European Journal of Scientific Research
ISSN 1450-216X Vol.26 No.2 (2009), pp.288-297

http://www.eurojournals.com/ejsr.htm

Automated *In-Situ* Soil Salinity Logging in Irrigated Agriculture

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Abstract

Saline soils are significant as formations of ecosystem on the earth affected by high concentrations of soluble salts, and as means of crop production with little economic value due to salinity. Many plants either fail to grow in saline soils or their growth is retarded significantly. However, few plants grow well on saline soils; therefore, soil salinity often restricts options for cropping in a given area. Understanding soil salinity helps understand subtle difference across the agricultural fields, and allows more precise management of irrigated fields. Salinity measurement is one the simplest, least expensive tool. This can be accomplished by using routine (EC meter, salinity bridge through salinity sensors) and modern equipment (EC Probe, EM38 and automated salinity measurement though salinity sensors). The choice of the technique depends upon the purpose, size of the area, soil depth, and frequency of measurement, accuracy required and the available resources. The International Center for Biosaline Agriculture (ICBA) Dubai United Arab Emirates has recently installed an automated salinity logging system in a grass field irrigated with three water salinity levels. In these fields salinity sensors have been buried at 30 and 60 cm depths in different treatments. Initial observations revealed that the dynamic changes of soil salinity within an irrigation cycle are showing the effect of water salinity on the salt concentration in the root zone and water suction and how this is constantly changing under irrigation. In this paper the system is fully described and the initial results about soil salinity, temperature and water suction are discussed.

Keywords: ICBA; Salinity Monitoring; Biosaline Agriculture; DataBus; Smart Interface

1. Introduction

Irrigated agriculture has faced the challenge of sustaining its productivity for centuries. One of the major threats to irrigated agriculture productivity is soil salinity, either developed through high water table and capillary rise and subsequent evaporation or through using alternative irrigation water sources where the quality of irrigation water is often low (variable salinity). Salinity can cause various salt stresses such as physiological drought (salt induced drought), potential nutrient and element toxicities or management problems, nutrient imbalances and induced deficiencies, inhibition of soil water & oxygen due to soil structure breakdown.

Soil salinity in an agricultural farm may exhibit considerable spatial and in depth variability (that is salt levels vary from one location to another & in depth) across the landscape because of water movement, infiltration rate, run-off and evapo-transpiration patterns. Seasonal variation may occur in response to change in irrigation regimes, cyclic natural precipitation and variability of water quality over a season. Once the salinity is developed it can decrease crop yield or complete failure of crop may occur if not properly managed in time. Salinity mapping & monitoring in agricultural fields is essential to track periodic salinity changes in the root zone and beyond to assess the performance of crops and to make management adjustments.

Soil section of the International Center for Biosaline Agriculture (ICBA) is specialized in dealing with saline lands from salinity mapping, assessment to management and reclamation for better crop production and soil health. ICBA accomplishes regular salinity mapping & monitoring through collecting soil samples, their processing and salinity measurement in the laboratory and through electromagnetic induction (EMI-EM38) characterization in the field. Recently ICBA has taken the lead in the advancement of salinity monitoring and installed a Real Time Dynamic Automated Salinity Logging System (DASLS) in a grass filed. The system allows an improved understanding of the dynamic behavior of *in-situ* salinity of the soil solution. Hourly data logging of soil salinity and temperature using soil salinity sensors connected to a “Smart Interface” enables direct and dynamic monitoring of soil salinity EC in units of dS/m at 25 ºC. With this addition it is now possible to hourly log soil salinity without soil sampling. The system is installed in a grass field irrigated with 10, 20 and 30 dS/m salinity water. Salinity sensors have been buried at 30 cm and 60 cm depths. The dynamic changes of soil salinity within an irrigation cycle have shown the effect of water salinity on the salt concentration in the root zone of the grass and how this is constantly changing under irrigation.

The National Agricultural Research Systems (NARS) and Agricultural Extension Departments, by including initial salinity mapping/monitoring plans coupled with selection of salt tolerant varieties into good agricultural practices (which are technically sound, economically attractive, environmentally safe, feasible in practice and socially acceptable) can contribute significantly to poor farmer’s returns by improving crop yields from the saline soils.

2. Why Salinity Assessment and Monitoring in Irrigated Agriculture?

Salinity measurement and mapping prior to seeding/plantation can provide a general guidance about yields from salinized area relative to that without salinity. Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called threshold level). At salinity levels greater than the threshold, crop yield reduces linearly as salinity increases. Using the salinity values in a salinity/yield model developed by Maas and Hoffman in 1977, predictions of expected yield loss can be made (Maas, 1986). Typically, plant growth is suppressed when a threshold value of salinity is exceeded. Maas and Hoffman expressed salt tolerance of many crops by this relationship: $Yr = 100 - s(ECe - t)$, where Yr = percentage of the yield of crop grown in saline conditions relative to that obtained on non-saline conditions; t = threshold salinity level where yield decrease begin; s = percent yield loss per increase of ECe (dS/m) in excess of t. In this model it is assumed that crops respond primarily to the osmotic potential of soil solution, and specific ion effects is of secondary importance. Salinity monitoring helps understand the root zone salinity levels, whether below or above threshold level of crop in the field. The latter will require extra water to be applied based on the leaching fraction to maintain the root zone salinity below crop threshold salinity. The Table below (Shahid, 2004) provides general information about threshold levels of different crops and relative yield decline above threshold salinity.

Table 1: Relative productivity (%) of some important crops with respect to soil salinity (ECe in dS/m)

Plant	**Scientific Name**	**Relative Productivity (Yr) at Selected ECe (dS/m)**								
		1	**2**	**4**	**6**	**8**	**10**	**14**	s^1	t^2
Bean	*Phaseolus vulgaris*	100	81	43	6	0	0	0	18.9	1.0
Carrot	*Daucus carota*	100	86	58	30	1	0	0	14.1	1.0
Onion	*Allium cepa*	100	87	55	23	0	0	0	16.1	1.2
Cabbage	*Brassica oleracea*	100	98	79	59	40	20	0	9.7	1.8
Cucumber	*Cucumis sativus*	100	100	81	55	29	3	0	13.0	2.5
Pepper	*Capsicum annum*	100	91	65	39	13	0	0	13.0	1.3
Lettuce	*Lutuca sativa*	100	93	65	37	8	0	0	14.1	3.2
Potato	*Solanum tuberasom*	100	96	72	48	24	0	0	12.0	1.7
Radish	*Raphanus sativus*	100	90	64	38	12	0	0	13.0	1.2
Spinach	*Spinacia oleracea*	100	100	85	70	55	39	9	7.6	2.0
Tomato	*Lycopersicum esculentum*	100	100	85	65	46	26	0	9.9	2.5
Brocoli	*Brassica oleracea*	100	100	89	71	52	34	0	9.1	2.8
Alfalfa	*Medicago sativa*	100	100	85	71	56	42	12	7.3	2.0
Corn (F)	*Zea mays*	100	99	84	69	54	39	10	7.4	1.8
Berseem	*Trifolium alexandrinium*	100	97	86	74	63	51	29	5.8	1.5
Barley (F)	*Hordeum vulgare*	100	100	100	100	86	72	44	7.0	6.0
Barley (G)	*Hordeum vulgare*	100	100	100	100	100	90	70	5.0	8.0
Sorghum	*Sorghum bicolor*	100	100	100	98	78	63	43	7.6	4.8
Wheat	*Triticum aestivum*	100	100	100	100	86	71	43	7.1	6.0
Date	*Phoenix dactylifera*	100	100	100	93	86	78	64	3.6	4.0

S^1 = % yield decrease per 1 dS/m increase in ECe above threshold ECe
t^2 = salinity threshold ECe (dS/m), where yield is optimum

3. Description of the DASLS

A feature of the salinity logging system is that it does not require any knowledge of electronics or computer programming. To operate the salinity station simply plug in a salinity sensor and the Smart Logger will then search the databus and automatically identify the number of salinity sensors connected and begin logging them at hourly intervals. For custom configuration of the Smart Logger or salinity sensors a simple menu system can be accessed through HyperTerminal that provides complete control over each individual sensor's set-up. Instantaneous readings from sensors can be viewed on the logger's display directly in the field without the need for a laptop. Data can also be accessed in the field by memory stick or remotely using a mobile phone modem. This data is then available for graphing and interpretation in Excel.

3.1. System Installation & Operation

Salinity sensors are buried at 30 and 60 cm depths in a grass field (*Distichlis spicata* & *Sporobolus virginicus*) irrigated with 10, 20 and 30 dS/m salinity water (Figure 1). The sensors through smart interface are connected to DataBus leading to smart Datalogger. The Smart datalogger search the DataBus and automatically identify the number of salinity sensors connected and begin logging them at hourly intervals. For custom configuration of the Smart Logger or salinity sensors a simple menu system can be accessed through HyperTerminal that provides complete control over each individual sensor's set-up. Instantaneous readings from sensors can be viewed on the logger's display directly in the field without the need for a laptop. Data can also be accessed in the field by memory stick or remotely using a mobile phone modem. This data is then available for graphing and interpretation in Excel.

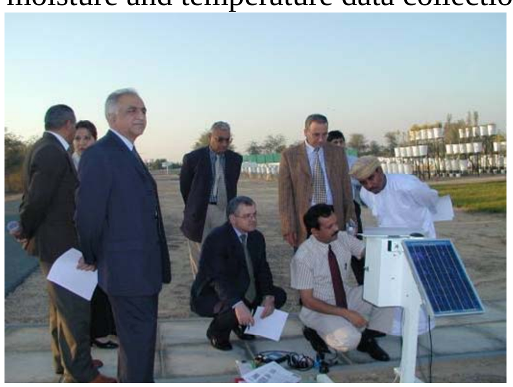
Figure 1: Installation of DASLS in a grass field

Sensor placement in the grass rootzone

Buried sensors connected to smart interface

Smart interface connected to DataBus, which is connected to Smart Datalogger

Instantaneous salinity, moisture and temperature data collection on smart Datalogger



4. Results and Discussions

4.1. Soil and Water Resource Information at ICBA Experimental Field

The experimental site is generally level, loose sandy surface, very deep and calcareous. Due to sandy nature, the soil has very high drainage capacity (well to somewhat excessively drained), and are moderate to rapidly permeable. The soils are developed from wind blown sandy calcareous material and are highly prone to wind erosion.

4.1.1. Soil Taxonomic Class of the Experimental Site

The experimental site was assessed for taxonomic class using the norms and standards of the United States Department of Agriculture "Soil Taxonomy" (Soil Survey Division Staff, 1993; USDA-NRCS, 1999 & 2003). The soil is classified as *Carbonatic, Hyperthermic Typic Torripsamment.* Where carbonatic is the mineralogy class i.e., more than 40% $CaCO_3$ in fine earth fraction, hyperthermic is soil temperature regime (the mean annual soil temperature is 22ºC or higher, and the difference between mean summer and mean winter soil temperature is more than 6ºC at a depth of 50 cm from the soil surface). Typic torripsamment indicates typical desert sandy soil at soil subgroup level of USDA Soil Taxonomy.

4.1.2. Physical and Chemical Characteristics of Surface Soil

The methods used are from USDA-NRCS (2004), except where otherwise stated. Complete Particle Size Distribution Analysis (PSDA) was made by using modified hydrometer method (Day, 1965; Shahid, 1992) supplemented with wet sieving (that allows quantification of sub fractions of sand) suitable for soils with low organic matter contents. The data (sand, silt, clay) presented is on less than 2 mm basis. Textural class is reported by plotting the sand (2-0.05 mm), silt (0.05 to 0.002 mm) and clay (<0.002 mm) values on the textural triangle (Soil Survey Division Staff, 1993). Saturation percentage (SP) is determined by volume of water added to a known amount of soil to prepare saturated soil paste, the SP value is plotted into the model suggested by USDA (USDA-NRCS, 1995) to determine water retention at 15 bars (W15) and available water capacity (AWC) of soils. The pH was measured on a saturated soil paste (pHs) and Electrical Conductivity in the saturation extract collected from the saturated soil paste under vacuum. The calcium carbonates equivalents were determined by Calcimeter procedure, where a known amount of soil was reacted with known amount of 1N HCl, and the CO_2 produced is measured and converted to $CaCO_3$ equivalents.

The soil results are presented in Table 1, which clearly reveals that native soil at ICBA is fine sand in texture, non-saline, moderately alkaline and strongly calcareous. Organic matter is very low (<0.5%) and the Munsell Soil Color-dry (GretagMacbeth, 2000) is 10YR 6/4 pale brown, which is a composite reflection from the dominance of carbonates and sand, with insignificant contribution of organic matter to color composition. The high $CaCO_3$ (53%) can cause soil buffering capacity and affect nutrient availability to plants. Available water capacity is low, suggesting careful water management plan to offset plant requirements and to avoid pressure on drainage system.

Table 1: Physical and Chemical Characteristics of Soil (0-30 cm)

Physical Characteristics	
Gravels (2-5 mm)	<0.5%
Very coarse sand (2-1 mm)	3%
Coarse sand (1 – 0.5 mm)	3%
Medium sand (0.5 - 0.25 mm)	4%
Fine sand (0.25 – 0.1 mm)	51%
Very fine sand (0.1-0.05 mm)	37%
Coarse silt (0.05 – 0.02 mm)	0.5%
Fine silt (0.02 – 0.002 mm)	0.5%
Clay (<0.002 mm)	1.0%
Total Sand (2-0.05 mm)	98%
Total silt (0.05-0.002 mm)	1.0%
Total clay (<0.002 mm)	1.0%
Textural Class	Fine sand
Saturation Percentage	26%
Water retention at 15 bar (W15)	6.5%
Available Water Capacity (AWC)	4.13%
Chemical Characteristics	
Electrical conductivity of saturation extract (ECe)	1.2 dS/m
pHs	8.22-moderately alkaline
$CaCO_3$ (equivalents)	53%

4.1.3. Water Quality

There is one water source (flow rate 45 $m^{3/}$hr) at ICBA station that is saline and sodic [(EC 30 dS/m & SAR 31 $(mmole/l)^{0.5}$] and the quality fluctuates slightly with aquifer recharge after heavy rain. Water composition is shown in Table 2. Low salinity water (EC = 3 dS/m) is brought from Dubai-Al-Ain area at Habab, which flows from Dubai Municipality water line at a rate of 40 m^3 per hour. There are two water pumps, which extract water from these two sources. From these sources two water lines run parallel to each other and enter into mixing chambers where two waters are mixed in different ratios to achieve desired salinity levels before entering into experimental plots.

Irrigation water from ICBA source was analyzed for standard water quality parameters (water salinity, residual sodium carbonates-RSC, and sodium adsorption ratio-SAR). The importance of these parameters in relation to water quality for irrigated agriculture is discussed in detail by Shahid (2004). Water salinity refers to the total concentration of dissolved salts-salinity hazard. Sodicity-relative proportion of sodium cations to other cations particularly Ca and Mg i.e., SAR ($SAR = Na/[(Ca+Mg)/2]^{0.5}$) expressed as $(mmoles/l)^{0.5}$, where all concentrations are in meq/l. The high SAR deteriorates soil structure and reduces water penetration into and through soil. Similar to drought and salinity, excess proportion of sodium, in comparison to calcium and magnesium, reduce water availability to the crops. Residual Sodium Carbonates (RSC) – bicarbonate anion and carbonate anion concentration as related with calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations [$RSC = (CO3^{2-} + HCO3^{-}) – (Ca^{2+} + Mg^{2+})$] where all concentrations are in meq/l.

Table 2: Water quality at ICBA experimental station

Water Quality	
Water salinity	EC = 30 dS/m
Water Conductivity Class	C4 (very high salinity water)
Residual Sodium Carbonates	Nil
Sodium adsorption Ratio	31 $(mmoles/l)^{0.5}$
Water Sodicity Class	S4 (very high sodium water)
Water Class (Richards, 1954)	C4S4

4.1.3.1. Water Salinity and Sodicity Class – C4S4

C4 water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and highly salt-tolerant crops should be selected. S4 class is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

4.2. Salinity, Temperature and Moisture Monitoring in a Grass Field

The monitoring is taking place in a grass field which is being irrigated with 10, 20 and 30 dS/m salinity water. Salinity sensors have been buried at 30 cm and 60 cm depths. The dynamic changes of soil salinity within an irrigation cycle are showing the effect of the salinity of the irrigation water on the salt concentration in the rootzone of the grass and how this is constantly changing under irrigation. The soil temperature can gave assistance with interpretation of soil moisture movement as no soil moisture sensors were installed.

Highlights of salinity, temperature and moisture monitoring for 25 days are presented here. Days 15-19 was the rainy period.

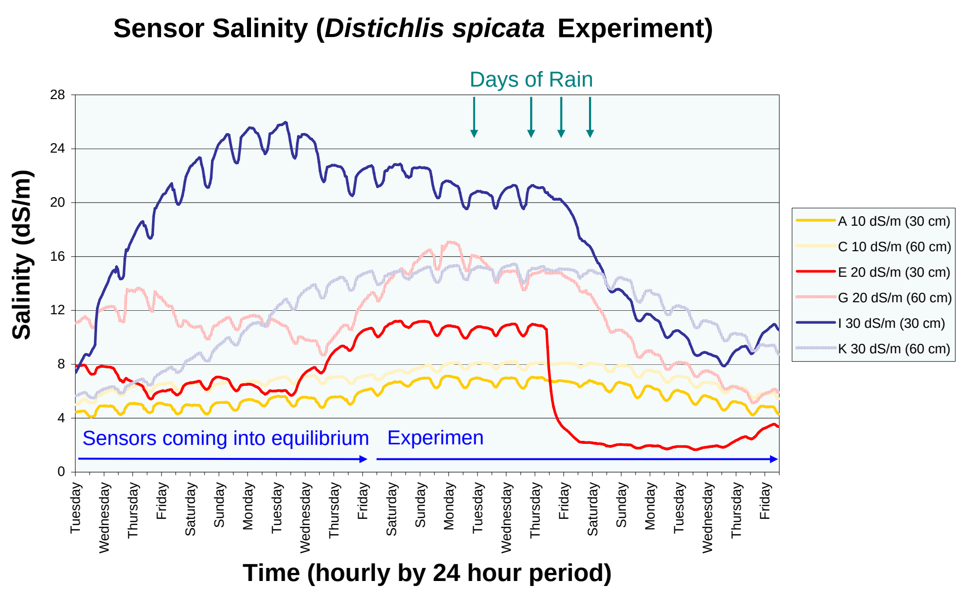
4.2.1. Soil Salinity Monitoring

The soil salinity data recorded in the *Distichlis spicata* grass field (Figure 2) shows;

- After initial installation it takes about 10 days for the sensors to come to equilibrium with the soil solution. This is especially for the 30 dS/m treatment.
- Salinity levels for the 10 dS/m irrigation water treatment are stable and typically 6-8 dS/m with little change after rainfall.

- Salinity levels for the 20 dS/m irrigation water treatment are 10 dS/m at 30cm and 14-16 dS/m at 60cm under standard irrigation and management practice. Rainfall rapidly reduces the salinity level at 30cm and 60cm. At 60cm the salinity level falls by 8-10 dS/m from 16 to 6 dS/m.
- Salinity levels for the 30 dS/m irrigation water treatment are above 20 dS/m at 30cm and 14-16 dS/m at 60cm under standard irrigation and management practice. These values are higher than for the other treatments reflecting the higher salinity of the applied irrigation water.
- The sensitivity of the sensors to changing soil salinity levels is illustrated by both the diurnal fluctuation of salinity levels and the rapid changes that were measured after rainfall. Diurnally the data is indicating a slight decline in soil salinity as the soil dries between 9:00 am and 4:00 pm, when irrigation water is again applied to the treatments (Figure 1).

Figure 2: Soil salinity monitoring in Distichlis spicata grass field



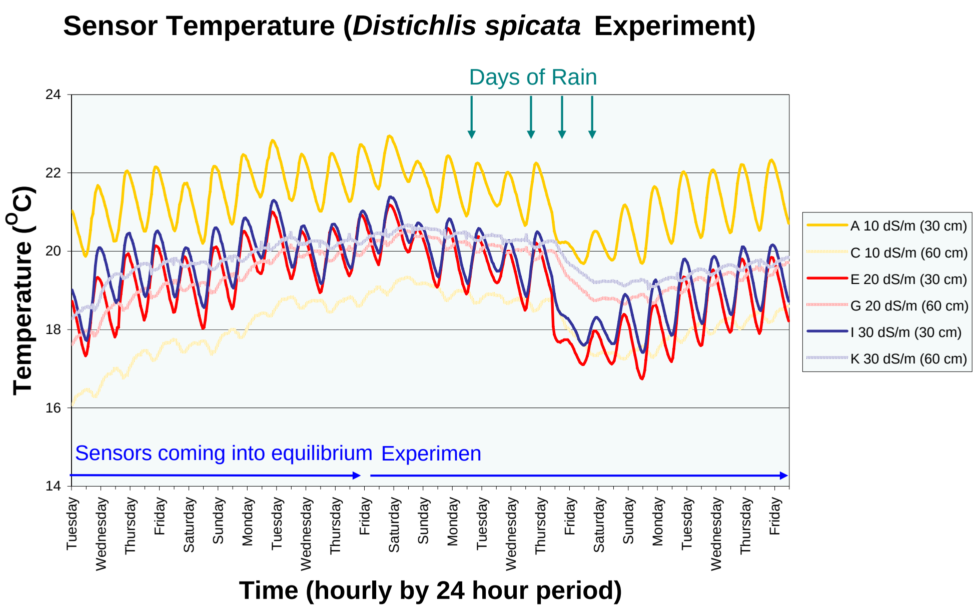
Note: AC, EG & IK indicates that the experimental plot was irrigated with 10, 20 & 30 dS/m salinity water. Y-axis shows soil salinity fluctuation in different days.

4.2.2. Soil Temperature Monitoring

The soil temperature data (Figure3) shows:

- Diurnal fluctuation in 30cm temperature and a more stable temperature at 60cm.
- After rainfall the soil temperature decreased at both the 30cm and 60cm depths. This indicates rainfall infiltration to 60cm. This was associated with a fall in soil salinity after the rainfall at both 30cm and 60cm (Figure 1)

Figure 3: Soil temperature monitoring in Distichlis spicata grass field



4.2.3. Soil Moisture Monitoring

The soil moisture (tensiometer) was data logged in only one treatment 10 dS/m at 30cm in *Sporobolus virginicus* grass field (Figures 4 & 5).

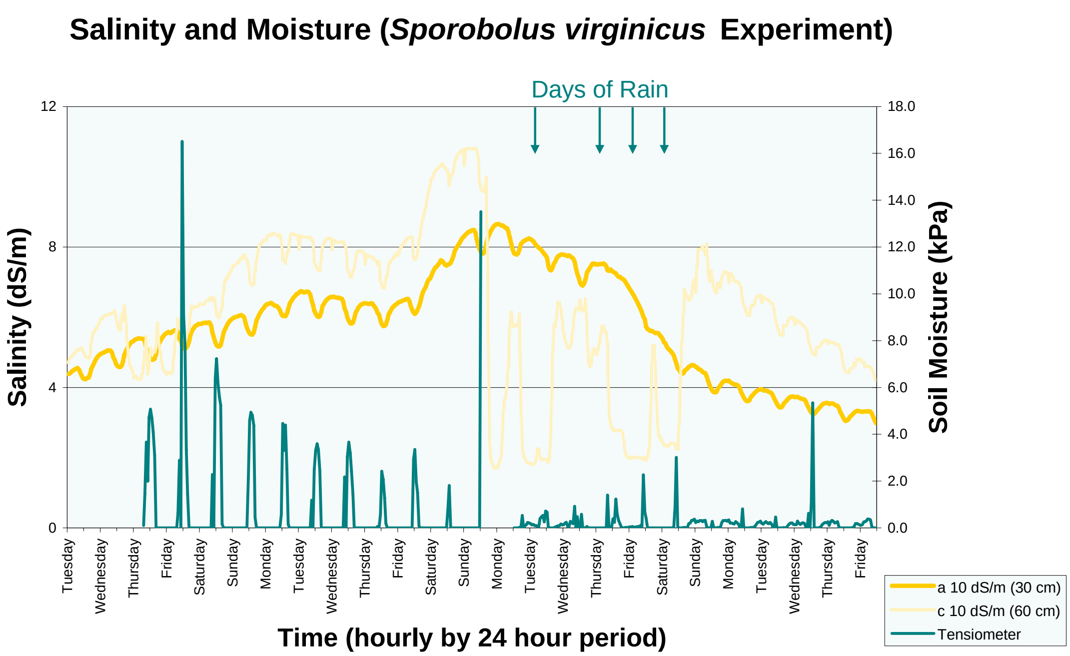
The soil tension levels are 0 kPa from 4:00 pm to 9:00 am each day indicating that the soil at 30cm is at field capacity overnight. Each day the tensiometer first increases suction at the 9:00 am reading as the soil begins to dry from plant water use. The soil suction is driest at 1:00 pm each day and typically prior to the rainfall events 2-4 kPa at 1:00 pm. After this time the soil suction declines due to upward flux of water from depths below 30cm at a rate sufficient to satisfy the demands of plant water use. This flux will impact the salinity levels within the profile and indicates the necessity to monitor closely soil water movement and soil salinity dynamics at the same time.

5. Conclusions

For agricultural fields irrigated with brackish or saline water it is essential to regularly monitor soil salinity to allow take necessary action to avoid salinity build up in the root zone of any crop. The objective of such a monitoring is to avoid build up of soil salinity above threshold salinity level. The monitoring could be achieved through routing salinity measurement by EC meter in the laboratory. This is laborious procedure, therefore, any system that is technically sound, simple and fully automated is the best choice. The dynamic changes of soil salinity within an irrigation cycle are showing the effect of water salinity on the salt concentration in the root zone and water suction and how this is constantly changing under irrigation. The results of pilot scale DASLS installed in a grass field has been very promising to accomplish salinity, temperature and soil moisture monitoring, and this could be a choice, however, the system is costly and should be used carefully from sensor calibration and measurement in the field.

Figure 4: Soil moisture monitoring – Field demonstration Tensiometer in *Sporobolus virginicus* grass field

Figure 5: Soil moisture monitoring in Sporobolus virginicus grass field



Acknowledgment

The authors like to acknowledge the interest and approval of budget by Prof. Faisal Taha (Director Technical Programs) of International Center for Biosaline Agriculture Dubai, UAE and Dr. Peter Cull of ICI International Australia for his assistance in setting up the Automated Salinity Logging System in grassfield at ICBA experimental station and follow up support.

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