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Archuna Vathani
Faculty of Science, University
of Colombo, Western Province,
Sri Lanka

Erandathi Lokupitiya
Faculty of Science, University
of Colombo, Western Province,
Sri Lanka

Dinaratne Sirisena
Rice Research and
Development Institute,
Western Province, Sri Lanka

Gamini Seneviratne
National Institute of
Fundamental Studies, Central
Province, Sri Lanka

Corresponding Author:
Archuna Vathani
Faculty of Science, University
of Colombo, Western Province,
Sri Lanka

Best agriculture management practices for reducing greenhouse gas emissions from salinity affected tropical coastal paddy fields: A case study from Sri Lanka

Archuna Vathani, Erandathi Lokupitiya, Dinaratne Sirisena and Gamini Seneviratne

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Abstract

This study was initiated to identify the best agricultural management practices (BMPs) with low Greenhouse GAS (GHG) emissions supporting climate change mitigation in salt affected paddy soils, as it would eventually help sustain the rice production in such areas of Sri Lanka.

The research was carried out in Madampe, Puttalam District and Umaneri, Mannar in Maha season (during north-east monsoon from September to March). The newly improved salinity tolerant variety BG 310 was planted in the salinity affected (i.e. Electrical conductivity of saturation extract (EC- Sat) in the range 2-4 dS/m) paddy fields to study the variations in GHG emissions under different combinations of the following management options; a) maintaining a 2-3 cm water level until milking, b) organic matter addition, c) broadcasting seeds and d) transplanting of rice seedlings. The above options were considered variably in 4-plots within each field along with a control. The closed chamber method was used to collect three replicates of gas samples from each plot. Collected gas samples were analyzed using gas chromatography. CH₄, N₂O and CO₂ emissions were measured starting from the date of seeding (broadcasting or transplanting) onwards at weekly intervals. The weekly CH₄ and CO₂ fluxes ranged from 0.27 to 0.628 mg m⁻² hr⁻¹ and -115.05 to 549.78 mg m⁻² hr⁻¹, respectively in both sites. Emission of N₂O was negligible. Organic matter addition seemed to reduce denitrification, though intermittent water supply (with dry and wet periods) seemed to induce it; but the N₂O emissions were still too low. The lowest GHG emissions were observed when intermittent irrigation water supply, addition of organic matter, and transplanting method were applied as the combination of BMPs.

Keywords: Salinity intrusion, greenhouse gas emissions, best management practices, salinity tolerance

Introduction

Climate Change presents significant obstacles to global food security. The agriculture sector is already experiencing long-term shifts in temperature, humidity rainfall pattern and extreme weather events, which in turn are affecting farming methods, crop yields and the nutritional value of food crops. The global nations are preparing themselves to adapt to current and future climatic impacts or issues. The developed nations already have come up with policies and strategies to face it. However, developing nations have been more vulnerable and adopting appropriate policies and strategies to overcome climate related impacts has been a huge challenge for them.

Changes in land and water quality due to climate change have affected food security in most of the arid and semi-arid tropical regions. Also, it will increase the vulnerability of rural and poor farmers and families. The availability, accessibility, and stability of utilization of food will become questionable in future.

Climate change causes various issues, and water plays an important role in the agriculture sector. Climate change causes high water temperatures and extreme events including floods and droughts. It also affects the quality of water and aggravates many forms of water pollution. Climate change affects ground water table, and the productivity of the agriculture sector highly depends on spatial and temporal distribution of precipitation and evaporation. Availability of freshwater for irrigation is more important. Increased climatic vulnerability

Causes high risks in the productive systems, and land degradation can occur through various factors including salinization.

Furthermore, sea level rise is likely to extend the Salinity-affected areas of land, freshwater and estuaries, resulting in a decrease of arable land and freshwater available to maintain the productivity in coastal ecosystems. The sea level rise is projected to cause substantial geographical variability in coastal lines and inundation of low-lying areas, with the greatest effect in river deltas and low-lying islands.

On a global scale, increased emission of Greenhouse Gases (GHGs) play a major role in the observed changes in our climate system. Several sources and sinks such as managed wetlands, permafrost, paddy fields, etc., have contributed to increased methane emissions. The enhanced greenhouse effect due to anthropogenic activities may increase the severity and variability of weather patterns and impact the ecosystem productivity. Semiarid and arid climates with high occurrence of saline water intrusion have also been highly vulnerable (World bank, 1994) [39].

Lowland paddy cultivation is the most widely practiced farming system in Sri Lanka. Rice is the dominant crop when considering land use of island and it is the staple food in Sri Lanka. As an island, Sri Lanka is more vulnerable to salinity intrusion. Already some parts of the county have been affected by salinity - both inland as well as costal salinity. Inland salinity exists in Anuradapura, Polonaruwa, Ampara, Hampantota and Puttlam districts of the country, and costal salinity exists in Jaffna, Mannar, Trincomalee, Kalutara, Galle, Puttlam, Ampara, Hambatota and Matara districts. When considering Sri Lankan scenario, salinity in soil is not the only problem but the salinity of irrigation water and saline water overflowing the lands also cause problems. According to the farmers' experiences, inorganic fertilizers are not the ultimate substance to supply nutrients to salinity-affected soil. But organic fertilizers provide more satisfactory results than inorganic fertilizers in terms of the yield and cost effectiveness. There are various types of traditional practices as well as technical remedies currently used by farmers to overcome soil salinity in paddy fields, including deep plowing, draining off the salt before cultivation, adding organic manure, mulching, and some irrigation techniques. However, the practices that have been used to mitigate salinity related stress in rice need to consider the GHG emissions associated with such remedial measures, as paddy fields are already sources of GHG emissions. Paddy fields lead to a considerable percentage

(~12%, Climate Home News) of methane emissions worldwide. Therefore, measuring the GHG emissions from the above remedial measures is an important aspect to focus on mitigation of GHG emissions from the salt-affected paddy fields.

Therefore, this study was conducted to identify the best management practices in salinity affected paddy lands while considering the mitigation of GHG emissions. A different combination of management practices was used in field plots to measure the GHG emissions. This study aimed to identify the climate friendly Best Management Practices (BMPs) which would produce high yields in rice cultivation by reducing the salinity of soil while lowering the emission of GHGs, so that the socio-economic returns would benefit the farmers. It would also help identify the BMPs and convey the same through awareness among the authorities and farmers to get the maximum benefit out of rice areas affected by salinity.

The study was conducted in two sites in Madampe and Mannar, which were affected by costal salinity. Madampe is located in the western coast and Mannar is located in the northern coast of Sri Lanka. Madampe and Mannar belong to intermediate and dry climatic zones, receiving 1500-2000 mm and 1000-1250 mm of rainfall, respectively, during Maha season.

2. Materials and Methods

2.1 Site description

The study was conducted in Maha season at two selected sites in Madampe (7°29'25.4"N 79°49'15.8"E) and Umaneri, Mannar (8°50'37.9"N 79°57'46.7"E) as shown in Figure 1.

Madampe is a town situated in the Puttalam District, of Northwestern Province, Sri Lanka. According to the Central Bank of Sri Lanka, 24,000 hectares are available for paddy cultivation in the Puttalam District. Soil salinity occurs in Puttalam district due to coastal salinity from sea water intrusion and salt accumulation in the irrigation water.

Mannar district is located in the Northern Province of Sri Lanka. District has a marine coastline which stretches up to 222 km. Mannar is in the low rainfall zone of Sri Lanka and receives an average of 500-1000 mm of rainfall per year, making it one of the driest parts of the country. As per the data of the Department of Census and Statistics (2019), the sown extent of paddy in Maha season was 47949.9 hectares. Soil salinity occurs due to costal salinity. The soil physicochemical properties of the experimental sites (0-15 cm depth) at the start of the experiment are given in Table 1.

Table 1: Soil physicochemical properties of the experimental sites

Soil physicochemical properties	Madampe	Mannar
Bulk density	0.98 g/cm ³	1.23 g/cm ³
pH	3-4	5.5-7.5
Soil organic carbon content	0.46%	0.54%
Electrical Conductivity (saturated)	3-4 dS/m	3-4 dS/m

2.2 Experimental design

The experimental design considered applying the Best Management Practices (BMPs) such as deep plowing, application of organic manure, land leveling, and maintenance of water level to 2-3 cm throughout the

growing season to reduce salinity levels in the paddy fields and measuring the greenhouse gas emissions.

Table 2 depicts the setup of the experiment in plots provided with four different treatments (i.e. a combination of management practices in each, including one control).

Table 2: Applied BMPs in different plots

Plots	Mgt* 1	Mgt 2	Mgt 3	Control
Water level until milking	2-3 cm	2-3 cm	intermittent	regular
Organic matter addition	Yes	Yes	Yes	No
Broadcasting (B) or transplanting (T)	B	T	T	B

*Management 1-3 indicate the combinations of different management practices used along with the Control.

Plot 1/ combination Mgt 1- after proper/deep ploughing, the compost was mixed, then puddling and leveling was done, seeds were broadcasted as a normal practice and 2-3 cm water level was maintained throughout the growing season.

Plot 2/ combination Mgt 2- after proper/deep ploughing, the compost was mixed, then puddling and leveling was done, 21 days old seedlings were transplanted, and 2-3 cm water level was maintained throughout the growing season.

Plot 3/ combination Mgt 3- after proper/deep ploughing, the compost was mixed, then puddling and leveling was done, 21 days old seedlings were transplanted, and intermittent irrigation was applied until harvest (water was supplied, when necessary, before the ground got fully dry- visual observation was needed, particularly based on farmers' experience). Plot 4/ Control plot - the plot was prepared based on the usual practices. Normal ploughing was done, the seeds were broadcasted, and plot was irrigated according

to the normal practice. The crop was irrigated fully with water whenever water was available; if there was no water availability and the ground was dry, ground cracks were also visible at times).

Newly improved salinity tolerant variety BG 310, which has a response to salinity levels up to 8 dS/m (further details of the variety BG 310 are given below), was cultivated. The average crop duration was 100 days. After proper ploughing, puddling and leveling was done (at the same time compost was also mixed with the soil for the required plots). 21-days old seedlings were manually transplanted at a density of 3-4 seedlings per hill with spacing of 15cm x 10 cm (row-to-row and plant-to-plant). All four plots were uniform and had the same dimensions.

Manual Pest management and weed management were done as needed. Information about the improved salinity tolerant variety BG 310 is shown in Table 3.

Table 3: Information of the improved salinity tolerant variety BG 310

Verity Name:	BG 310
Line Designation	BG 4-91
Pedigree	BG 300 x Pokkali
Type of Cultivar	Pure line
Origin	Developed through hybridization at the RRDI, Batalagoda
Method of Propagation	By Seeds

Source: Distinctness, Uniformity and Stability (DUS) report for candidate rice variety BG 4-91; RRDI, 2014

2.3 Gas Sampling and Estimation

The closed chamber method (Figure 2) was used to collect gas samples from plots. The fan inside each chamber was connected and activated five minutes before sampling. A 20-ml syringe was used to obtain gas samples from chambers and the collected samples were transferred into pre-evacuated gas-tight vacutainers. The temperature inside the chamber was measured at every sampling. Samples were collected at 0-minute, 30-minute and 1-hr intervals (intervals between 11am to 12 noon weekly). Collected gas samples were analyzed using gas chromatography (Shimadzu Model 9 AM) equipped with a Flame Ionization Detector (FID) and Thermal Capture Detector (TCD). Carboxin 1010 capillary column width 30 mm x 0.32 mm was used to detect the GHG and Helium was used as carrier gas at a flow rate of 30 ml minute⁻¹ and Hydrogen as the fuel gas. The injector, the column and the detector temperature were maintained at 150° C, 40 ° C and 200 ° C respectively. The following equation was used to estimate the GHG emissions (Dutta and Gokhale, 2017) ^[42]:

$$F = \frac{S \times V}{A}$$

Where:

F = CO₂/CH₄/N₂O flux from the paddy field which is expressed in mg m⁻² hr⁻¹

S = slope of regression obtained by plotting concentration of CO₂ / CH₄ / N₂O vs time as recorded during sampling

V = total volume of the chamber (m³)

A = area covered by the chamber (m²)

2.4 Plant growth analysis

Plant growth parameters (leaf area, leaf number and tiller number) were measured at weekly intervals. Leaf area was measured by a portable laser leaf area meter (Model LI 300 0C, USA). Rice yield was determined considering the total plot area at harvesting.

2.5 Statistical analysis

The Turkey method for one-factor ANOVA was used for pairwise comparison of the emission fluxes of CH₄ and CO₂ between the two sites (i.e. Comparison of control plot emissions of the two sites and the emissions from each respective management plots). Multivariate analysis of variance (MANOVA) was used to compare the CH₄ and CO₂ fluxes between the two sites and among control and management practices. SPSS (Statistical Package for the Social Sciences) version 10.0 was used for performing MANOVA and one-factor ANOVA).

3. Results

The study was carried out for the Maha season, which is ~16 weeks of the crop cycle. Results and findings indicate that the best management practices reduced the severity of soil salinity, while reducing the greenhouse gas emissions and increasing the crop yield.

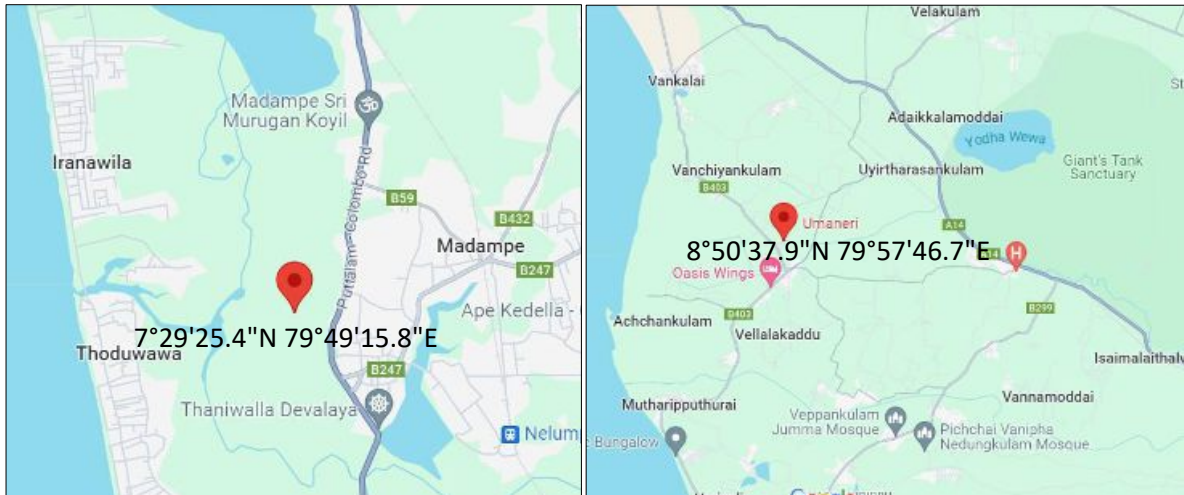
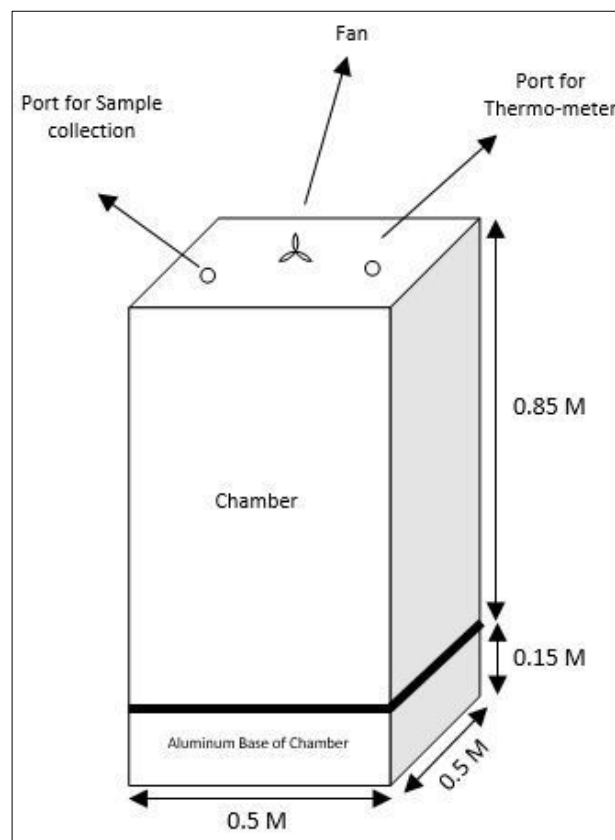


Fig 1: Location map of the study areas (top) and experimental plots (bottom) for Madampe (left) and Mannar (right) sites



Fig 2: Illustration of chamber used for collection of GHGs from experimental plots



3.1 Emission fluxes of methane, carbon dioxide and nitrous oxide

The methane (CH₄), carbon dioxide (CO₂) and nitrous oxide (N₂O) fluxes were measured in the four different management plots. CH₄ flux at sites of Madampe and Mannar are shown in Figure 3 and 4 respectively. CH₄ flux in all management plots were low during early growth stage in both sites (4th week). The CH₄ fluxes recorded from management practices ranged from zero (undetectable) to 1.253 mg m⁻² hr⁻¹. A progress in the rate of CH₄ emission was observed from 5th week onwards and thereafter

emission peaks were recorded during active vegetative growth and reproductive stage of the rice plant. Management practices Mgt 1 and Mgt 2 showed first peak during 5th week and Mgt 3 and control showed first peak during 6th week; second emission peak was recorded in Mgt 2 during 7th week and Mgt 3 during 8th week. The rate of emission started to decline after panicle emergence and a small amount of emissions were recorded at crop harvest. Among the different management practices, Mgt 1 and Mgt 2 recorded significantly higher seasonal CH₄ emission and Mgt 3 recorded the lowest emission.

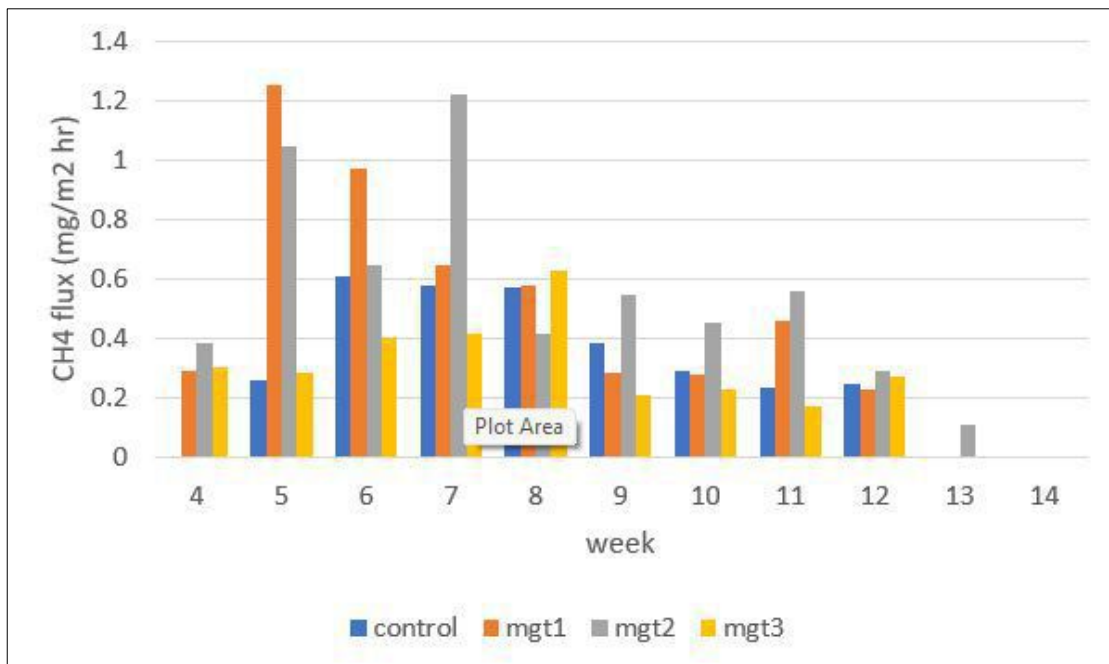


Fig 3: CH₄ flux from plots in Madampe

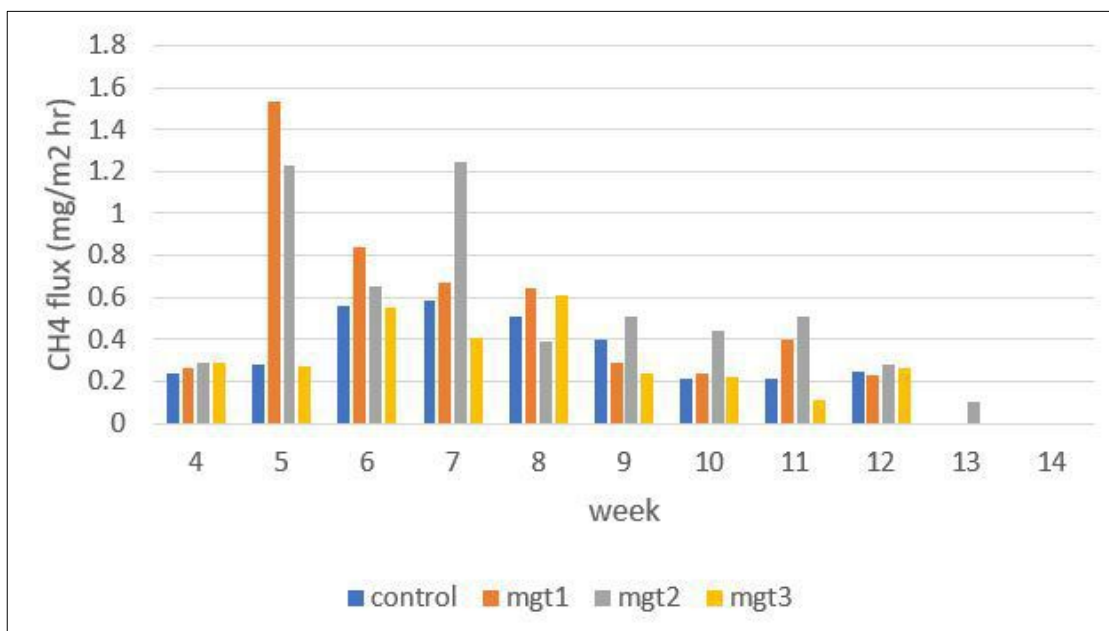


Fig 4: CH₄ flux from plots in Mannar

The CO₂ fluxes recorded from the different management practices at both sites ranged from -174.19 to 705.175 mg m⁻² hr⁻¹. Among the management practices, control plot recorded significantly higher seasonal CO₂ emission and Mgt 2 recorded lowest emission. Emission peaks were

recorded during the 5th, 7th and 11th weeks. Negative values were recorded during 8th to 9th weeks which corresponded to active vegetative and reproductive stages of the crop with high photosynthetic rates. CO₂ flux at the sites in Madampe and Mannar are shown in Figure 5 and 6 respectively.

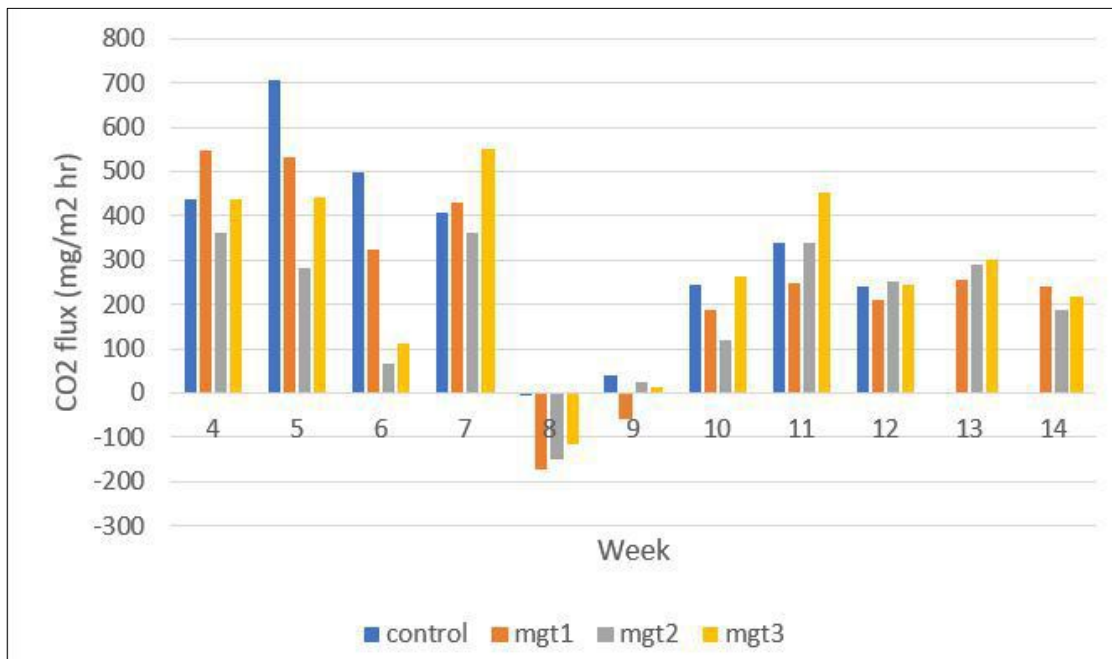


Fig 5: CO2 flux from plots in Madampe

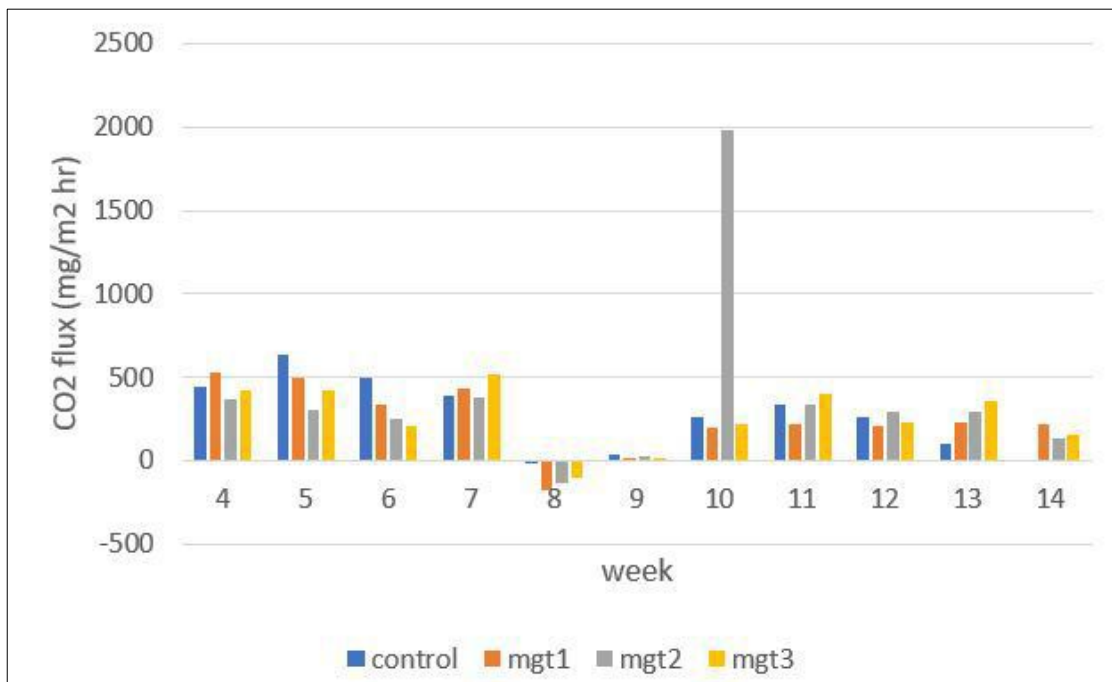


Fig 6: CO2 flux from plots in Mannar

3.2 Statistical analysis

The Tukey method for one-factor ANOVA was used for pairwise comparison of the emission fluxes of CH₄ and CO₂ between the two sites. According to the obtained result, there is no significant difference between pairwise comparison of emission fluxes of CH₄ and CO₂ between two sites. Therefore, the data was pooled and MANOVA was used to compare the CH₄ and CO₂ fluxes among control and management practices.

Figure 7 and 8 shows the results of Multivariate analysis of variance (MANOVA), which further allowed

Determination of the significantly different ones among the four management practices. According to the results, there is a significant difference between management plots and control plot in CH₄ flux and there is no significant difference in CO₂ flux (as $p > 0.05$). According to Figure 8, CH₄ flux of the control is significantly different from Mgt 2. And there is no significant difference between the control and Mgt 1 or Mgt 3. However, there is a significant difference between the Mgt 2 and Mgt 3 as well. The estimated Marginal Means of CH₄ show Mgt 3 as the lowest CH₄ emitted plot (figure 9).

Multivariate Tests						
Effect	Value	F	Hypothesis df	Error df	Sig.	
Intercept	Pillai's Trace	.795	127.899 ^b	2.000	66.000	.000
	Wilks' Lambda	.205	127.899 ^b	2.000	66.000	.000
	Hotelling's Trace	3.876	127.899 ^b	2.000	66.000	.000
	Roy's Largest Root	3.876	127.899 ^b	2.000	66.000	.000
Site	Pillai's Trace	.010	.334 ^b	2.000	66.000	.717
	Wilks' Lambda	.990	.334 ^b	2.000	66.000	.717
	Hotelling's Trace	.010	.334 ^b	2.000	66.000	.717
	Roy's Largest Root	.010	.334 ^b	2.000	66.000	.717
Mgt	Pillai's Trace	.191	2.353	6.000	134.000	.034
	Wilks' Lambda	.811	2.426 ^b	6.000	132.000	.029
	Hotelling's Trace	.230	2.496	6.000	130.000	.026
	Roy's Largest Root	.220	4.915 ^c	3.000	67.000	.004

a: Design: Intercept + Site + Mgt

b: Exact statistic

c: The statistic is an upper bound on F that yields a lower bound on the significance level.

Fig 7: Results from MANOVA

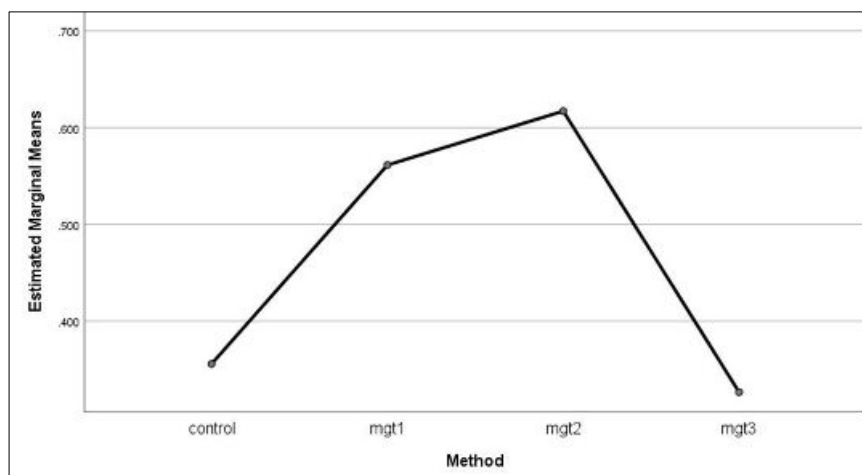
Multiple Comparisons (Tukey HSD)							
Dependent Variable	(I) Mgt	(J) Mgt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence interval	
						Lower Bound	Upper Bound
CH ₄	0.00	1.00	-0.2054	0.09293	0.131	-0.4503	0.0394
		2.00	-0.2612*	0.09293	0.032	-0.5061	-0.0164
		3.00	0.0292	0.09293	0.989	-0.2157	0.2740
	1.00	0.00	0.2054	0.09293	0.131	-0.0394	0.4503
		2.00	-0.0558	0.09293	0.932	-0.3006	0.1891
		3.00	0.2346	0.09293	0.065	-0.0102	0.4794
	2.00	0.00	0.2612*	0.09293	0.032	0.0164	0.5061
		1.00	0.0558	0.09293	0.932	-0.1891	0.3006
		3.00	0.2904*	0.09293	0.014	0.0456	0.5352
	3.00	0.00	-0.0292	0.09293	0.989	-0.2740	0.2157
		1.00	-0.2346	0.09293	0.065	-0.4794	0.0102
		2.00	-0.2904*	0.09293	0.014	-0.5352	-0.0456
CO ₂	0.00	1.00	70.9528	98.00589	0.887	-187.2634	329.1690
		2.00	17.3122	98.00589	0.998	-240.9040	275.5284
		3.00	58.2100	98.00589	0.934	-200.0062	316.4262
	1.00	0.00	-70.9528	98.00589	0.887	-329.1690	187.2634
		2.00	-53.6406	98.00589	0.947	-311.8567	204.5756
		3.00	-12.7428	98.00589	0.999	-270.9590	245.4734
	2.00	0.00	-17.3122	98.00589	0.998	-275.5284	240.9040
		1.00	53.6406	98.00589	0.947	-204.5756	311.8567
		3.00	40.8978	98.00589	0.975	-217.3184	299.1140
	3.00	0.00	-58.2100	98.00589	0.934	-316.4262	200.0062
		1.00	12.7428	98.00589	0.999	-245.4734	270.9590
		2.00	-40.8978	98.00589	0.975	-299.1140	217.3184

Based on observed means.

The error term is Mean Square (Error) = 86446.397.

*The mean difference is significant at the .05 level.

Fig 8: Pairwise comparisons of the different management practices and sites



N₂O fluxes were recorded very rarely and in Mgt 3 plot only. Detected values were insignificant (and not shown).

Fig 9: Estimated Marginal Means of CH₄ (mg m⁻² hr⁻¹)

3.3 Plant physiological parameters and yield characteristics

Plant physiological parameters are shown in Table IV. The physiological characteristics slightly vary in both sites. Mannar site has positive growth and yield characteristics than Madampe site. The number of tillers and leaf area become stagnant after panicle initiation stage. CH₄ emission

Showed positive correlation with leaf area (0.796) and number of tillers (0.898) (Correlation is significant at the 0.01 level of significance). Superior yield attributing characteristics such as number of panicles and number of filled grains without chaff were recorded in Mgt 2 and Mgt 3. Mgt 3 emits less CH₄ than Mgt 2.

Table 4: Variation in physiological parameters and yield characteristics

	Mgt 1		Mgt 2		Mgt3		control	
	Madampe	Mannar	Madampe	Mannar	Madampe	Mannar	Madampe	Mannar
seedling height (cm)	26-28	28-30	31-33	31-33	31-33	31-33	26-28	28-30
Number of tillers per plant (± 2)	8	8	10	14	12	14	6	8
Leaf area (cm ² per hill when flowering stage (± 0.6))	158.78	163.42	174.64	189.36	191.28	192.56	156.24	162.92
Number of panicles bearing tillers (± 2)	7	8	10	13	12	12	6	8
Number of grains per panicle (± 3)	160	172	184	178	180	192	152	164
Yield kg/20 m ²	5.6	7	9.7	11	9.9	11	4.8	6.7

4. Discussion

The current study evaluated the best management practices with minimum GHG emissions from salinity-affected coastal paddy fields in two districts of Sri Lanka having a tropical environment with the air temperature ranging from 29 °C - 40 °C during the crop growing season.

Air temperature in Sri Lanka has increased by 0.45 °C over the last 22 years, suggesting a rate of 0.2 °C increase per decade. The possible impacts predicted on the water sector due to climate change are severe droughts, floods and sea level rise etc. It has been predicted that by 2050, the amount of rainfall received from the north-east monsoon which is the major source of water for the dry zone of Sri Lanka at present, will be reduced by 34% while that received from the south-west monsoon will be increased by 38%. This would make the dry-zone districts more vulnerable to droughts and the wet zone districts more vulnerable to floods and landslides. Prominent change due to low rainfall will be the increase in the area that belongs to the dry zone. Due to such droughts, surface water availability and per capita water availability will be decreased. The floods due to increase in rainfall intensity will reduce ground water recharge and also would affect the quality of surface water, sediment generation and transport of sediments. Studies on the sea level rise have shown an increased trend for sea water intrusion in certain coastal areas. As a result, salinity of surface water and ground water in such areas will be increased (climate change secretariat, 2014) [8].

Changing climatic and weather patterns imply potential negative impacts on food production, food security, and natural resources in the country. The impending vagaries of climate change such as intense, uncertain, and highly variable rainfall and temperature and sea level rise, combined with deterioration and dwindling of natural resources stress the need for sustainable climate change adaptation technologies to increase the productivity, stability and resilience of the agriculture sector.

The country's dependence on the agriculture sector to meet the food needs of the population is much more significant than its relative share as an economic sector. The rural population in particular, which comprises more than 70% of the population, is directly or indirectly dependent on the

agriculture sector or related activities. Furthermore, it is estimated that the agriculture-related activities provide a major source of employment and livelihood for nearly a third of the Sri Lankan population. Hence, the sector's adaptability to climate change is critical for continued economic growth and food security.

In Sri Lanka, considerable amount of coastal paddy cultivation lands are affected by soil salinity. Since Sri Lanka is more vulnerable to climate change, sea level rise and associated climatic factors increase the chances of salinity intrusion in soil and water bodies. With increasing population and demand for food, sustainable utilization of the existing land is important. Salt-affected lands reduce the productivity of the soil and it makes the income/economic losses to the farmers.

The agricultural sector emits a considerable amount of GHG emissions. Even though emissions of Sri Lanka are less than 1 percent of the total global emissions, the country has taken mitigatory measures to reduce the GHG emissions. Sri Lanka is also a member county of the Paris agreement under UNFCCC and the country has developed Nationally Determined Contributions (NDCs) to reduce the emissions and prepared the net zero road map to achieve important targets by 2050.

As described earlier, currently there are many management practices applied by farmers to overcome salinity issues. However, when applying those management practices, studying their impact on the GHG emissions and mitigation co-benefits is important. Therefore, the current research was carried out in selected sites within Madampe and Mannar areas affected by coastal salinity to determine GHG emissions with different management practices, to determine the best management practices with regard to GHG emissions.

Based on the obtained experimental results and observations, only 50 to 60% of the crops survived in the plots with broadcast seeding. More than 95% of the sown seeds were germinated; however, in the early stages (1-2 weeks old) plants could not tolerate the salinity, and after 14 days, the tips of the leaves were burnt and wilted off eventually. In Mannar, the rate of survival was comparatively high in broadcasting plots, and around 70-

80% of crops survived. The reason for this difference might be the soil characteristics or properties such as texture, structure and porosity.

Plant tolerance for salinity increases with age until the tillering phase of growth and it decreases from panicle formation stage to flowering stage such that salinity stress at this stage invariably results in reduced grain yields. Keeping adequate soil moisture during the tillering phase to milking phase would help the crops to have high yields.

Lower methane emissions observed during early crop stages are the result of low methane transport from soil to atmosphere due to lower root weight and shoot growth (i.e. lower number of tillers and small leaf area, etc.). The first emission peak was observed during the active vegetative growth stage (week 5) of rice crops, and it is probably due to considerable root and shoot growth and increased soil CH₄ concentration due to added organic matter and crop residues in soil. About 70% of the total CH₄ of the whole crop season is reported to be emitted during the flowering stage because of the rice biomass which increases gradually, reaching the maximum by flowering stage (Holzapfel-Pschorn *et al.*, 1986) ^[43]. CH₄ and CO₂ emissions decreased after flowering stage and is further reduced close to the ripening stage of rice grains due to the declined rate of photosynthesis. There was approximately zero emission during one week before harvesting (the emission levels were not detectable in gas chromatography), the reason being that the vegetative part of the rice plant is almost dead, and soil has less moisture content (almost dried). Mgt 1 and control plots have lower emission during that time and those plants had lower yield potential due to crop losses that occurred in the early stages of rice plant.

Decline in methane emission (emission is not detectable in most of the plots) from week 13 to 14 before crop harvest observed in this study is perhaps due to absence of soil moisture, reduced carbon content in soil, and decline in the aerenchyma tissues in maturing of living tissues for transferring CH₄ from soil to the atmosphere.

The study found a positive relationship between organic matter and methane emission. Decomposition of organic matter in anaerobic condition/s produced considerably high methane emission. Waterlogged plots of Mgt 1 & Mgt 2 emitted higher methane than Mgt 3 and control plots. High water level during crop growing period created favorable conditions for methane production. Thus, the irrigation method or pattern plays an important role in the methanogenesis process. The most common practice in paddy rice cultivation in Sri Lanka is flooding or temporary water logging of the soil or land surface. The most common irrigation method is canal irrigation.

Organic matter in paddy soils from plant debris, animal manure and compost trigger microbial activity and thus the emission of GHGs. Organic matter enhances methane flux by increasing carbon supply to methanogens. Low soil organic carbon (without any added organic matter) in control plot emits relatively low methane than the organic matter added plots of Mgt 1, 2 & 3

N₂O is produced naturally in soils through microbial processes of nitrification and denitrification. Rainfed rice fields provide unique aerobic and anaerobic environments, making it a major source of CH₄ during the flooded season, and an important source of N₂O during the drained period. N₂O emissions are low or undetectable in flooded plots (Mgt 1 & Mgt 2). Application of inorganic fertilizers alone

increases the N₂O emissions, but organic amendments seem to be the best option for improving salinity affected soils as well as limiting N₂O emission, as we observed in the current study.

The broadcasting method (i.e. direct seeding of rice grains on the field) is a more cost effective method when compared with transplanting method (i.e. transplanting seedlings from the nursery). The practice of broadcasting instead of transplanting resulted in a 16 -54% reduction of CH₄ emission and CH₄ emission was further reduced under dry-direct seeding compared to wet-direct seeding (Corton *et al.*, 2000) ^[44]. However, when it comes to salt affected soil, transplanting would be the best suggestion in order to avoid early crop losses due to salinity, as rice plants are very sensitive to salinity during their early stages. Therefore, a better option is bringing matured (14 -21 days) seedlings from outside and transplanting those in the salt- affected paddy field; the grain yield in the broadcast plot was found to be lower than transplanted rice, probably due to salinity-related stress in the early crop stages leading to poor crop stand, less percentage of panicle bearing tillers, and more number of chaff gains.

Dry, wet or intermittent and mid-season drainage (irrigating the paddy fields when rice plant experiences visible moisture stress) practices are the best irrigation practices in salt affected paddy fields. It increases productivity while reducing greenhouse gases. Also, the draining out of flooded water from paddy fields will reduce pest and fungal attacks on the rice plants. This water management system reduces farmers' water requirements and unnecessary conflicts for the irrigation water, especially in dry periods and low rainfall seasons.

Conventional tillage practices increase the exposure of the soil organic matter to microbial decomposition, leading to higher CO₂ emission when compared with conservation - tillage practices (Dutta and Gokhale, 2017) ^[42]. Deep plowing is one of the saline soil reclamation methods adopted in the country. Deep plowing brings sub soil Calcium (Ca⁺) ions to the topsoil and allows them to exchange with sodium (Na⁺) ions. Supply of water after deep plowing helps to wash off the brought-up topsoil salts (Sirisena, 2013) ^[45]. The Mgt 1, Mgt 2 and Mgt 3 plots were deep plowed and washed off with water; then organic matter was added to all 3 plots and mixed with the soil during a second tillage.

Management practices also significantly affect the Soil organic carbon (SOC) content (Zhang *et al.*, 2015) ^[46]. The results and findings of this study indicate that there is no significant difference in CO₂ emission in management (organic matter added plots) and control plots. A decrease in CO₂ emission is seen during the panicle initiation and heading stages of rice plant growth, which can be attributed to the high rate of photosynthesis during the reproductive stages. During the study period, 5th to 7th peaks of CO₂ emission were observed during the early vegetative and tillering stages in all plots. Organic matter may have started to decompose during these stages.

Sri Lanka has been ranked as the 124th among 180 countries, based on the Sustainable Nitrogen Management Index (SNMI) under the Environmental Performance Index (EPI) by Pimonenko *et al.* (2018) ^[47], which indicates that the country needs significant improvement in the future. To reduce GHG emissions from the agriculture sector, appropriate management practices must be introduced to

minimize CO₂, CH₄ and N₂O emissions. The agricultural sector should pay more attention to reduce GHG emissions from rice fields, and in order to develop necessary mitigation measures, carbon dioxide and methane emissions must be quantified for paddy cultivated areas. Nitrous Oxide (N₂O) is liable for 6% of worldwide anthropogenic GHG emissions; 90% of those emissions are associated with agriculture. Increased N fertilizer usage and animal production are the most significant sources of the projected increase in N₂O. Agricultural soils are the key anthropogenic sources of N₂O and contribute around 60% of human derived N₂O emissions. However, the N₂O fluxes observed with the management practices considered under the current study were minimal.

Urea is the major source of supply of nitrogen to crop production in Sri Lanka and urea is imported to Sri Lanka for agricultural use. Around 64% of the imported urea, with a nitrogen content of 46%, is used in paddy cultivation. The recovery of applied nitrogen to wetland paddy is around 20-40%. The agronomic efficiency of nitrogen (additional grain yield per kg N applied compared to without-Nitrogen) is as low as 10 kg per kg of Nitrogen added.

According to the result of MANOVA, there is a significant difference between management plots and control plot with regard to CH₄ flux and there is no significant difference in CO₂ flux. The CH₄ flux of the control is significantly different from Mgt 2, and there is no significant difference between the control and Mgt 1 or Mgt 3. However, there is a significant difference between the Mgt 2 and Mgt 3 as well. Estimated Marginal Means of CH₄ show the lowest CH₄ emission from plot Mgt.3. MANOVA also shows that there is no difference between the two sites, when the emissions from each management practice, including the control, were compared. When considering better yield, more efficient irrigation method, and less GHG emissions, Mgt 3 plot (i.e. the combination of addition of organic matter to soil, transplanting of seedlings and intermittent water supply/irrigation) came up as the best option among all the other management plots.

5. Conclusion

Soil salinity is an emerging problem in most of the paddy fields in the coastal areas as well as in highly irrigated paddy cultivating areas. Identification of these saline areas and introduction of suitable management measures are needed to keep up the productivity of these soils in the long run. Experiments conducted in Madampe and Mannar of tropical Sri Lanka indicated that the combination of management options under Mgt-3, i.e. the combination of addition of organic matter to soil, transplanting of seedlings and intermittent water supply/irrigation, is the best option for cultivating paddy in salt affected soils among the set of management practices used, in terms of better yield and reduced GHG emissions. Preparation of drainage canals, deep plowing, application of organic manure, land leveling, and maintenance of water level at 2-3 cm throughout the growing season helped reduce the salt level considerably, resulting in soil suitable for rice cultivation. However, maintenance of water level at 2-3 cm increases the CH₄ emission. Cultivation of salt tolerant varieties was more beneficial under these conditions and produced good yield levels. Introduction of salt tolerant varieties that are resistant to pests and diseases with implementation of suitable agronomical practices will allow salt affected paddy lands in

Sri Lanka to reach their full potential. Further research is necessary to improve knowledge of the status and actual distribution of salt-affected soils to implement the best management practices appropriately.

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