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Site-specific management of soil salinity in rice growing soils in the dry zone of Sri Lanka

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Abstract

Development of saline conditions in rice growing soils has become one of the major constraints that reduce the crop productivity in a number of irrigated areas in the Dry Zone of Sri Lanka. This study was conducted to assess the effectiveness of the application of sitespecific management practices to the salinity management classes identified based on the proximally sensed soil electrical conductivity on mitigation of soil salinity in rice growing soils in the dry zone of Sri Lanka. Two sites were selected in Galnewa and Thalawa areas in Mahaweli system 'H' where rice - OFCs cropping system has been practiced for nearly thirty years. The salinity management classes identified based on the proximally sensed electrical conductivity data of the topsoil in the Galnewa and Thalawa experimental sites in a previous study were used for the experiment. The resultant average electrical conductivity (EC_e) values were 0.38 dS m^{-1}, 0.48 dS m^{-1} and 0.60 dS m^{-1} in the identified salinity management class 1, 2 and 3 respectively. Non-salinity tolerant rice variety Bg 300 and salinity tolerant variety Bg 310 were investigated for their growth and yield performances without and with the application of Partially Burnt Rice Husk (PBRH). The EC_e levels in all the salinity management classes at the commencement of the *Yala* growing season were significantly higher than the EC_e levels recorded at the commencement of the *Maha* growing season indicating a greater salt stress for rice cultivation from the onset of the *Yala* season. The variety Bg 310 showed 25 - 45 % yield increment compared to the yield of the variety Bg 300 in the salinity management classes with comparatively higher electrical conductivity levels in the *Yala* **growing season. The application of PBRH increased the rice yields and**

the benefits were more distinct under the salt affected conditions recording around 20 % more yields from the higher rate of PBRH applied plots compared to the yields obtained from the PBRH unamended plots in the salinity management classes with higher electrical conductivity levels in the *Yala* growing season. Therefore, site specific varietal selection and application of PBRH to the salinity management classes identified based on the proximally sensed soil electrical conductivity has a considerable potential for further improvement of the rice yields in the dry zone of Sri Lanka. Further, the results of this work showed the need of further increasing of the PBRH rates in the salinity management classes with higher electrical conductivity levels.

Key words: Partially burnt rice husk, Proximal soil sensing, Salt-tolerant rice varieties, Soil salinity

Introduction

The present population growth rate and the rice consumption patterns in Sri Lanka deduce a demand of 3.04 million tons of rice by 2020 (Sirisena *et al*., 2011). Under the constraint of limited availability of arable lands, enhancing national average yield is the main option available to meet this demand (Weerakoon *et al*., 2000). Therefore, attempts should be taken to maximize the productivity of existing rice lands in major rice growing areas of Sri Lanka. However, a gap has been identified between the potential yield and the farmer's average yield in many studies undertaken (Sirisena and Hemachandra, 2007; Sirisena *et al*., 2011). Sirisena *et al*. (2011) found that poor soil conditions resulted rice yields below 4 t ha^{-1} in major rice growing areas even under favorable climatic conditions. Development of saline conditions in rice growing soils has become one of the major constraints that reduces the crop productivity (Perera *et al*., 2015; Sirisena and Hemachandra, 2007). Salinity problems have been reported in a number of irrigated areas in the Dry Zone of Sri Lanka (Matsumo *et al*., 1998; Perera *et al*., 2015; Sirisena *et al*., 2011). Nayakkorala (1998) and Perera *et al*. (2015) reported the development of salinity in some of the agricultural lands of the Mahaweli irrigation systems.

Leaching of the accumulated salts in the soils (FAO, 1998), proper land preparation (Sirisena *et al*., 2011), improvement of drainage condition (Sirisena *et al*., 2011), addition of organic matter and adoption of appropriate nutrient management practices (FAO, 1998) are some of the available measures for rectifying the negative impacts of soil salinity development. Wickramasinghe and Wijewardena (2000) found an increase in rice yields in fields applied with paddy husk and charcoaled paddy husk. Application of partially burnt rice husk (PBRH) at the rate of 625 kg ha^{-1} is recommended by the Department of Agriculture (DoA) for the rice growing soils to improve their important physical, chemical and biological properties and thereby to increase the productivity of these soils even under unfavourable conditions (Wickramasinghe, 2004). However, the reclamation of salt affected soils is a challenging task due to the complexity of managing the soil salinity. Introduction of salt-tolerant rice varieties such as Bg 310 (RRDI, 2019) is a viable adaptation strategy to improve the productivity of the salt affected soils (Sirisena and Hemachandra, 2007). Moreover, integration of cultivation of salt tolerance rice varieties together with implementation of the recommended other reclamation measures would help to attain the full productivity of salinity affected rice grown soils in Sri Lanka (Sirisena and Hemachandra, 2007; Sirisena *et al*., 2011).

The importance of site-specific soil nutrient management to maintain fertility status in more efficient and effective manner and to maximize the productivity in rice cultivation in Sri Lanka has been reported (Wickramasinghe and Wijewardena, 2000). However, the site-specific management of soil salinity has not been considered adequately in the crop production in Sri Lanka. Moreover, the spatial variability of soil salinity is one of the main factors that has limited the effectiveness of the reclamation measures on the salinity affected rice lands. Electromagnetic Induction (EMI) based soil apparent electrical conductivity (EC_a) measurements is one of widely used soil proximal soil sensing methods. Apparent soil electrical conductivity is influenced by a combination of physico-chemical properties including soluble salts, clay content and mineralogy, soil water content, bulk density, organic matter, and soil temperature (Corwin and Lesch, 2005). Therefore, there is a considerable potential to use EMI based EC_a sensing to assess soil salinity effectively. However, soil specific prediction model development is essential to infer EC_e values from EC_a measurements (Corwin and Lesch, 2005). Studies have shown that the proximal soil sensing of EC_a is a very satisfactory method for explaining the soil variability at field scale (Vitharana, 2008) and has a strong potential as a promising tool for spatial prediction of salinity in Low Humic Glay soils (Typic Endoaqualfs) in rice

- other field crops cropping system in the Dry Zone of Sri Lanka (Perera *et al*., 2015). Further, Perera *et al*., 2015 reported the ability of proximal soil sensing to be used in identifying the 'Potential Salinity Hazard Zones' in soils with a minimum effort of field sampling to determine the appropriate site-specific management decisions of soil salinity.

Hence, this study was conducted to assess the effectiveness of the application of site-specific management practices to the salinity management classes identified based on the proximally sensed soil electrical conductivity on mitigation of soil salinity in rice growing soils in the dry zone of Sri Lanka.

Materials and methods

Site selection for the experimental plots

This study was conducted in two sites in Thalawa (80 14' 12.87" N, 800 17' 41.50" E) and Galnewa (80 00' 39.19" N, 800 29' 54.31" E) areas in the 2015/16 *Maha* and the 2016 *Yala* growing seasons. The study sites fall into the DL_{1b} agro-ecological region and the soils of the experimental sites belong to the Hurathgama series (Typic Endoaqualfs) of Medawachchiya - Ranorawa - Elayapattuwa - Hurathgama - Nawagaththegama soil association (Mapa *et al*., 2010)

Application of proximal soil sensing to identify salinity management classes

Spatial variability of salinity in the two sites have been extensively researched using proximal soil sensing in a previous study by the authors (Perera *et al*., 2015). In that study, the Dualem - 1S proximal soil sensor was used to measure the apparent electrical conductivity (EC_a) and the Geographical Information System (GIS) maps showing the spatial variability patterns of EC_a were constructed using Ordinary Kriging procedure using Idrisi Kilimanjaro software. Subsequently, the Regression Kriging procedure was used to develop the EC_e maps. Further, Fuzzy k-mean classification algorithm was used to demarcate the potential salinity hazard zones using the GIS based FuzMe software. Thus, Galnewa and Thalawa experimental sites were classified into two and three 'potential salinity hazard zones', respectively (Perera *et al*., 2015). Based on the average electrical conductivity (EC_e) values, these potential salinity hazard zones were renamed as 'salinity management class 1', 'salinity management class 2' and 'salinity management class 3'

(Plate 1) and used for this study. Electrical conductivity values of salinity classes of Galnewa and Thalawa experimental sites are provided in the Table 1 (Perera *et al*., 2015).

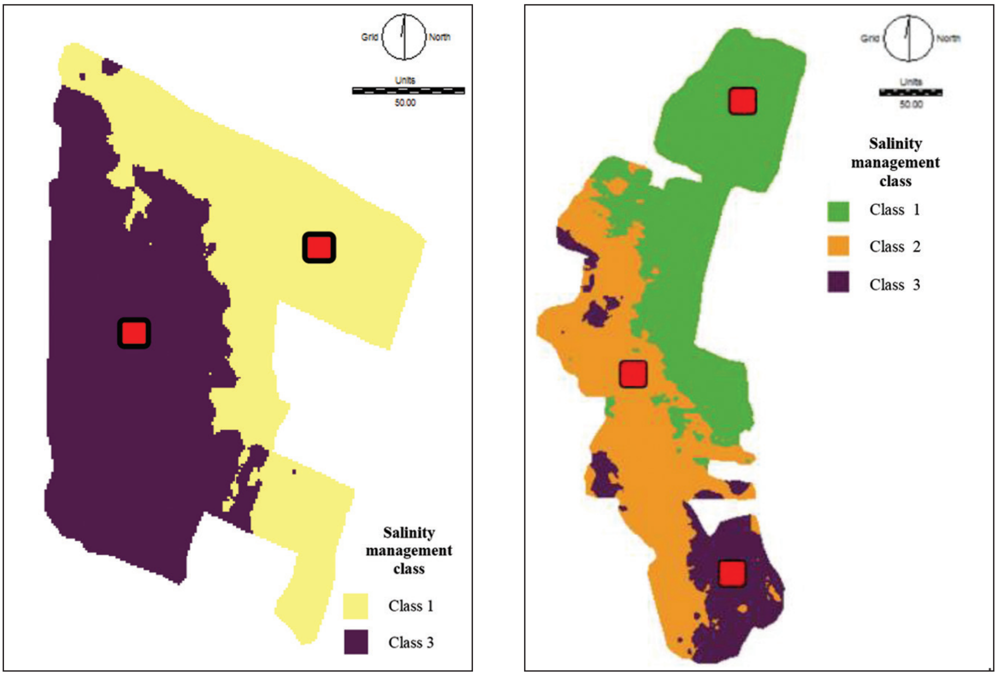


Plate 1. Salinity management classes of the (a) Galnewa and the (b) Thalawa experimental sites. Squares show the locations of the experimental plots.

Table 1. Electrical conductivity in the salinity management classes in the (a) Thalawa and the (b) Galnewa experimental sites

Site	Salinity management class	EC_e (dS m^{-1})
Galnewa	1	0.39
	3	0.59
Thalawa	1	0.37
	2	0.48
	3	0.60

Establishment of the experimental plots

Two rice varieties, Bg 300 and Bg 310 were cultivated with or without the application of PBRH in each salinity management class. Thus, the treatment combinations consisted of two rice varieties (Bg 300 and Bg 310) with application of (a) Partially Burnt Rice Husk (PBRH) at the rate of 625 kg ha^{-1} (Wickramasinghe, 2004), (b) PBRH at the rate of 1250 kg ha^{-1} (twice the DoA recommended rate) and (c) without application of PBRH. Thus, six treatments (2 rice varieties x 3 PBRH treatments) were tested in each of the salinity management class with 3 replicates arranged in Randomized Complete Block Design. Each experimental plot (7 m x 3 m) was separated by bunds and had access to individual irrigation and drainage. PBRH prepared by the barrel method (Wickramasinghe, 2004) was spread on the soil and incorporated into the soil after the second land preparation in each season and the pre-germinated paddy seeds were broadcasted uniformly at the rate of 100 kg ha^{-1}. The application of fertilizer and the pest and disease management were adopted according to the DoA recommendations (Bentota *et al*., 2017). Weeds were controlled manually in all the plots. Water management was practiced according to the DoA recommendations (Bentota *et al*., 2017) based on the irrigation water supply schedules of Mahaweli Authority of Sri Lanka.

Data collection and analysis

Two sub samples were demarcated avoiding the boarder rows in each plot using 1 m^2 quadrat and the number of tillers were recorded at 5 weeks after sowing. The panicles within those subplots were counted at the harvesting. The rice crop in each demarcated sub plot was harvested at 95 days after sowing. The seeds were sun dried after threshing and cleaning and the yield was recorded at 14 % moisture content for each plot. At the beginning of the growing season, two topsoil (0 - 20 cm) samples were collected from each of the three randomly selected sampling points in the experimental area in each salinity management class and composited and subsequently analyzed for available soil P using Olsen method (Olsen *et al*., 1954), exchangeable soil K in ammonium acetate extraction (Jackson, 1979), soil organic matter content (Dry Ashing), soil pH (1 : 2.5 - soil : water) and soil electrical conductivity (1 : 5 - soil : water) using multi parameter analyzer (Hatch, USA). A topsoil (0 - 20 cm) sample was taken from each experimental plot at the end of each season and analyzed for soil electrical conductivity. The electrical conductivity values were converted into EC_e values using the conversion models developed for each experimental site (Perera *et al*., 2015). Data were separately analyzed for 2015/16 *Maha* and 2016 *Yala* seasons using ANOVA procedure and the means were compared using the Duncan mean separation test. The seasonal EC_e changes were analyzed using the Repeated Measured t Test procedure. The effect of experimental sites was not considered in ANOVA since, the electrical conductivity and the other soil properties of the relevant salinity classes were similar.

Results and discussion

Soil salinity at the commencement and the end of the growing seasons

Soil pH, soil available P and soil exchangeable K of the salinity management classes are shown in the Table 2. There were no significant differences in soil pH, soil available P and soil exchangeable K between the three salinity management classes (Table 2). At the commencement of both 2015/16 *Maha* and 2016 *Yala* seasons, significantly high EC_e was observed in the salinity management class 3 than that of both salinity management class 1 and 2 (Table 2).

Except the higher EC_e levels in both salinity management class 2 and 3 at the commencement of both growing seasons (Table 2), values of other soil parameters observed in this study were comparable with the reported levels for the Hurathgama series in the soil map of the dry zone of Sri Lanka (Mapa *et al*., 2010). These findings highlighted the importance of characterization of the spatial variability of soil salinity in paddy tracts to address the soil salinity related problems through site-specific management options.

Table 2. Soil fertility status in the salinity management classes at the commencement of the 2015/16 *Maha* and the 2016 *Yala* season

Salinity management class	EC_e (dS m^{-1})		pH		Exchan. K (ppm)		Availa. P (ppm)		OM (%)	
	2015/16 *Maha*	2016 *Yala*	2015/16 *Maha*	2016 *Yala*	2015/16 *Maha*	2016 *Yala*	2015/16 *Maha*	2016 *Yala*	2015/16 *Maha*	2016 *Yala*
1	0.20 [b]	0.34 [b]	5.9 [a]	6.2 [a]	127 [a]	151 [a]	8 [a]	6 [a]	1.19 [b]	1.39 [a]
2	0.25 [b]	0.44 [b]	6.0 [a]	6.3 [a]	73 [a]	95 [a]	5 [a]	2 [a]	0.82 [c]	1.03 [a]
3	0.58 [a]	1.12 [a]	6.2 [a]	6.5 [a]	104 [a]	125 [a]	6 [a]	4 [a]	1.54 [a]	1.48 [a]
CV (%)	19	28	16	23	24	28	32	58	17	38

Note: The means denoted by the same letter within the growing season are not significantly different at $p = 0.05$.

In all the salinity management classes, EC_e increased from the commencement to the end of both 2015/16 *Maha* and 2016 *Yala* growing seasons (Figure 1). The evaporation and precipitation data obtained from the weather station at Mahaillupallama during these growing seasons indicated a soil moisture deficit in the latter part of both growing seasons. Thus, it is likely that excessive evaporation of soil moisture during latter part of the growing seasons could result in the accumulation of soluble salts in the surface soil. Both salinity management class 1 and 2 showed > 150 % increment of EC_e during the 2015/16 *Maha* growing season (Figure 1). However, the increment of EC_e in the salinity management class 3 was relatively smaller (around 60 %) than that of the other classes during the 2015/16 *Maha* growing season (Figure 1). Similar trends in increasing EC_e values were observed for the three salinity management classes during the 2016 *Yala* growing season (Figure 1). However, the increasing rates were lower compared to those of the 2015/16 *Maha* growing season (Figure 1).

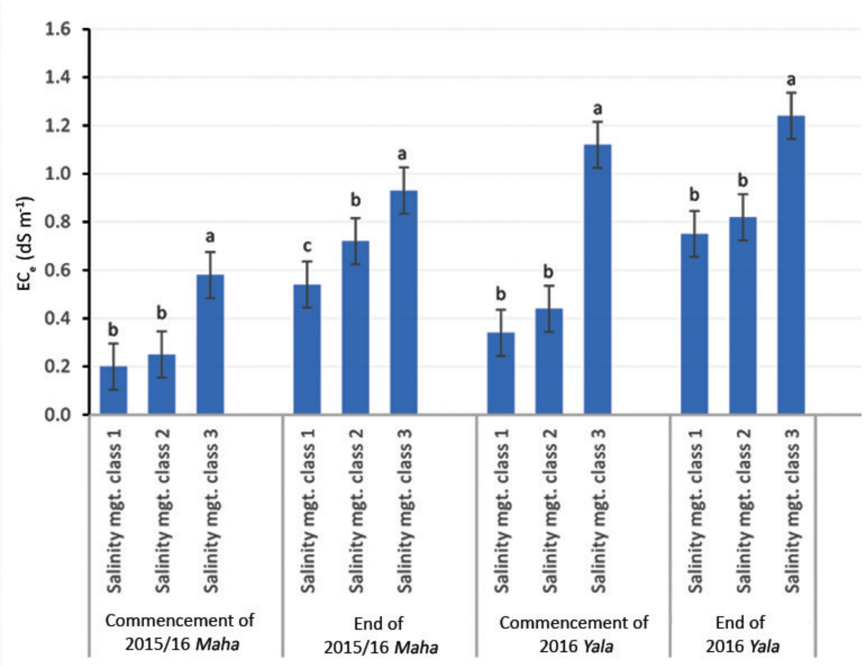


Figure 1. EC_e levels at different stages of the growing seasons. The means denoted by the same letter within the stage of the growing season are not significantly different at p = 0.05.

The EC_e levels in all the salinity management classes at the commencement of the 2016 *Yala* growing season were significantly higher (p = 0.0039) than the EC_e levels recorded at the commencement of the 2015/16 *Maha* growing season (Figure 1) indicating a greater salt stress for rice cultivation from the onset of the *Yala* season. The data obtained from the weather station at Mahaillupallama indicated greater net evaporation loss of soil water under lower precipitation received in between the 2015/16 *Maha* and the 2016 *Yala* growing seasons compared to evaporation loss of soil moisture between the 2015 *Yala* and the 2015/16 *Maha* growing seasons, leading to comparatively higher salinity at the on-set of *Yala* growing season. Similarly, the EC_e levels in all the salinity management classes at the end of the 2016 *Yala* growing season were significantly higher (p = 0.001) than the EC_e levels recorded at the end of the 2015/16 *Maha* growing season (Figure 1). The higher evaporation rates under lower precipitation during the 2016 *Yala* growing season compared to those during the 2015/16 *Maha* growing season have resulted in these changes.

The effects of the salinity on the growth and the yield performances of rice

Significant interactions were found between the salinity management class and the rice variety for the grain yields and the number of panicles in both 2015/16 *Maha* and 2016 *Yala* growing seasons. The tiller count showed salinity management class x rice variety interaction only in the 2016 *Yala* growing season. The interaction between the salinity management class and the PBRH application was significant only for the grain yields in 2015/16 *Maha* growing season.

Varietal effect on the growth and the yield performances of rice

Both Bg 300 and Bg 310 rice varieties showed the highest average grain yields, the number of tillers and the number of panicles in the salinity management class 1 in both 2015/16 *Maha* and 2016 *Yala* growing seasons (Table 3). Further, comparatively higher yields were produced by Bg 300 under low saline conditions prevailed in the salinity management class 1. During the 2015/16 *Maha* growing season, the variety Bg 300 showed considerable decrease in all the growth and the yield parameters in both salinity management class 2 and 3 (Table 3). However, the negative impacts of comparatively high salinity levels in the salinity management class 2 and 3 on the yields of Bg 310 was less prominent when compared to that of Bg 300 (Table 3). During the 2016 *Yala* growing season, the negative impact of the high salinity level in the salinity management class 2 and 3 on the growth and the yield performances was considerable for both Bg 300 and Bg 310 varieties (Table 3). However, comparatively better yields (25 - 45 % more yields) were observed for Bg 310 in these salinity management classes than those of Bg 300 (Table 3).

Table 3. Varietal effect on the growth and the yield performances in the 2015/16 *Maha* and the 2016 *Yala* growing seasons

Salinity management class	Variety	Grain yield ($t\ ha^{-1}$)		Number of tillers (number/ m^2)		Number of panicles (number/ m^2)	
		2015/16 *Maha*	2016 *Yala*	2015/16 *Maha*	2016 *Yala*	2015/16 *Maha*	2016 *Yala*
1	Bg 300	8.1 ^{a}	7.2 ^{a}	357 ^{a}	322 ^{a}	346 ^{a}	312 ^{a}
	Bg 310	7.6 ^{b}	6.9 ^{a}	348 ^{a}	330 ^{a}	336 ^{a}	320 ^{a}
	CV %	9	9	6	7	7	7
2	Bg 300	6.9 ^{a}	4.0 ^{b}	325 ^{a}	280 ^{b}	310 ^{a}	251 ^{b}
	Bg 310	7.4 ^{a}	5.8 ^{a}	324 ^{a}	312 ^{a}	308 ^{a}	292 ^{a}
	CV %	10	11	5	5	5	6
3	Bg 300	7.2 ^{a}	3.7 ^{b}	326 ^{a}	240 ^{b}	308 ^{b}	196 ^{b}
	Bg 310	7.4 ^{a}	4.7 ^{a}	340 ^{a}	270 ^{a}	330 ^{a}	229 ^{a}
	CV %	4	20	5	6	6	9

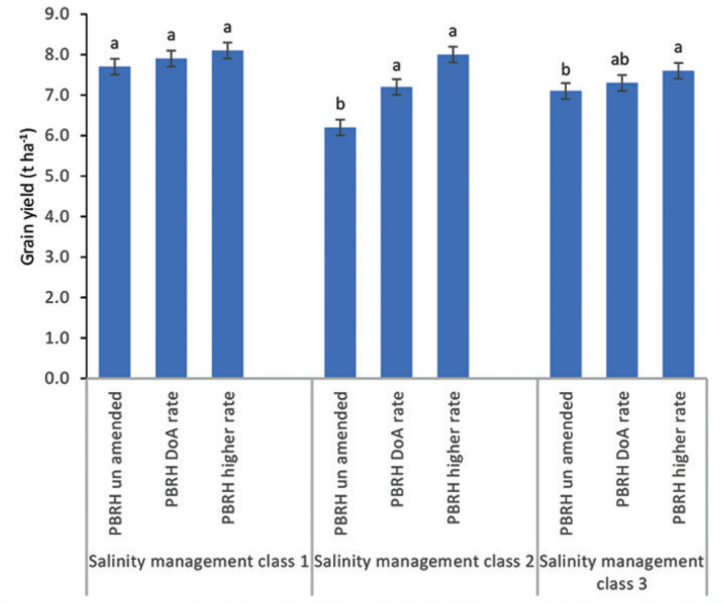
Note: The means denoted by the same letter within the salinity class in the growing season are not significantly different at $p = 0.05$.

Sirisena *et al*. (2011) identified the EC value of 0.12 $dS\ m^{-1}$ (soil : water - 1 : 5) as the critical level for rice cultivation. Based on the EC (soil : water - 1 : 5) to EC_e conversion models developed for Galnewa and Thalawa sites (Perera *et al*., 2015), this critical value corresponds to an average EC_e of 0.94 $dS\ m^{-1}$. The average EC_e indicated that the salinity management class 3 reached the critical EC_e level at the onset of the 2016 *Yala* growing season (Figure 1). Further, many studies have shown the higher tendency of the development of salinity conditions during the comparatively drier *Yala* season. The resulted impacts on the growth and the yield performances have been shown by both salinity tolerant (Bg 310) and salinity sensitive (Bg 300) varieties in the 2016 *Yala* growing season (Table 3).

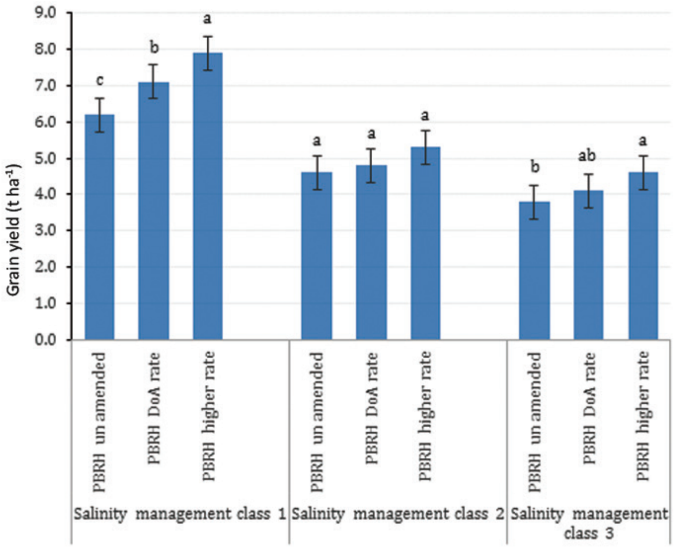
The number of tillers and the panicles resembled the grain yields shown by two rice varieties at different salinity management classes (Table 3). Thus, the crop performances explained by the growth parameters were significantly higher in the salt tolerant rice variety Bg 310 compared to those of the non-salt tolerant rice variety Bg 300 in the salinity management class 2 and 3 in the 2016 *Yala* growing season indicating a higher potential of the salt tolerant rice variety to give higher yields in salt affected soils (Table 3). The grain yields obtained in both salinity management class 2 and 3 were less than 5.8 t ha^{-1} from both rice varieties in the 2016 *Yala* growing season. These low yields were the results of the low number of tillers and the panicles recorded in both rice varieties in the 2016 *Yala* growing season (Table 3). Shaobing *et al*. 2008 has reported that the number of panicles should be around 300 m^{-2} or greater to obtain a higher yield from rice crop. Sirisena *et al*. (2011) has also reported obtaining significantly higher rice yields from newly developed salt tolerant rice lines compared to those of the salt sensitive varieties in salt affected soils in major irrigated areas.

Effect of partially burnt rice husk on growth and yield performances of rice cultivation

In the salinity management class 1, the application of PBRH did not significantly increase the filled grain yield in the 2015/16 *Maha* growing season (Figure 2 (a)). However, the application of PBRH significantly increased the rice yields in the same salinity management class in the 2016 *Yala* growing season (Figure 2 (b)). This indicated benefits of application of PBRH for relatively less saline salinity management class 1 during the drier *Yala* season within which an increase of soil sanity level was observed. The amendment of PBRH showed significantly higher rice yields in the salinity management class 2 in the 2015/16 *Maha* growing season (Figure 2 (a)) whereas, the recorded yield increments were not significant in the 2016 *Yala* growing season (Figure 2 (b)). The application of PBRH at the higher rate gave significantly higher rice yields in the salinity management class 3 in both 2015/16 *Maha* (around 7 % more yields) and 2016 *Yala* (around 20 % more yields) growing seasons compared to those obtained from the PBRH unamended plots (Figure 2). However, the recorded yield differences under both PBRH rates were not significant in both 2015/16 *Maha* and 2016 *Yala* growing seasons (Figure 2).



(a)



(b)

Figure 2. Effect of PBRH on the rice grain yields in the (a) 2015/16 *Maha* and the (b) 2016 *Yala* growing seasons. The means denoted by the same letter within the salinity management class in the growing season are not significantly different at p = 0.05.

Previous studies have revealed the reasons for the positive impact of PBRH on mitigating the soil salinity. Varela *et al*. (2013) reported the high contents of Si and K in rice husk biochar and Jindo *et al*., 2014 also documented the higher availability of Si in rice-based biochar. Coskum *et al*. (2016) has shown the ability of Silicon (Si) to promote plant growth and development, particularly under stress conditions, including salinity in various means. Further, the role of Potassium (K) in minimizing the negative impacts of soil salinity on crop growth has been documented by Tchiadje (2007). The results shown in the Figure 2 clearly indicate the importance of the application of PBRH on the basis of salinity management classes to enhance the productivity in rice cultivation. Especially in the drier *Yala* season, further increase of the application rate of PBRH need to be researched for the salinity management classes 2 and 3.

Conclusion

The study reveals the importance of cultivating rice varieties matching the level of salinity in the salinity management classes identified based on the proximally sensed soil electrical conductivity. Growing a non-salt tolerant rice variety in the soil salinity management class with lower EC_e values can bring a higher productivity while a salt tolerant variety is best suited for the salinity management classes showing comparatively higher EC_e to obtain a higher productivity. Thus, the choose of rice varieties based on the EC_e levels of the soil salinity management classes could improve the overall productivity of the paddy tracts in the dry zone of Sri Lanka. The application of PBRH increases rice yields. However, the benefits are more distinct under the salt affected conditions. The results of this work showed the need of further increasing the PBRH rates in salinity management classes with higher EC_e for the *Yala* season.

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