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Effect of Gypsum Application and Irrigation Intervals on Clay Saline-Sodic Soil Characterization, Rice Water Use Efficiency, Growth, and Yield

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Abstract

Saline-sodic soil is considered as a serious problem which could negatively affect rice water use efficiency, plant growth, and yield. Therefore, the objective of the current study was to investigate the effects of gypsum applied before sowing (i.e. gypsum and without gypsum) and irrigation interval treatments applied after anthesis (irrigation every 4, 6, 8 days) on chemical characterizations of clay saline-sodic soil. In addition, the effect of these treatments on rice growth, water use efficiency and related parameters and yield were investigated. A significant higher efficiency in reclamation of clay saline-sodic soil was obtained in terms of reducing SAR, Na^+ and EC when gypsum was applied and water was added every four or six days intervals in comparison to non-treated soil with gypsum and water added every eight days interval. The highest number of spikelets per panicle, ripened grains percent, grain and straw yields were obtained when rice plants were grown on soil treated with gypsum and irrigated every four and/or six days intervals compared to soil with no gypsum and irrigated every eight days interval. The highest water use efficiency was obtained from rice irrigated every six days interval. In conclusion, it may reduce the hazards of the saline-sodic soil due to application of gypsum which improved soil properties, rice growth and its productivity when plants were irrigated every four or six days intervals. This might be due to the valuable nutrient source of gypsum interns of Ca, which mitigated the toxicity caused by salts in saline soils. Gypsum can also be considered as an effective application for clay saline-sodic soil in the North Delta, Egypt.

Keywords: crop-water relations, gypsum, irrigation interval, rice, soil characterization, saline-sodic soil, yield

1. Introduction

Soil degradation, which can be caused by salinity and sodicity, is considered as an environmental impairment with severe adverse effects on agricultural productivity, particularly in arid and semiarid regions (Qadir et al., 2006). Saline soils contain high concentration of soluble salts including sodium chloride (NaCl) and/or sodium sulphate ($Na_2 SO_4$). Sodic soils contain high level of exchangeable sodium (Na), and mostly linked with high soil pH; and are known with their clayey structure (Abrol et al., 1988). Therefore, soils that contain high levels of soluble and exchangeable Na are categorized as saline-sodic soils. Saline soils can be reclaimed by washing with excess of water which can leach and remove the soluble salts out of the root-zone. Nevertheless, the amelioration of saline-sodic soils needs sodium (Na^+) to be removed from soil and this can be managed by adding soluble calcium (Ca^{2+}) salts such as gypsum, and afterward leaching the exchanged Na^+ out of the root-zones (Khosla et al., 1979).

The excessive soluble and exchangeable Na has negative effect on physical- and chemical soil characterizations, and plant growth. For instance, the effects of high level of soluble salts in soil mainly cause an increase in osmotic pressure; consequently plants are hindered to uptake water from soil. The high soil pH, which is correlated with the sodicity, can cause deficiency of some nutrients by reducing their solubility in root zones. Moreover, exchangeable and soluble Na at higher levels can cause toxicity on plant species (Abrol et al., 1988).

Soil salinity is considered the most critical environmental stress which can negatively affect rice growth and the metabolism process (Rodriguez-Navarro & Rubio, 2006). Salinity usually appears in the arid and semi-arid areas where the evaporation process is noticeably higher than the total precipitation (Qadir et al., 2008). Worldwide, over than 76.0 M ha of soils are affected by salinity (Eger et al., 1996), as a result of salts accumulation during long periods of time in soils or groundwater. The increase of salinity in soils and groundwater is a major concern in Egyptian agriculture as a result of inadequate drainage conditions and the reduction in Nile demineralization of the soil owing to the deficiency of flooding (Mohamed et al., 2011). About 33.0 % of total land area cropped is salt-affected land in Egypt (Ghassemi et al., 1995), and is characterized as saline-sodic soils due to their poor physical and chemical properties.

There are many procedures and strategies that can be used to improve salt affected cropland. One of the approaches for the economic utilization of moderately salt affected land is to grow salt tolerant plant species with appropriate agricultural practices (Mokoi & Verplancke, 2010). The chemical remediation is one of these reclamation strategies (Sharma & Minhas, 2005). The application of Ca amendments can improve different properties of soil and act as soil modifiers that can prevent development of sodicity which is directly related to plant growth, crop productivity and crop yields (Wong et al., 2009; Chintala et al., 2010). Specific chemical amendments such as calcium chloride ($CaCl_2{\cdot}2H_2O$) and gypsum ($CaSO_4{\cdot}2H_2O$) can be used as direct source for Ca^{2+} cation; however gypsum is normally available and relatively cheap. In heavy-textured soil, application of gypsum is more appropriated to hasten the process of reclamation in comparison to light-textured soil (Khosla et al., 1979). Gypsum plays a significant role in the reclamation of saline-sodic soils by providing a Ca^{2+} cation to replace the exchangeable Na^+ from the colloid's cation exchange positions and leaching it out from the root zone into groundwater (Ilyas et al., 1997; Sharma & Minhas, 2005).

In order to utilize clay saline-sodic soils, rice (*Oryza sativa* L.) can be planted in these regions. Since the flooded water is not only advantageous to the plant growth but also is needed for leaching salts from the profile soil (Abrol et al., 1988). Rice is the staple food for almost 50.0% of the global population particularly whom live in developing countries such as Egypt. Even though, the rice is considered the second ranked crop after wheat, it is considered the most vital food crop and also the largest irrigated crop in the globe among the different field crops (Roel et al., 1999). Rice occupies approximately one-third of global cultivated area from cereals, and provides about 50.0–80.0% of the total calories consumed by three billion populations (Khush, 2005). In 2010, almost 154 M ha were harvested worldwide, of which 0.62 M ha were in Egypt (FAOSTAT, 2012). Rice is considered as a semi-aquatic crop, since it is generally grown in flooded environment. Nevertheless, approximately 50% of global cultivated area with rice does not have adequate resource of water to maintain such flooded conditions and for this reason the rice growth and consequently its productivity is decreased under drought stress conditions (Hanson et al., 1990). Rice plants have shallow-rooting system, and for this reasons the water uptake from soil might not be adequate for plant growth under drought stress (Fukai & Inthapan, 1988), even though some rice cultivars have longer roots (Lilley & Fukai, 1994). Thus, water is considered an essential factor for cultivation and growth of rice. Fageria and Knupp (2014) reported that gypsum and lime application significantly improved growth and yield of rice.

Nile River, which is the main source of the water in Egypt, provides about 55.5×10^9 m^3 yearly. With the increase in Egyptians population, rice production should be increased and also irrigation of the rice should be handled in the proper way in terms of saving water (FAOSTAT, 2012). During last few years, there was a shortage of water resources in many Egyptian zones. Therefore, rice production in the future will depend mainly on efficient irrigation practices by conserving water (Wong et al., 2009). Such approaches are very imperative for other regions of the globe, in particular Egypt. Saving water from rice irrigation by using advanced technologies, without adverse effect on the growth and yield, is considered an important factor to any strategy of water shortage (Li & Barker, 2004). There is a need to reduce the percolation loss of water and avoid the impact of moderate drought stress on growth of rice plants in saline soil conditions.

The objectives of the current study were (a) to investigate the effects of gypsum applied before sowing (i.e. gypsum and without gypsum) and irrigation intervals treatments applied after anthesis (Irrigation every 4, 6, 8 days) on chemical characterizations of clay saline-sodic soil at harvest, (b) to investigate the effect of these treatments on growth and yield of rice, and (c) to study the effect of these treatments on water use efficiency and related parameters.

2. Materials and Methods

2.1 Plant Materials and Experimental Design

Field experiments were conducted at El-Karada Water Requirements Research Station, Kafr El-Sheikh (North Delta), Egypt (Latitude: 31°6'N/ Longitude: 30°56'E) during two successive growing seasons (2012 and 2013) to investigate the effect of gypsum application and irrigation intervals treatments on chemical characterizations of clay saline-sodic soil at harvest, growth, yield and its component of a moderately salt-tolerant rice (*Oryza sativa* L., cv. Giza 178). The soil characterization before starting the experiment at 0-20, 20-40, 40-60 cm depth is presented in Table 1. The properties of the top soil were: pH 8.2, EC > 9.7 dS m^{-1}, Na^+ 77.0 meq L^{-1} and ESP 35.2% (Table 1). The type of soil was clayey in texture, where the particle size distribution (0-20 cm depth) was clay 44.1%, silt 28.60% and sand 27.3%. Experiments design was split-plot based on randomized complete blocks with four replications. Irrigation intervals treatments (Irrigation every 4, 6 or 8 days after anthesis) were placed in main plots, while gypsum treatments (with- and without gypsum) were placed in sub-plots to form in total six treatments as follows:

Control – I_4 = Irrigation every 4 days + No gypsum

Control – I_6 = Irrigation every 6 days + No gypsum

Control – I_8 = Irrigation every 8 days + No gypsum

Gypsum – I_4 = Irrigation every 4 days + Gypsum

Gypsum – I_6 = Irrigation every 6 days + Gypsum

Gypsum – I_8= Irrigation every 8 days + Gypsum

The size of sub-plot was 67.5 m^2 (13.5 m × 5.0 m). Main plots were designed and separated well to avoid infiltration when different irrigation intervals treatments were applied. Leaching was carried out with canal water whose composition was: EC 0.60 dS m^{-1}, SAR 3.90, Na^+ 3.30 meq L^{-1}, K^+ 0.25 meq L^{-1}, Ca^{2+} 1.30 meq L^{-1}, Mg^{2+} 0.15 meq L^{-1}, HCO^{3-} 0.10 meq L^{-1}, Cl^- 1.60 meq L^{-1} and SO_4^{2-} 2.45 meq L^{-1}. The gypsum purity was 97.0%, and it was mixed well with the upper soil layer (0-20 cm depth). Gypsum application was added to soil before sowing at rate of 9.50 t ha^{-1} in comparison to control treatment (i.e. without gypsum). The dose of gypsum was estimated to reduce about 6 meq L^{-1} of Na, since each 1.70 t of gypsum can reduce one meq L^{-1} of Na per ha. Also, the dose of gypsum was estimated to reduce the initial ESP in soil profile from 35.2% to 20.0% (USDA, 1954).

Table 1. Physical and chemical properties of the different soil layers at the experimental field during 2012 and 2013 seasons as average

Parameters	Depth of soil (cm)		
	0-20	20-40	40-60
Physical properties			
Clay content (%)	44.1	40.0	40.0
Silt content (%)	28.6	29.7	31.0
Sand content (%)	27.3	29.3	29.0
Dry bulk density (g cm^{-3})	1.28	1.34	1.35
Wilting point (%)	26.7	24.3	24.2
Field capacity (%)	40.3	37.8	37.8
Saturation capacity (%)	51.7	49.6	49.0
Chemical properties			
$pH_{1:5}$	8.2	8.0	8.2
$EC_{1:5}$ (dS m^{-1})	9.7	8.1	8.0
Na^+ (meq L^{-1})	77.0	65.0	62.0
K^+ (meq L^{-1})	0.46	0.42	0.41
Ca^{2+} (meq L^{-1})	7.3	4.5	4.3
Mg^{2+} (meq L^{-1})	12.5	11.5	10.5
HCO_3^- (meq L^{-1})	8.5	7.1	7.0
Cl^- (meq L^{-1})	58.0	44.0	40.0
SO_4^{2-} (meq L^{-1})	30.8	30.2	30.1
SAR	24.5	23.0	22.8
ESP (%)	35.2	32.9	32.7

Note. EC = Electrical conductivity; SAR = Sodium Adsorption ratio; ESP = Exchangeable sodium percentage.

Calcium super phosphate (15.5% P_2O_5) was applied at rate of 15.5 kg P_2O_5 ha^{-1} before sowing. Total N fertilization was added at the rate of 160 kg N ha^{-1} as urea product (46.5%) and applied on three equal doses during rice growth to avoid the leaching of N. Seeding rate was 140 kg ha^{-1}. Grains were germinated and grown in nursery field for 30 day, then transplanted into permanent field. In the permanent field, about six plants were placed in each hill on 15 × 15 cm distance. Rice seeds were sown on May 10th in 2012 and May 15th in 2013. Recommended agricultural practices were applied during growing seasons as described by Egyptian Ministry of Agriculture. Meteorological data at El-Karada station during two growing seasons (2012 and 2013) are presented in Table 2.

Table 2. The recorded data of El-Karada meteorological station during 2012 and 2013 seasons

Month	2012				2013			
	Temperature (°C)		Wind speed (km day^{-1})	RH (%)	Temperature (°C)		Wind speed (km day^{-1})	RH (%)
	max	min			max	min		
May	28.7	12.6	135.0	58.8	26.9	14.4	96.0	60.7
June	33.6	19.0	115.1	62.5	33.5	14.4	102.0	61.4
July	33.9	20.9	97.1	67.5	32.0	20.0	102.1	65.1
Aug.	33.5	19.7	79.5	68.4	34.0	21.2	93.5	67.9
Sept.	32.5	19.0	83.3	64.5	33.4	19.2	88.2	65.4
Average	32.4	18.2	101.9	64.3	31.9	17.8	96.3	64.1

Note. max = maximum, min = minimum, RH = relative humidity, there was no precipitation during the growing period.

2.2 Measurements

2.2.1 Soil Analysis

Soil samples were collected before sowing from following depths: 0-20, 20-40 and 40-60 cm and at harvest from 0-20 cm depth using auger. Each soil sample was divided into two subsamples; first subsample was air-dried and passed through a 2-mm sieve for physical and chemical properties analysis, while second subsample was stored in -20 ºC for further analysis.

Physical and chemical analysis was done according to hydrometer method by using hydrogen peroxide and sodium hexametaphosphate (dispersing agents) according to Bouyoucos (1962) and as explained recently by Sarkar and Haldar (2005). Dry bulk density (g cm^{-3}) was measured as explained by Vomocil (1957). Electrical conductivity ($EC_{1:5}$) and $pH_{1:5}$ were measured using a portable EC and pH meters. Na^+ and K^+ were analyzed using the flame photometer (USDA 1954; Chintala et al., 2014a). Ca^{2+} and Mg^{2+} were analyzed by titration method using versant solution. Ferrochrome black T was used as indicators for Ca^{2+}, Mg^{2+}, while ammonium purported was used to determine Ca^{2+} (Jackson, 1967).

Bicarbonate (meq L^{-1}) was analyzed using the titration against standard solution of potassium hydro-sulphate. Phenolphthalein was used as an indicator for carbonates and methyl orange for the bicarbonate (Nelson, 1982). Sulfate (SO_4^{2-}) was analyzed by weighing 50.0 g air-dried soil sample (> 2.0 mm) and mixed with 50.0 mL distilled water (1 w: 1 v). Samples were shaken for 10 min, centrifuged on 3000 rpm for 5 min, and then filtered using Whatman paper no. 42. Conditional reagent was prepared from analytical grade chemicals by adding 50.0 mL glycerol into a solution consists of 30.0 mL HCl (37%), 300.0 mL distilled water, 100.0 mL ethanol (95%) and 75.0 g NaCl. About 2.0 to 4.0 mL from extracted sample was diluted into 100 mL and mixed with 5.0 mL of conditional reagent and 0.2 g of $BaCl_2$ crystals. Immediately, samples were stirred for 1.0 min. Finally, samples were measured using UV-VIS spectrophotometer at the absorbance of 420 nm with standard sulfate (0.1 N) curve prepared from Na_2SO_4.

Chloride concentration in soil extracts (1:5 soil/ water) was analyzed as described in Mohr's titration method (Rhoades, 1982) using silver nitrate $AgNO^3$ (0.025 M) with potassium chloride KCl (0.l00 M) as an indicator.

Sodium adsorption ratio (SAR) was calculated as indicator for potential soil sodification using following Equation (1) as described in USDA (1954):

$$SAR = \left[Na^+\right] / \sqrt{\frac{\left(\left[Ca^{2+}\right] + \left[Mg^{2+}\right]\right)}{2}} \tag{1}$$

Where, Na^+, Ca^{2+} and Mg^{2+} were expressed in meq L^{-1}.

2.2.2 Rice growth, Yield and Its Components

Ten plants were randomly collected at maturity from the middle of each plot to measure plant height (cm), panicle length (cm) and number of spikelets per spike. Plants were harvest at the ground level, dried at +72 °C for 2 days, and panicle weight (g) and 1000-grain weight (g) were measured. One m^2 from each plot was harvested, dried at +72 °C for 2 days, for measuring grain and straw yields (kg DM ha^{-1}). Ripened grains percent was calculated as described in following Equation (2). Number of unhulled brown rice grains trapped in a 1.8-mm screen was used in the calculation.

$$Ripened\ grain\ (\%) = \frac{Number\ of\ unhulled\ brown\ grains\ per\ panicle}{Total\ number\ of\ spikelets\ per\ panicle} \times 100 \tag{2}$$

2.2.3 Rice Water Relations Measurements

Irrigation water applied (IWA), water consumptive use (CU), rice water use efficiency (WUE), water utilization efficiency (WUtE) were measured during the two successful growing seasons.

IWA was recorded (m^3) using Woltmann Removable Dry Type Water Flow Meter (Model: LXLC-50-500, ECVV, Ningbo Yinzhou Tongda Meter Factory, Zhejiang, China). It was expressed as an amount of water applied to each treatment plus the amount of water applied in both nursery field during 30 days after sowing and permanent field. The irrigation in the permanent field was begun after seven days from the transplanting and was ended 15 days before harvest during both of growing seasons. The irrigation was transmitted by means of lined ditches with controlled gates to each plot. The submerged head of each irrigation time was approximately 5 cm at irrigation intervals every 3 days (continuous flooding).

Water consumptive use (CU) was calculated by determining the soil moisture content prior to and after 48 h from each irrigation according to Israelsen and Hansen (1962) as following Equation (3):

$$CU\ (\text{m}^3\text{ha}^{-1}) = \frac{\theta 2 - \theta 1 \times BD \times ERZ \times 10000}{100 \times 100} \quad (3)$$

Where, CU = amount of consumptive use ($m^3\ ha^{-1}$), θ_2 = soil moisture content after irrigation, θ_1 = soil moisture content prior to the following irrigation, BD = bulk density ($g\ cm^{-3}$), ERZ = effective root zone (0.6 m).

Rice water utilization efficiency (WUtE) was calculated using the following Equation (4) (Michael, 1978):

$$WUtE\ (kg\ m^{-3}) = \frac{\text{Rice grain yield (kg ha}^{-1})}{\text{Total water applied (m}^3\text{ ha}^{-1})} \quad (4)$$

Rice water use efficiency (WUE) was calculated as described in Equation (5) (Jensen, 1983):

$$WUE\ (kg\ m^{-3}) = \frac{\text{Rice grain yield (kg ha}^{-1})}{\text{Total consumptive water used (m}^3\text{ ha}^{-1})} \quad (5)$$

2.3 Statistical Analysis

The obtained data of the different traits were statistically subjected to the analysis of variance (ANOVA) using PASW statistics, version 22.0 (IBM Inc., Chicago, IL, USA). Standard error of means (S.E.M.) was obtained from the analysis of variance using PASW.

3. Results

3.1 Soil Characterization at Harvest

The application of gypsum into clay saline-sodic soil resulted in a significant decrease in the Na^+ content, SAR and EC at harvest when water was added every four days after anthesis in comparison to other treatments (Table 3). Na^+ was decreased in the upper layer (0-40 cm) of soil treated with gypsum – I_4 by 41.3% and 39.3% compared to control – I_8 and gypsum – I_8, respectively.

Table 3. Chemical analysis of soil treated with gypsum and different water irrigation interval at harvest

Treatment	Na^+ ($g.kg^{-1}$)	Ca^{2+} ($g.kg^{-1}$)	Mg^{2+} ($g.kg^{-1}$)	SAR	EC ($ds.m^{-1}$)
Season 2012					
Control – I_4	49.0	7.93	6.66	18.14	5.9
Gypsum – I_4	39.7	9.16	8.33	13.43	5.5
Control – I_6	57.0	7.03	6.12	22.23	6.6
Gypsum – I_6	51.1	7.98	6.34	19.10	6.0
Control – I_8	67.8	6.23	5.40	28.12	7.3
Gypsum – I_8	68.6	7.34	6.01	26.56	7.4
S.E.M.	0.43	0.12	0.12	0.81	0.10
Season 2013					
Control – I_4	41.1	8.54	7.11	14.69	4.6
Gypsum – I_4	33.7	9.50	8.44	11.25	4.1
Control – I_6	49.4	7.59	6.63	18.52	5.5
Gypsum – I_6	37.9	10.3	8.98	12.21	4.9
Control – I_8	57.2	7.53	6.65	21.48	6.6
Gypsum – I_8	52.5	7.43	6.34	20.01	5.9
S.E.M.	0.41	0.15	0.11	0.94	0.10

Note. S.E.M. = standard error of means.

In addition, EC was decreased by 66.0 and 65.0% in gypsum – I_4 with respect to the control – I_8 and gypsum – I_8, respectively. This indicates that gypsum was effective method to reduce the salinity and sodicity in clay soil when irrigation was added every 4 or 6 days after anthesis, in comparison to the irrigation every 8 days. On the other hand, content of Ca^{2+} and Mg^{2+} was significantly increased in soil treated with gypsum (Table 3). However, there were no significant differences between Na^+, SAR, and EC obtained from the control – I_8 and gypsum – I_8 (Table 3).

3.2 Growth Parameters, Yield and Its Components

Growth parameters and yield components of rice plants in soil treated with gypsum – I_6 and gypsum – I_8 were improved in comparison to non-treated soil (Tables 4 and 5). Gypsum application resulted in a significant increase in plant height, panicle weight and its length compared to non-treated soil (Table 5). The panicle weight of rice was increased from 1.70 g in control – I_8 to 2.20 g in gypsum – I_8. In addition, results showed that application of gypsum and irrigation interval treatments, particularly I_4 and I_6, significantly increased number of spikelets per panicle, ripened grains percent, 1000-grain weight and yield of grain and straw per ha compared to control – I_8 and gypsum – I_8 (Table 5 and Figure 1). The increase was higher by 18% for number of spikelets per panicle, 7% for ripened grains, 32% for grain yield, 20% for straw yield when rice was grown on soil treated with gypsum – I_6 than those grown with gypsum – I_8 (Table 5 and Figure 1). Gypsum – I_6 and gypsum – I_8 increased 1000-grain weight by 34.0% higher than grown on control – I_6 and control – I_8**,** and by 46.0% higher than those grown on soil treated with gypsum – I_8 (Table 5).

Table 4. Growth traits of rice plants grown with different water irrigation interval and on soil treated with gypsum application

Treatment	Plant height (cm)	Panicle length (cm)	Panicle weight (g)
Season 2012			
Control – I_4	80.9	17.4	1.90
Gypsum – I_4	82.0	17.8	2.20
Control – I_6	80.7	17.3	1.81
Gypsum – I_6	81.8	17.8	2.10
Control – I_8	80.3	17.1	1.71
Gypsum – I_8	81.8	17.4	2.21
S.E.M.	0.40	0.19	0.12
Season 2013			
Control – I_4	80.7	17.5	2.00
Gypsum – I_4	82.2	17.9	2.31
Control – I_6	80.8	17.4	1.91
Gypsum – I_6	81.9	17.9	2.21
Control – I_8	80.5	17.3	1.70
Gypsum – I_8	81.8	17.6	2.00
S.E.M.	0.41	0.14	0.11

Note. S.E.M. = standard error of means.

Table 5. Yield and its components of rice plants grown with different water irrigation interval and gypsum application

Treatment	Spikelets No. Per Panicle	1000-grain weight (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})
Season 2012				
Control – I_4	102	23.5	9334	9456
Gypsum – I_4	136	34.2	10220	10450
Control – I_6	98	26.5	8298	8652
Gypsum – I_6	131	33.4	9944	10260
Control – I_8	78	22.3	6637	7865
Gypsum – I_8	109	22.8	7414	8523
S.E.M.	1.3	0.21	64.3	65.4
Season 2013				
Control – I_4	106	23.8	10162	9745
Gypsum – I_4	139	34.4	9468	10350
Control – I_6	102	26.9	8365	8793
Gypsum – I_6	134	33.5	9954	10500
Control – I_8	82	22.4	6854	8045
Gypsum – I_8	114	22.9	9954	8754
S.E.M.	0.94	0.20	93.8	77.3

Note. S.E.M. = standard error of means.

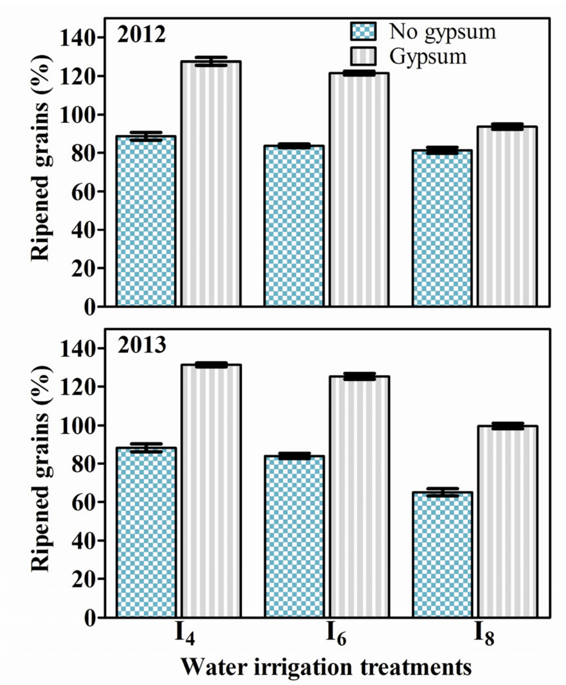

Figure 1. Ripened grain % of rice grown with different water irrigation interval and gypsum application

3.3 Crop-Water Relations

Gypsum – I_6 significantly increased WUtE and WUE in comparison to all other treatments (Table 6). On the other hand, the highest irrigation water applied and water consumption use were obtained when irrigation was added every 4 days interval (Table 6).

Table 6. Irrigation water applied (IWA), water consumptive use (CU), rice water use efficiency (WUE), water utilization efficiency (WUtE) of rice plants grown with different water irrigation interval and on soil treated with gypsum

Treatment	IWA (m^3 ha^{-1})	CU (m^3 ha^{-1})	WUTE (kg m^{-3})	WUE (kg m^{-3})
Season 2012				
Control – I_4	13587	11352	0.68	0.81
Gypsum – I_4	14350	10254	0.71	1.10
Control – I_6	11465	9763	0.72	0.82
Gypsum – I_6	11644	8805	0.86	1.20
Control – I_8	10353	7543	0.64	0.91
Gypsum – I_8	10184	6701	0.73	1.10
S.E.M.	274.6	72.85	0.014	0.010
Season 2013				
Control – I_4	13153	11362	0.72	0.83
Gypsum – I_4	14258	10412	0.71	0.97
Control – I_6	11401	9325	0.73	0.89
Gypsum – I_6	11325	8597	0.88	1.16
Control – I_8	10342	7436	0.66	0.92
Gypsum – I_8	10052	6832	0.76	1.12
S.E.M.	195.3	53.3	0.012	0.009

Note. S.E.M. = standard error of mean.

4. Discussion

A significantly higher efficiency in reducing soil sodicity was obtained in soil treated with gypsum – I_4 followed by gypsum – I_6 compared with non-treated soil (Table 3). This was attributed to gypsum application which resulted in an increase for Ca^{2+} within the soil solution and promoted the displacement of adsorbed Na^+, subsequently leaching process (Chi et al., 2012). A decrease in SAR was furthermore obtained from control – I_8. This was might be attributed to the removal of Na^+ from the soil solution through leaching process. Also, it could be due to dilution of valence (Reeve & Bower, 1960). In a soil–water system, there is a balance between the monovalent cations such as Na^+ and divalent cations such as Ca^{2+} on exchange sites and those in soil solution (Chi et al., 2012; Chintala et al., 2014b). In case of adding the water to the system as in the current study, the balance condition will be changed because this dilution of the soil solution will favor the adsorption of divalent cations (i.e. Ca^{2+}) more than monovalent cations (Na^+) (Chi et al., 2012).

The Na^+ content at harvest in soil treated with gypsum was much lower than in non-treated soil under all irrigation treatments (Table 3). This was due to the dissolution of gypsum in treated soil whereby Ca^{2+} cations replaced Na^+ cations on the colloidal surface and consequently excess water leached the replaced Na^+ out of the upper layer. Furthermore, the reduction in Na^+ from the treated soil with gypsum could be linked to improved rice root growth. Usually, H^+ is released out of the root cells owing to the active electrogenic transport mechanism which is known in plant root cells accumulating Na^+ cations in saline environment conditions (Gorham et al., 1985).

Soil salinity was significantly reduced in terms of EC in soil treated with gypsum compared with non-treated soil (Table 3). Also, adding irrigation every 4 days intervals resulted in a significant reduction in soil salinity compared to other irrigation treatments. This could be due to the increase in the leached soluble salts from soil in this treatment.

Gypsum application into clay saline-sodic soil and irrigation rice plants every 4 days interval followed by 6 days interval improved growth and yield compared to soil with no gypsum particular when irrigation was added every 8 days intervals (Tables 4 and 5). This could be due to higher reclamation efficiency in terms of chemical soil properties (Table 3). For instance, the level of salinity in terms of EC which is safe (EC 3 dS m^{-1}) for rice growth was obtained from soil treated with gypsum – I_4 (Table 3), and such progress in soil reclamation might resulted in an evident reduction in osmotic potential. The slight soil salinity in soil treated with gypsum – I_6 did not affect grain yield of rice. It seems that gypsum was more efficient in presence of irrigation, and consequently the regular irrigated crops are recommended in such clay saline-sodic soils, since the leaching level after the irrigation is more efficient in removing salts from the saline soils (Ali & Yousofi-Falakdehi, 2009). Moreover, the soluble Ca^{2+} might decrease the binding of Na^+ to the cell wall and plasma membrane (Rengel, 1992) and consequently improve the integrity and functions of the plasma membrane (Lauchli, 1990). Therefore, soluble Ca^{2+} released by gypsum could be a factor that alleviated the stress effect of Na^+ on rice growth (Chi et al., 2012).

The highest WUtE and WUE were obtained from rice grown on soil treated with gypsum – I_6 in comparison to other treatments. This was mainly due to the high grain yield of rice. WUE was significantly higher in desiccated conditions than irrigated conditions (Hafez et al., 2014).

The most critical cases of yield reduction when plants grown on saline soils that have not undergone remediation are a subsequent effect of toxic ion accumulation in the plant cells (Hasaneen et al., 2009), which can cause a reduction in water use efficiency. Yueqing et al. (2013) showed that the soil salt reduction increased with the increasing discharge frequency at a 30-mm irrigation water depth. Because of this, rice yield and irrigation water use efficiency were significantly higher under the traditional practice of high-irrigation with low-frequency discharge.

5. Conclusions

After two successive seasons of rice grown on clay saline-sodic soil treated and non-treated with gypsum and irrigated with three different intervals after anthesis (I_4, I_6 and I_8), the conclusions are:

Gypsum application significantly increased Ca^{2+} and Mg^{2+} of the clay saline-sodic soil. The improvement of soil chemical properties in terms of removal Na^+ salt and reducing EC that caused a significant reduction in soil salinity and sodicity was obtained from gypsum – I_4. Highest water use efficiency and water utilization efficiency in rice grown on clay saline-sodic were obtained with gypsum – I_6. A significant improvement in growth and increase in yield of rice were obtained when gypsum was applied into clay saline-sodic soil and irrigation was added every 4 days interval followed by 6 days interval. Therefore, gypsum – I_6 is considered as effective treatments to leach the soluble salts for reclamation of clay saline-sodic soil and improved water use efficiency, plant growth, and yield of rice.

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