp. Bot.*, **60**, 344–351(2007).

Kumar, N., S.D.V.N., M. Kaur, G. Boricha and M.P. Reddy: Effects of NaCl on growth, ion accumulation, protein, proline contents and antioxidant enzymes activity in callus cultures of *Jatropha curcas. Biol.,* **63**, 378–382 (2008).

Ministry of Agriculture (MOA): Agricultural statistics books, 2007. Publication Department, Putrajaya, Malaysia (2007).

Moradi, F. and A.M. Ismail: Responses of photosynthesis, chlorophyll fluorescence and ROS-scavenging systems to salt stress during seedling and reproductive stages in rice. *Ann. Bot.,* **99**, 1161–1173 (2007).

Munns, R.: Comparative physiology of salt and water stress. *Plant Cell Environ.,* **25**, 239–250(2002).

Munns, R.: Genes and salt tolerance: bringing them together. *New Phytol.,* **167**, 645-663(2005).

Nguyen, H.T.T., I.S. Shim, K. Kobayashi and K. Usui: Effects of salt stress on ion accumulation and antioxidative enzyme activities of *Oryza sativa* L. and *Echinochloa oryzicola* Vasing. *Weed Biol. Manag.,* **5**, 1–7 (2005).

Peng, S., J. Huang, J.E. Sheehy, R.C. Laza and R.M. Visperas: Rice yield decline with higher night temperature from global warming. PNAS, **101**, 9971–9975(2004).

Rahman, M.U., U.A. Soomro, M. Zahoor-ul-Haq and S. Gul: Effects of NaCl salinity on wheat (*Triticum aestivum* L.) cultivars. *World J. Agric. Sci.,* **4**, 398–403 (2008).

Rao, A.N., D.E. Johnson, B. Sivaprasad, J.K. Ladha and A.M. Mortimer: Weed management in direct-seeded rice. *Adv. Agron.,* **93**, 153–255 (2007).

Saleque, M.A., N.N. Choudhury, S.M.R. Karim and G.M. Panaullah: Mineral nutrition and yield of four rice genotypes in the farmers' fields of salt-affected soils. *J. Plant Nutr.,* **28**, 865–875(2005).

Selamat, A. and M.R. Ismail: Growth and production of rice for the increased Malaysian population as affected by global warming trends: forecast for 2057. *Trans Malaysian Soc. Plant Physiol.,* p. 17 (2008).

Summart, J., P. Thanonkeo, S. Panichajakul, P. Prathepha and M.T. McManus: Effect of salt stress on growth, inorganic ion and proline accumulation in Thai aromatic rice, Khao Dawk Mali 105, callus culture. *Afr. J. Biotechnol.,* **9**, 145–152(2010).

Thomas, A.G.: Weed survey system used in Saskatchewan for cereal and oilseed crops. *Weed Sci.,* **33**, 34–43(1967).

Veeranagamallaiah, G., P. Chandraobulreddy, G. Jyothsnakumari and C. Sudhakar: Glutamine synthetase expression and pyrroline-5-carboxylate reductase activity influence proline accumulation in two cultivars of foxtail millet (*Setaria italica* L.) with differential salt sensitivity. *Env. Exp. Bot.,* **60**, 239–244(2007)

Wilson, C., S.M. Lesch and C.M. Grieve: Growth stage modulates salinity tolerance of New Zealand Spinach (*Tetragonia tetragonoides*, Pall) and Red Orach (*Atriplex hortensis* L.). *Ann. Bot.,* **85**, 501–509 (2000).

Yamamoto, A., I.S. Shim, S. Fujihara, T. Yoneyama and K. Usui: Physio-chemical factors affecting the salt tolerance of *Echinochloa crus-galli*. *Weed Biol. Manag.,* **3**, 98–104 (2003)

Zhang, Z.P.: Agricultural weeding in conjunction with herbicide application in rice. In: Proceedings of the 18th Asia Pacific Weed Science Conference, Beijing, China, pp 211–214 (2001).



Online Copy