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Soil Salinity Dynamics in Raised Bed and Furrow (RBF) System and its Effect on Alleviating Waterlogging in the Coastal Lowlands

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Abstract

In the coastal and humid tropical island regions waterlogging and soil salinity are serious threat to the sustainability of rainfed agriculture due to sea water inundation and intensive monsoonal rainfall. The present study was set out to evaluate and assess the raised beds technique to alleviate this problem in coastal lowlands. The raised bed and furrow (RBF) system reduced the overall salinity by 85%, improved the drainage of the raised beds, harvested rain water, and prevented entry of tidal and runoff water into the furrow. Based on the rate of reduction in salinity lag phase, leaching phase and equilibrium phase were recognised during the leaching of salts from the raised beds. But coastal lowlands experienced waterlogging (5-81 cm) and salinity (3.0-9.1 dS m^{-1}) which closely followed the rainfall pattern. Waterlogging and salinity peaks at different seasons requiring different management strategies but, raised bed and furrow system are effective in addressing this challenge together.

Key words: Coastal salinity, Waterlogging; Raised bed system, Rainwater harvesting

Introduction

On a global scale, irrigation induced salinity and waterlogging severely affects about 30 m ha with an additional 80 m ha to be affected to some extent (El-Ashry and Duda, 1999). The diversion of agricultural land for non-agricultural purposes and the need for increasing food production from the limited land resources to meet the ever growing demand, have brought the focus on salt-affected and degraded lands. Initially the focus was on the better use of land that was becoming salinized because of irrigation, whereas in recent years the focus has moved to ''dryland salinity''- land salinized because of rising water tables associated with the replacement of perennial vegetation with annual crops and pastures (Ghassemi *et al.*, 1995). Similarly the secondary salinization process has become a major concern for land managers in the north-western part of India.

In an island ecosystem of Andaman, high and intensive rainfall received during monsoon season and sea water intrusion during high tide together with high evaporation experienced during the dry season create waterlogging-salinity problem in the coastal lowlands though they peak at different time period (Velmurugan *et al.*, 2015). Although coastal salinity due to sea water inundation has been experienced in India and throughout the world it varied in terms of degree of salinity, depth of ground water as well as salinity of surface water resources (Yadav *et al.*, 1979). There are several reports indicating reduction in crop growth, yield and quality of produce, decreased nutrient uptake, reduced root growth and damage to the root system due to soil salinity (Malik *et al.*, 2002; Dong *et al.*, 2008). Consequently, waterlogging and soil salinity together with poor drainage and lack of quality irrigation water impaired agricultural development in coastal areas.

It is therefore, urgent need to reclaim the areas affected with these problems and make them to productive (Dam *et al.*, 2013). In recent years permanent raised bed systems have been adopted in a wide range of irrigated and dryland farming systems to increase the water use efficiency, providing better opportunities for leaching of salts (Devkota *et al.*, 2015) and growing rainfed cereals (Bakker *et al.*, 2005) in waterlogged-saline areas. Owing to limited land resources, geographical isolation, waterlogging-salinity and the looming problem of climate change, raised bed system provides scope for efficient utilization of available resources. However, scientific studies on leaching of soluble salts from the raised bed and its pattern are lacking which are vital to understand its impact on agricultural production and environment quality. Therefore, an attempt was made to study the effect of raised bed and furrow system in coastal lowlands of Andaman Islands on leaching of soluble salts and temporal changes in salt dynamics in the raised beds by harvesting rain water in the furrows. The basic intention was to find suitable ways to manage coastal waterlogging-salinity together.

Material and Methods

Study area

An experiment was conducted to assess the effect of raised bed and furrow system made at three sites in Dasrathpur village (12° 292 38.203 N, 92° 562 1.143 E) located in the coastal waterlogged-saline soils of Middle Andaman Islands, India. Andaman Islands located in the Bay of Bengal, about 1,200 km from the Indian mainland experiences hot and humid climate with distinct dry (January to April) and wet season (June to November). The annual rainfall varies from 2900 to 3100 mm with mean maximum and minimum temperature of 32°C and 22°C, respectively. The relative humidity varies from 68 to 86% and during most part of the year it is hot and humid. As these islands are situated close to the equator intensive solar radiation is received resulting in high evapo-transpiration particularly during dry period far exceeding precipitations which creates water deficit conditions. The major land forms are longitudinal hills, intermountain valleys and coastal plains. Agriculture is confined to valleys and coastal plains. The soils are derived from coastal alluvium and subjected to periodic sea water inundation thereby developed into acid-saline soils. Heavy rainfall during the monsoon season often results in water stagnation in the coastal areas while it experiences salinity during January to May. The situation was further aggravated by December 2004 Indian Ocean *tsunami* (Velmurugan *et al.*, 2014).

Raised bed and furrow (RBF) system

Raised bed and furrow (RBF) system suitably modified for lowland conditions is locally also known as broad bed and furrow (BBF) system. The basic design of RBF system comprised of four raised beds of 4 m width and three furrows of 6 m width formed to a convenient length (~ 50 m). It was made in February/March 2009 by excavating the soil from either side of the bed and putting it in the bed area by cut and fill method. The excavated area is formed into a furrow of 6 m width having a depth of 1.5 m and 1:1 slope. At the end of the furrow an area of 2 m x 2 m was further deepened up to 2.5 m depth to collect water which will act as fish shelter during dry period. Each raised bed was made into an inverted trapezium and are stabilized by planting annual grasses on either side (Ambast *et al.*, 2011).

The beds were left fallow and exposed to rain during the subsequent rainy season (June to November) favouring natural drainage to leach out the salts and other toxic substances into the furrow. It was essential to drain out the excess water from the furrow by installing PVC pipes at a height of 1.2 m from the base of the furrow in the downward slope of RBF system. This also ensured proper drainage and unsaturated root zone condition in the raised beds. The system was brought under cultivation from December 2010 beginning with green manure legumes followed by growing seasonal vegetables. However, irrigation was not provided for the first two years till the time the salinity of furrow water become normal. Fresh water fishlings were introduced in the second year after the onset of monsoon and the furrows were filled with fresh water to ensure proper growing environment for fishes.

Sampling and analysis

The study involved collection and laboratory analysis of soil and water samples from raised beds and furrow at periodic intervals to capture the temporal variations in salinity. After making raised beds and furrows, surface and sub-surface soil samples (0-15, 15-30, 30-45, 45-60 cm) were taken from the raised beds at monthly intervals from April 2009 to November 2013 to monitor the salt dynamics. Here soil samples were collected from 3 beds in each site and pooled to form one representative sample and all the three sites constituted the replications. However, data relevant to leaching of salts and salinity dynamics of RBF system were presented.

Water samples were collected from the furrows at monthly intervals from 2009-13 to determine the salinity parameters. In addition to this soil and water samples from the coastal lowlands were collected in March 2009 to assess the pre-intervention properties. Rainfall at required frequency and climatic normal was computed from the climatic data repository of the institute.

The soil samples were shade dried and sieved through 2 mm sieve for further analysis. Saturation paste extract was used to determine the electrical conductivity (EC_e), pH, and concentrations of cations (Na^+, Ca^{2+} and Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-) by following standard procedures (Page *et al.*, 1982). Particle size distribution, soil bulk density, soil organic carbon (g kg^{-1}) and the available N, P and K status were determined by following standard procedures (Jackson, 1973).

Statistical analysis

The mean values of salinity parameters between different years and seasons were compared by one way analysis of variance (ANOVA). Significant differences were assessed on probability level of 5%. Regression analysis was carried out to build salinity prediction model. All the statistical analysis was carried out in SAS programme.

Results and Discussion

Soil characteristics

The initial soil properties of the study site showed that the soils are clay loam in the surface layer and clay of fluvial / marine origin in the sub-surface layer. The soils are acid-saline but the degree of salinity or acidity varies with locations based on the magnitude of marine influence and Al^{3+} / Fe^{2+} content. The surface soils of the coastal lowlands are acidic (pH 5.9) with high variations than the layers below (pH 5.5) because these coastal lowlands are more often subjected to pH modifying factors and circumstances (Singh and Mongia, 1985). The soil salinity was high at the surface which marginally decreased with depth and varied with season. Soil bulk density was more at the top which decreased with depth indicating soil compaction and impeded drainage conditions. As expected, soil organic carbon content was high due to addition of organic materials from left over crop residues and natural vegetation. The available N, P and K status were medium, low and low, respectively.

Salinity dynamics in RBF system

The primary effect of RBF system made in the coastal low lands was by way of improved drainage along with leaching of toxic compounds. This process enables RBF system to provide for proper crop growing conditions on the raised beds. The temporal and seasonal distribution of soil salinity was captured by measuring the electrical conductivity of saturation extract (EC_e) at monthly intervals. As expected top soil salinity was much lower during wet season (June-November) than the dry season (Jan-May). The observation of temporal distribution of surface soil salinity in RBF system showed significant reduction in salinity ($p \le 0.05$) from its high value in March 2009 to relatively low value in June 2013. In a humid tropical zone with high annual rainfall substantial amount of salts is being removed from the coastal soils over the period of time by the percolating rainwater (Rachman *et al.*, 2008). In general, three fairly distinct phases were observed when leaching proceeds from high salinity to relatively lower value based on the rate of reduction in soil salinity viz., lag phase, leaching phase and equilibrium phase (Fig. 1).

After the formation of raised beds by cut and fill method the salt concentration on the beds was high. The beds were characterised by clamps of large size and lots of cleave between them. With no appreciable amount of rainfall received for the next two months there was little chance for downward movement of salts and clay migration which was recognised as lag phase. With the onset of monsoon during June the leaching process proceeded in a faster rate almost for two years except for slight rise in salinity during the intervening summer. Mondal *et al*. (2001) also reported increasing trend in salinity during dry period from January to April in the coastal rice soils. On an average, EC_e decreased from the high value of 8.45 dS m^{-1} in March 2009 to 1.34 dS m^{-1} in March 2011 recording 86% reduction from the initial level. This phase was termed as leaching phase as it recorded maximum decrease in soil salinity. The duration of leaching phase may vary in other locations depending on the amount of rainfall, initial salt concentration and area of water conducting pores. The rapid decrease in soil salinity from the raised beds was due to removal of soluble salts by the percolating rainwater as evidenced by the significant decrease in ionic concentration and improved drainage conditions created by RBF system (Table 1). The improvement in drainage is

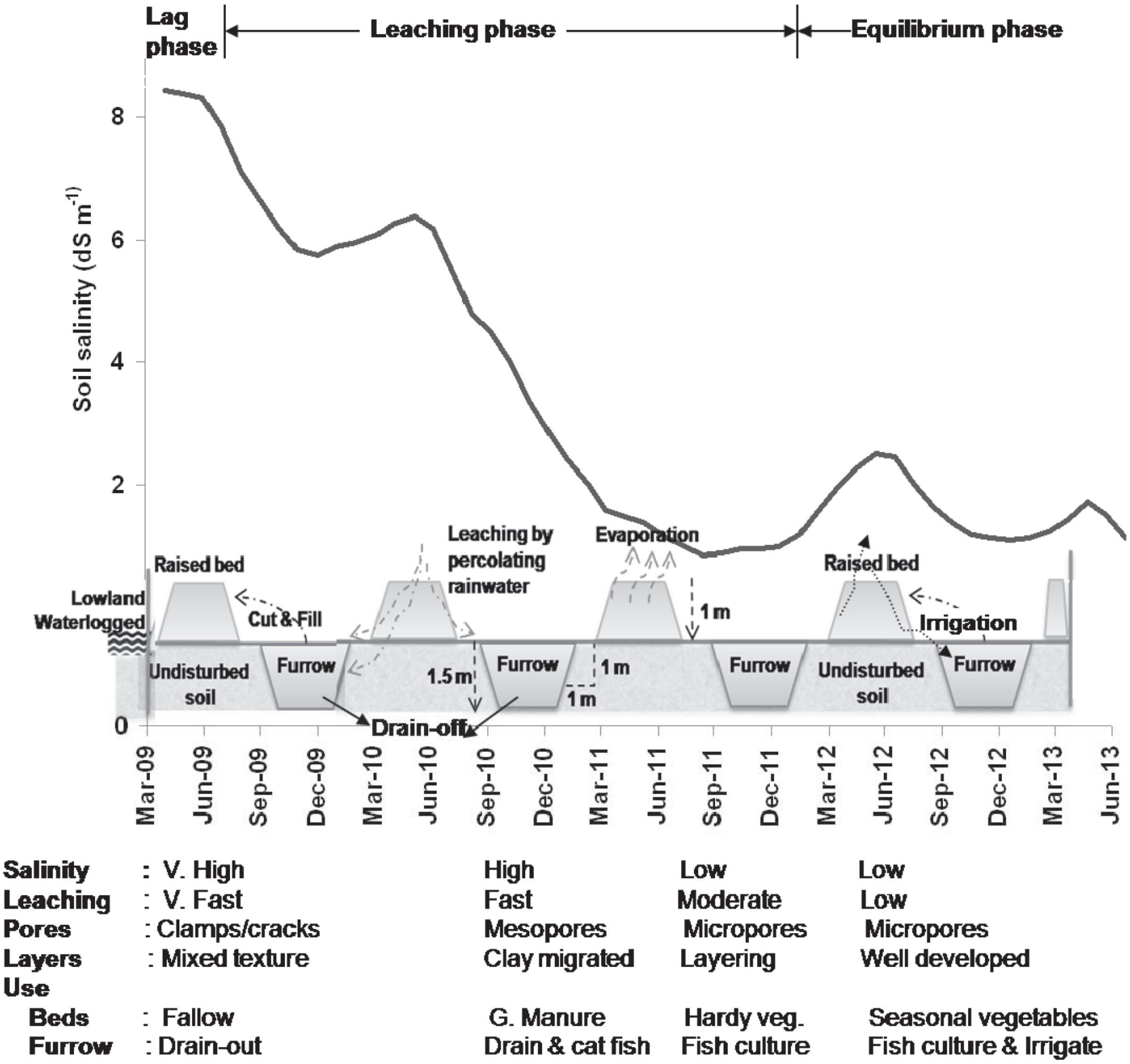

Fig. 1. Design of RBF and description of leaching phases as observed in the system

Table 1. Temporal changes in ionic concentration of coastal lowlands and RBF system

Parameters	Coastal lowlands in March 2009		RBF system in March 2013	
	Soil	Water	Raised bed	Furrow water
Soil texture	Clay loam	-	Clay loam	-
Bulk density (g cc^{-1})	1.26	-	1.30	-
pH	5.89	6.1	6.36	6.4
EC_e (dS m^{-1})	8.45	4.6	1.4	0.76
Ca^{2+} (meq l^{-1})	7.3	8.6	8.6	1.9
Mg^{2+} (meq l^{-1})	3.9	6.1	3.3	1.5
Na^{+} (meq l^{-1})	82.6	76.9	32.5	4.6
K^{+} (meq l^{-1})	43.6	29.3	27.6	2.3
SO_4^{2-} (meq l^{-1})	98.6	21.7	22.3	4.3
Cl^{-} (meq l^{-1})	123.7	86.4	60.2	18.4
HCO_{3-} (meq l^{-1})	1.3	3.8	1.1	1.3
SAR	34.9	28.4	13.3	3.5

attributed to higher percentage of macropores created by piling of soil lumps in the first year thereafter, decomposition of root system of the original vegetation resulted in higher percentage of mesopores (Minh *et al.*, 1997).

Subsequently soil salinity attained dynamic equilibrium with the rainfall pattern as the possibility for significant salt addition from outside the RBF system was minimised. This process of detoxification also significantly increased soil pH (6.36) of the beds than that of the surrounding soils (pH 5.80) treated as control. This was equilibrium phase during which the salinity only fluctuated between wet and dry season around a mean value. Meanwhile, the leachate collected in the furrows along with the rain water was drained-off by providing drainage pipes at the lower end of the slope. This helped to ease out the salt concentration in the furrow water and inturn from the RBF system.

Rainwater harvesting in the furrows

In contrast to waterlogging of coastal lowlands due to heavy monsoon rainfall, RBF system was aimed to harvest and store the rain water in the furrows. The temporal observations of depth of water in the furrows indicated 120 cm during the monsoon period upto the level of drainage pipes while it falls back to 40-60 cm during dry period in April-May (Fig. 2). Significant variations in dry season rainfall during 2009-13 contributed to the water level fluctuations during the period. Even during the peak of dry season in April 2012 the furrow could store water to a depth of 0.40 m (±0.15m) and it reached the full level (1.2 m) by the end of July. The harvested rain water can be used for multiple purposes such as fish culturing and providing supplemental irrigation to crops grown on the raised beds during dry season. Further, the bunds of RBF system effectively prevented intrusion of sea water during high tides

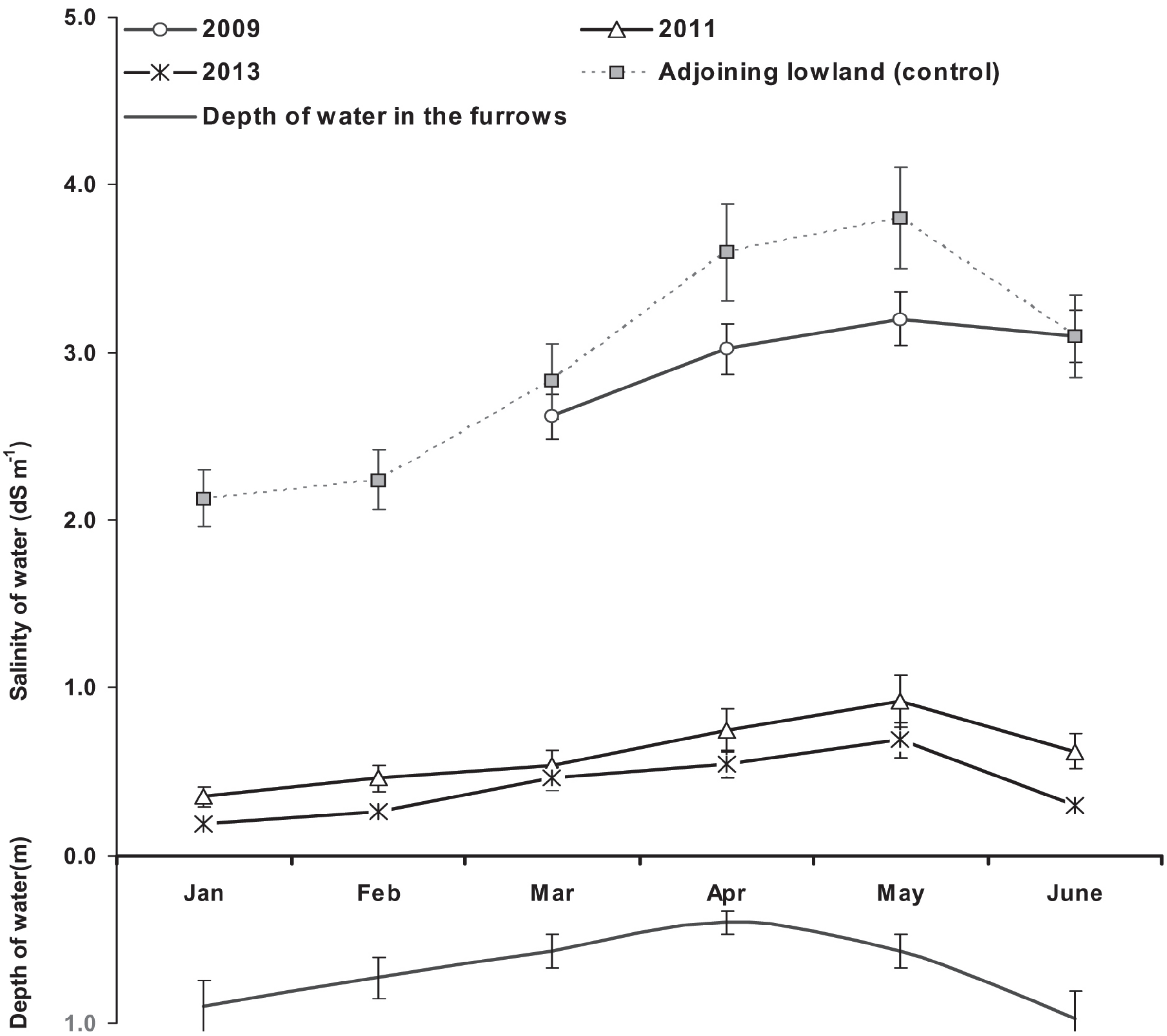

Fig. 2. Temporal changes in depth of water harvest and salinity in the furrows

directly into the furrows. This was evidenced from relatively lower chlorine (18.4 meq l^{-1}) and sulphate (4.3 meq l^{-1}) concentrations of furrow water. The prevention of waterlogging by improved drainage and *in-situ* water harvesting in the furrows facilitates crop diversification by growing different vegetables on the beds.

Salinity in the furrows

The salinity of water in the furrows primarily originated by way of leaching of soluble salts from the raised beds by the percolating rain water. It was also possible from the rising saline ground water level and sea water intrusion. Consequently, during the first year after making of RBF system the salinity level in the furrow was very high due to the reasons cited above. Irrigating the crops with high salinity water will add salts and toxic compounds back into the raised beds. Therefore, water from the furrows was drained out during the first year after making RBF system (2009-10) which enabled harvesting of fresh rain water for its subsequent use for irrigation.

As the rain water harvested in the furrows is mainly meant for providing irrigation during dry periods, it is very much pertinent to monitor the salinity during this season. The temporal changes in EC of furrow water over the years indicated significant reduction in salinity though it varied concomitant with the changes in dryness experienced during February - April. After the stabilization of salinity in raised beds by 2012, leaching of salts into the furrow water significantly decreased as evidenced from the lower EC of water (0.76 dS m^{-1}) and other soluble ions. Thereafter, the observed seasonal variation in salinity was possibly due to salt addition from outside the system as in the case of rise in saline ground water level and seepage of sea water from the surrounding coastal lowlands.

Alternatively, salinity of water collected in the coastal lowlands adjoining the RBF system was found to be high (4.6 dS m^{-1}) and reached its maximum during May. The higher salinity level could be due to saline ground water ingression which was within 2-4 m and movement of salts to the surface through water vapour. This was evidenced by the higher soluble ionic concentration and SAR value of water collected from the coastal lowlands surrounding the intervention sites. With the onset of rains during June, the salt content was reduced by dilution and removal of saline water by runoff. Rasel *et al.* (2013) also reported higher soil salinity in coastal areas of Bangladesh during dry months of April/May due to sea water ingression.

Effect of raised beds over coastal lowland

In contrast to the leaching process occurring in the raised bed the salinity level in the adjoining coastal lowlands fluctuated seasonally with high concentration of salts observed during dry period (Fig. 3). After stabilization of RBF system surface soil salinity during dry period of 2012 recorded EC_e < 2.0 dS m^{-1}, however in adjoining flat land it raised beyond 9 dS m^{-1} in 2012 and similar trend was observed again in 2013 due to less than normal dry season rainfall. However, due to leaching of soluble salts and dilution effect of standing water with the onset of rains (Mondal *et al.*, 2001; Rasel *et al.*, 2013) soil salinity (EC_e) during wet season (June to November) decreased and remained below 3 dS m^{-1} with lowest values recorded during August-September. Beginning from the month of January again there was an increase in soil salinity due to ingression of sea water through creeks and upward movement of salt from the saline ground water (Rasel *et al.*, 2013). In general, the soil salinity closely followed the rainfall pattern of the Island.

Soluble ion concentration of surface soil determined immediately after making of RBF system indicated higher concentration (meq l^{-1}) of cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (Cl^-, SO_4^{2-} and HCO_3^-) which corresponds to higher EC_e. Significant reduction in concentration of soluble salts with the corresponding decrease in EC_e was recorded as these salts were leached out in the subsequent years by percolating rain water. The SAR decreased to a value of 13.3 in the raised bed from a high value of 34.9 estimated before the intervention indicating the easing of Na^+ toxicity. In contrast, the soluble ion concentration in coastal lowlands was high with seasonal fluctuations (Velmurugan *et al.*, 2015).

Predicting soil salinity in the raised beds

Soil salinity varied widely across the years between dry and wet periods in raised beds so as in coastal lowlands. Analyzing and establishing the quantitative relationship of EC_e with other hydrological factors will help to understand the occurrence and movement of salts in soil. Soil moisture content in raised beds depends on the physical properties of soils and land use. It has strong

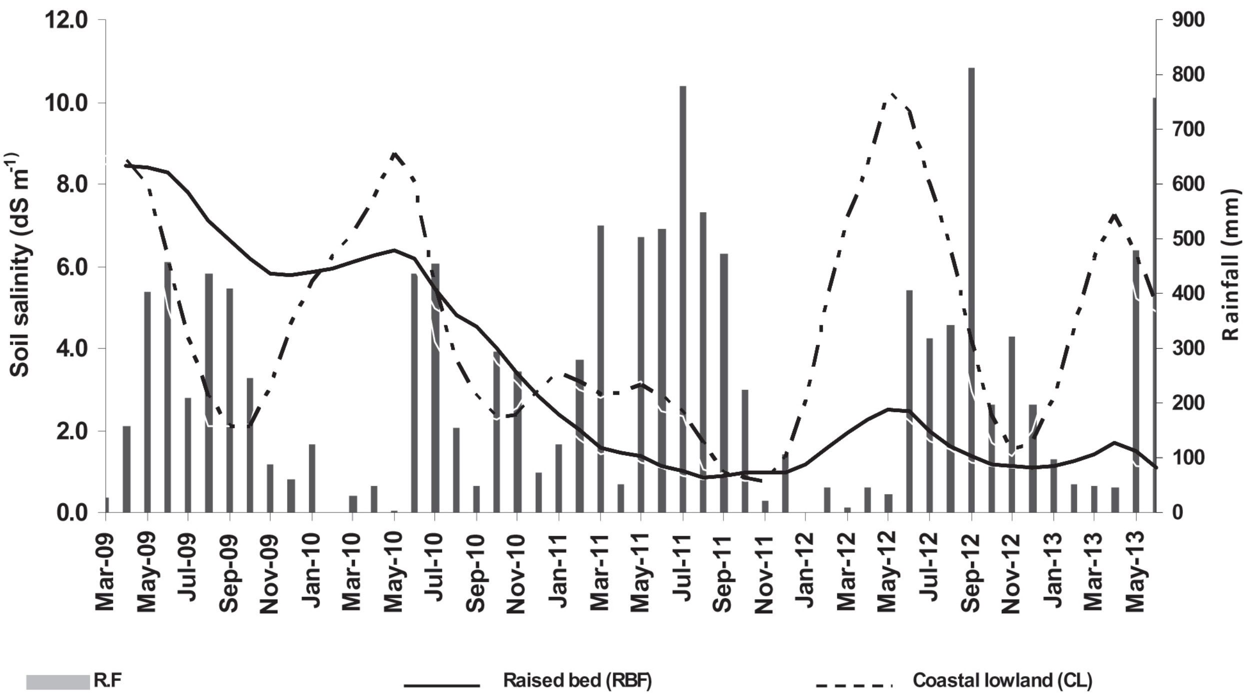

Fig. 3. Salinity dynamics in RBF system and coastal lowlands in relation to rainfall distribution

relationship with both rainfall and evaporation, therefore, its statistical relationship with surface soil salinity was computed as given below:

$$Y = 0.0002x^2 - 0.175x + 6.435$$

where Y, is the soil salinity (EC_e) expressed in dS m^{-1} and x is the soil moisture content (%). The best fit equation showed a significant but negative relationship ($R^2 = 0.6648$) between EC_e and soil moisture content. At higher soil moisture content salinity decreased not only by dilution effect but favouring downward movement of salts. In contrast, high EC_e observed at low soil moisture was attributed to concentration of salts at the surface as water evaporates during dry season. The analysis indicated that the salinity in the raised beds could be reduced by maintaining sufficient moisture at the surface during dry season, and allowing rain water as much as possible to percolate during the monsoon season which was not possible in lowlands. Thus, the RBF system installed in the degraded areas not only favored drainage but also lowered EC_e thereby it addressed the twin problem of waterlogged-salinity in the coastal lowlands effectively.

Conclusions

This study has demonstrated the potential of raised bed system in alleviating the land degradation caused by waterlogging coupled with soil salinity in environmentally constrained areas. The raised beds encouraged leaching of soluble salts and reduced the accumulation of salts after the monsoon season. Soil salinity has tremendously decreased during the leaching phase before stabilizing around a mean while large fluctuations were observed in the adjoining coastal lowlands constraining crop production.

Similarly, salinity of water in the furrows also reduced. The rain water harvested in the furrows can be used for growing fish and irrigating the crops grown on the beds during dry months. Because of improved drainage, the beds facilitate growing of arable crops mainly seasonal vegetables which are vital to address the nutritional security of the island population. Combining RBF system with proper water, crop and fertility management practices will certainly break the yield barrier prevalent in most of the coastal areas. This research also provides some baseline information and understanding with regards to the state of waterlogged-salinity of the study area and ways to manage this problem in an island ecosystem. This will also probably address the concerns emanating from climate change events associated with the sea water inundation in coastal lowlands.

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