Adaptation to climate change on rice cultivation in the marginal coastal land through optimizing soil ameliorant application

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Abstract. Global warming has widely impact on increasing sea water level, resulting in high soil salinity in the agricultural coastal land. As consequence, rice productivity in Coastal land may decrease due to soil salinity disrupt plant physiological processes. The study aimed to analyze the impact of ameliorants application on plant and soil in rice cultivation. The study was conducted in coastline land, locating at 750 m from the Java Sea. The land was treated with several types of soil ameliorant (dolomite, agricultural lime) under dosage 1000 kg ha$^{-1}$ as a control, and several dosages of gypsum ranged between 500 kg ha$^{-1}$ to 2000 kg ha$^{-1}$. Soil ameliorants were significantly increased nutrient uptake by the plant, resulting in increases of biomass up to 42.8% compared to control in the treatment of 1000 kg ha$^{-1}$ dolomite. This was probably due to the application of soil ameliorants decreased salinity level by lowering pH by 4-5%; EC by 42-57%; Na by 39.1%; and Cl by 12.2%. Improving soil nutrient content was reached by applying 1000 kg ha$^{-1}$ gypsum which increases total N by 5-25%; Ca by 5%, and S by 28% compared to control and increased another soil nutrient content compared to before treatments.

1. Introduction
Climate change directly affects the agricultural industry through increasing atmospheric temperature and erratic rainfall which leads to water balance alteration impacted to irrigation water compliance [1-3]. Further, climate change blamed as changes in land use in agricultural sectors because of losing ideal climatic cultivation zones which lead to a decline in soil quality such as reduction of soil organic matter, degrading soil nutrient content as well soil acidification, and inclining greenhouse gas emission [4-6]. Since water and nutrients are important pillars of cultivation, crop production is also disrupted. It is reported by several researchers that climate change decreases crop production in tropical countries [4, 7, 8]. Rice productivity in Indonesia is also affected by this phenomenon.

In 2020, national rice production was 54.6 million tons which was 8% lower than the previous year because the cultivation area also decreased by 6.7%. Regarding the data, land productivity also weakened by year due to the climate change effect. In China, climate change negatively affected net primary productivity by 70.72% [9]. Thus, a strategy to mitigate the effect of climate change is needed to improve national rice production by enlarging land utilization in a marginal area, such as saline soil,
peatland, etc. Besides widen cultivation areas, extensification reduces the negative effect of intensive agriculture management such as nutrient loss, carbon dioxide emission, reduced biodiversity, etc [10].

The coastal area is one marginal area that is potentially utilized as a rice field. Indonesian shoreline length is approximately 106,000 km which has a potential cultivation area of 1,060,000 ha has not been used much as an agriculture center because of its low fertility level [11]. However, salinization is considered the highest problem in the coastal area [12]. Salinity is induced by seawater intrusion into the soil which leads to increasing content of NaCl and EC value in soil [12-13]. Salinity becomes a serious threat to crop because it interferes with physiological processes causing membrane damage, nutrient imbalance, enzymatic inhibition until the death of the crop [14]. Hence, soil improvements are required to reduce salinity levels by applying soil ameliorants.

Soil ameliorants can improve soil physical, chemical, and biological properties such as improving soil aggregate, reducing pH and EC level, and activating microbial community as well as increasing plant growth [13, 15-17]. A combination of using gypsum as ameliorants and salt-tolerant rice varieties yielded up to a 25% increasing in rice production along with increasing soil health [18].

This paper aims to investigate how Ca-based soil ameliorants such as gypsum affect to improve soil quality in saline soil especially in a coastal area as well as increasing rice productivity. Field research was conducted under different dosages of gypsum to evaluate the best effective dosage giving the highest rice yield.

2. Materials and methods

2.1. Study site characteristics

The study was conducted in the northern coastline of Paciran Village (112° 34’ 23.2” E and 6° 87’ 47.4” S) located in Lamongan, East Java, Indonesia which approximately 750 meters from the sea. By the distance, it is considered that the paddy cultivation is affected by seawater intrusion. The preliminary field survey was conducted to select representative paddy fields in a coastal area. The soil samples were collected at 0-20 cm depth to assay the level of soil salinity. The soil chemical properties were described in Table 1.

Table 1. Initial soil chemical properties.

| Parameters      | Units   | Value  | Criteria |
|-----------------|---------|--------|----------|
| pH H₂O          |         | 7.3    | Neutral  |
| pH KCl          |         | 6.8    |          |
| EC              | dS m⁻¹  | 2.55   | Moderate |
| N total         | %       | 0.18   | Low      |
| Available P     | mg kg⁻¹ | 1.6    | Very low |
| K-dd            | me 100 g⁻¹ | 0.29 | Low      |
| Ca-dd           | me 100 g⁻¹ | 37.60 | Very high|
| Mg-dd           | me 100 g⁻¹ | 2.66  | high     |
| S-SO₄₂         | ppm     | 52.70  | Low      |
| Na-dd           | me 100 g⁻¹ | 4.53  | Very high|
| Cl              | %       | 0.38   | Very high|

2.2. Research design

The experiment was arranged in a randomized block design with 8 treatments and 3 replications. The 8 treatments included the following: (L1) Inorganic fertilizer without ameliorants amended; (L2) Inorganic fertilizer + dolomite 1000 kg ha⁻¹; (L3) Inorganic fertilizer + agricultural lime 1000 kg ha⁻¹; (L4) Inorganic fertilizer + gypsum 500 kg ha⁻¹; (L5) Inorganic fertilizer + gypsum 1000 kg ha⁻¹; (L6) Inorganic fertilizer + gypsum 1500 kg ha⁻¹; (L7) Inorganic fertilizer + gypsum 2000 kg ha⁻¹. Soil ameliorants were amended 7 days before planting of Inpari 33 rice cultivar. Soil ameliorants were
manually mixed with 0-20 cm soil layer. The inorganic fertilizers used were 200 kg ha\(^{-1}\) Urea (containing 46% N) and 300 kg ha\(^{-1}\) NPK (containing 15% N, 15% P\(_2\)O\(_5\), 15% K\(_2\)O). Inorganic fertilizers were added 3 times during rice growth (7, 14, 35 days after planting).

2.3. Soil and plant samples collection
Soil samples obtained from each plot were mixture soil collected from five points at a depth of 0-20 cm after harvest. Soil samples were air-dried at room temperature, passed through a 0.5 mm diameter sieve before measured in the laboratory. The parameters measured were soil pH, EC, Na, Cl, N, P, K, Ca, Mg, S. All chemical properties represented after harvested condition.

Plant parameter measured divided into 3 categories: plant growth, production, and nutrient uptake. Plant growth parameters (plant height, leaves (number of leaves, leaves color index), number of tillers) were measured gradually during the vegetative phase. Plant productions (fresh weight and dry weight of grain) were measured after harvesting. Nutrients (N, P, K, Ca, Mg, S) uptake were measured from the whole rice plant after harvesting.

2.4. Laboratory analysis
Air-dried soil samples that passed through 2 mm sieved were used for measuring soil pH (by using H\(_2\)O at a ratio of 1: 1), soil organic C (Walkley and Black method), total N (Kjeldahl method), available P (Spectrophotometry method), and base cations (K-dd, Na-dd, Ca-dd, and Mg-dd) by using soil filtrate analyzed by flame photometer and EDTA titration.

2.5. Statistical analysis
The effect of soil ameliorants on the obtained parameters was assessed using one-way ANOVA, when F values were significant, Duncan Multiple Range Test (DMRT) was further used to compare the means of different treatments. The analysis was performed using the R program.

3. Results and discussion
3.1. Effect of soil ameliorants upon plant growth and production
Rice growth parameters include plant height, the number of leaves, leaves color index, and the number of tillers measured regularly during the plant vegetative phase. The plant height increased by ages, but statistically, soil ameliorants had not significantly affect (p≥0.05) plant growth (i.e. plant height, number of leaves, number of tillers). Rice plant height in 10 weeks after planting ranged from 71.86 cm to 73.72 cm with the highest plant was in the treatment of 1000 kg agricultural lime ha\(^{-1}\) (Figure 1a), the number of leaves ranged between 74 to 83 (Figure 1b), and the number of tillers ranged between 22 to 27 tillers (Figure 1c). Even though there was a development of rice growth, however, maximum height was not reaching the average height of Inpari 34 rice cultivar which height approximately 107 cm according to cultivar description [19]. The reduction of paddy height was due to salinity reduced the ability of plants in water absorption [20]. Therefore, although soil ameliorants did not significantly affect rice growth, in general, the application of soil ameliorants increased plant height and number of leaves by 1.1% and 6.9% compared to control. Another research reported that gypsum application under different dosages was not significantly affected rice growth [21, 22]. This stated that both dolomite, agricultural lime, and gypsum in the same dosage gave the same effect on rice growth in saline soil. The insignificant effect of soil ameliorants on growth parameters was caused by sufficient nutrients given to the plant which inorganic fertilizer applied in this study was 137 kg N ha\(^{-1}\) higher than the nitrogen need of rice plant which about 90 – 120 kg ha\(^{-1}\) [23].
Figure 1. Effect of Ca-based soil ameliorants upon (a) rice height, (b) number of leaves, and (c) number of tillers.

3.1.1. Leave chlorophyll and color index. Soil ameliorants did not show a significant effect (p>0.05) on leaves chlorophyll index and leave color index of rice planted in saline soil, but there was an increasing trend on the soil ameliorants treatments (Figure 2a). Since NaCl stress-induced reduction of chlorophyll content in chloroplast from the sensitive plant [24], adding soil ameliorants on saline soil could increase chlorophyll content on rice leaves by 3.5% compared to control. Ca contained in soil ameliorants blocked the intrusion of Na into plant cells, therefore it could negatively affect to decline of chlorophyll content.

Figure 2. Effect of Ca-based soil ameliorants upon (a) leaves chlorophyll index and (b) color index

3.1.2. Rice production. The effect of soil ameliorants upon rice production in saline soil was measured by some parameters including the number of productive tillers, fresh grain weight, dried grain weight, and 100 grains weight. Statistically, soil ameliorants significantly affected (p<0.05) to fresh and dried grain weight, but did not show a significant effect (p>0.05) on the number of productive tillers and 100 grains weight. Soil ameliorants increased fresh and dried grain weight by 18.6% and 21.7%, respectively (Table 2). The highest production was in treatment L2 (1000 kg dolomite application ha\(^{-1}\)), with average dried grain weight reached 5.30 tons ha\(^{-1}\). This yield had no significant difference with other Ca-based soil ameliorants in the same dosage of application (~1000 kg ha\(^{-1}\) of agricultural lime (L3) and gypsum
(L5)) (Table 2). This stated that Ca-based soil ameliorants improved saline soil and reduced the salinity effect in the plant [13, 25, 26]. Although the yield was increasing, it was not reaching the maximum yield of Inpari 34 cultivar which hit 8.1 tons ha\(^{-1}\) [19]. The decreasing of grain weight was induced by salinity stress which caused decreasing in plant water content because of barriers by Na\(^+\) or Cl\(^-\) [27-28]. In contrast to grain weight, the number of productive tillers and 100 grains weight was not significantly affected (p>0.05) by soil ameliorants but showed an increasing trend in the treatments of Ca-based soil ameliorants. The number of productive tillers ranged between 12 – 15, with the highest number of productive tillers was in the application of 1000 kg ha\(^{-1}\) dolomite (L2). In line with the number of productive tillers, the yield of L2 was the highest among all. Meanwhile, the weight of 100 grains in all treatments ranged from 2.03 g to 2.23 g. Applying soil ameliorants increased grain weight by 4.3% compared to control, respectively. Overall data of rice production is mention in Table 2.

**Table 2. Rice production**

| Treats | Number of productive tillers | Fresh grain weight (ton ha\(^{-1}\)) | Dried grain weight (ton ha\(^{-1}\)) | 100 grains weight (g) |
|--------|-----------------------------|-------------------------------------|------------------------------------|----------------------|
| L1     | 13                          | 5.51 ab                             | 3.71 a                             | 2.07                 |
| L2     | 15                          | 7.44 c                              | 5.3 d                              | 2.13                 |
| L3     | 14                          | 7.09 c                              | 4.85 cd                            | 2.23                 |
| L4     | 12                          | 5.64 ab                             | 4.02 ab                            | 2.13                 |
| L5     | 14                          | 6.63 bc                             | 4.5 bc                             | 2.23                 |
| L6     | 14                          | 7.11 c                              | 4.76 cd                            | 2.03                 |
| L7     | 14                          | 5.31 a                              | 3.68 a                             | 2.17                 |
| f prob | 0.301                       | 0.006                               | 0.001                              | 0.531                |

3.2. Effect of soil ameliorants upon nutrient uptake by plant

Statistically, soil ameliorants application significantly affected (p<0.05) nutrient uptake by the plant, except N and S uptake. Even so, N uptake in the treatment of soil ameliorants was higher than control by 11.4% - 74.9% compared to control (Table 3). Ca-based soil ameliorants increased N uptake by root plants, especially in the vegetative stage [29].

In contrast, the uptake of P, K, Ca, Mg, and S were significantly affected (p<0.05) by soil ameliorants. P uptake ranged between 0.38 – 2.12 g per clumps of rice, which the highest uptake was in the treatment of 1000 kg gypsum ha\(^{-1}\) (L5) that increased P uptake up to 185% compared to control. In line with the increase of P uptake because of soil ameliorants treatments, the K uptake showed the same trendline which L5 absorbed the highest P up to 189% compared to control. It was indicated that Ca-based soil ameliorants were able to increase the effectiveness of primary nutrient uptake. The addition of Ca reduced the negative impact of salt by increasing osmotic pressure in the soil, so it created balancing between ions. Further, adding Ca led exchangeable capacity between Na and Ca which induced Na to be leached, and increased the change of other cations to be absorbed.

The uptake of Ca and Mg significantly inclined along with adding Ca-based soil ameliorants with the highest uptake of Ca was at the treatment of 1000 kg agricultural lime ha\(^{-1}\) (L2) which increased the uptake by 159% from control, while the highest uptake of Mg was in 1000 kg dolomite ha\(^{-1}\) (L3), with the increasing of the uptake reached 94% compared to control. It was understandable since the input of each nutrient was different. Agricultural lime (CaCO\(_3\)) contained the highest Ca compared to other soil ameliorants which were 33% of the chemical compound, while dolomite and gypsum contained 14% and 21% of the chemical compound, respectively. Meanwhile, only dolomite contained Mg so the highest available Mg might be in the dolomite treatment. And so, the highest S uptake was in the treatment of 2000 kg gypsum ha\(^{-1}\) (L7) which had the highest input of S among all treatments. However, statistically, the update had no different with the lower dosage of gypsum.
Table 3. Effect of soil ameliorants upon nutrient uptake.

| Treats | N uptake | P uptake  | K uptake | Ca uptake | Mg uptake | S uptake |
|--------|----------|-----------|----------|-----------|-----------|----------|
|        | gram per clumps of rice |          |          |           |           |          |
| L1     | 0.39     | 0.72 a    | 2.07 bc  | 0.22 a    | 0.17 a    | 0.032    |
| L2     | 0.39     | 1.20 a    | 3.35 cd  | 0.36 ab   | 0.33 b    | 0.039    |
| L3     | 0.35     | 0.86 a    | 1.92 a   | 0.57ab    | 0.20 a    | 0.035    |
| L4     | 0.46     | 2.07 b    | 4.56 c   | 0.30 a    | 0.19 a    | 0.038    |
| L5     | 0.55     | 2.12 b    | 5.99 d   | 0.34 bc   | 0.15 a    | 0.049    |
| L6     | 0.46     | 0.94 a    | 2.12 bc  | 0.56 bc   | 0.18 a    | 0.049    |
| L7     | 0.44     | 0.96 a    | 2.57 bc  | 0.75 c    | 0.19 a    | 0.052    |
| f prob | 0.389    | <0.01     | <0.01    | <0.01     | 0.03      | 0.09     |

3.3. Effect of soil ameliorants upon soil fertility

3.3.1. Salinity indicators. Salinity indicators measured contained soil pH, EC, Na, and Cl. Statistically, soil ameliorants application did not significantly affect (p \geq 0.05) soil pH, which ranged from 6.93 – 7.02 (Figure 3a). Even so, soil pH level decreased by 4 – 5% compared to before treatment condition. The highest decrease was found in the treatment of gypsum (contained 18% S) combined with Urea application that yielded H⁺ because of nitrification processes [30].

Soil Electrical Conductivity (EC) was not also affected (p>0.05) by soil ameliorants, even though there was decreasing in EC level compared to before treatments by 42 – 57% from 2.55 dS/m to 1.02 –
1.76 dS m$^{-1}$ (Figure 3b). In contrast to soil pH and EC, the content of Na and Cl in soil was significantly affected (p<0.05) by soil ameliorants. Adding soil ameliorants reduced the content of Na$_{exch}$ and Cl$^-$ by 39.1 and 12.2%, respectively. However, the content of Na$_{exch}$ and Cl$^-$ was not significantly different between any treatments (Figure 3c and 3b).

3.3.2. Soil nutrient content. Application of soil ameliorants gave a significant impact (p<0.05) on soil nutrients content (N, P, Ca, S) after treatments (Table 4). Applying 1000 kg gypsum ha$^{-1}$ (L5) resulted in a higher total N than applying agricultural lime (L3) and dolomite (L2) in a similar dosage (5 – 25%). Likewise, Ca and S-SO$_4$ content in treatment L5 were higher than other Ca-based soil ameliorants in the same dosage (L2 and L3) by 5% and 28%, respectively. However, the increase of gypsum dosage did not show significant differences between under dosage applications. Otherwise, the highest content of available P was in the treatment of 1000 kg dolomite ha$^{-1}$ (L2) which reached 31.5 ppm, 81% higher than applying agricultural lime (L3) and 57% higher than applying gypsum in the same dosage (L5).

On the other hand, K and Mg content in soil was not affected by soil ameliorants, but it showed increasing compared to its content before treatment. K content after treatments increased by 54% compared to before treatments caused by applying fertilizer during rice cultivation. Likewise, Mg content after treatments increased by 58 – 142% compared to before treatments (Table 4).

| Table 4. Effect of soil ameliorants upon soil nutrient content. |
|---------------------------------------------------------------|
| **Kode** | **N Total (%)** | **Available P mg kg$^{-1}$** | **K-dd** | **Ca-dd Me 100g$^{-1}$** | **Mg-dd** | **S-SO$_4$ mg kg$^{-1}$** |
|-----------|----------------|-----------------------------|---------|------------------------|---------|-------------------------|
| L1        | 0.20 a         | 20.8ab                      | 0.43    | 25.2 e                 | 4.21    | 51.4                    |
| L2        | 0.16 b         | 31.5 a                      | 0.46    | 28.2 b                 | 6.52    | 40.7                    |
| L3        | 0.19ab         | 17.4 b                      | 0.51    | 28.0 b                 | 6.42    | 53.7                    |
| L4        | 0.20 a         | 17.4 b                      | 0.48    | 27.0 e                 | 5.59    | 44.3                    |
| L5        | 0.20 a         | 20.1ab                      | 0.54    | 29.4 a                 | 6.34    | 60.5                    |
| L6        | 0.18ab         | 16.5 b                      | 0.45    | 26.1 d                 | 5.36    | 47.1                    |
| L7        | 0.18ab         | 24.1ab                      | 0.45    | 26.3 d                 | 6.46    | 57.4                    |
| f prob    | 0.09           | 0.007                       | 0.39    | <0.01                  | 0.39    | 0.03                    |

4. Conclusion
The addition of Ca-based soil ameliorants improved soil quality in saline soil by lowering pH level by 4-5%; EC by 42-57%; Na by 39.1%; and Cl by 12.2%. The addition of gypsum increased total N in soil by 5 – 25% compared to other ameliorants in the same dosage, likewise Ca and S increased 5 and% 28% compared to other types of Ca-based soil ameliorants. Furthermore, rice production was also increasing by addition Ca-based soil ameliorants with the highest dried grain weight was in the treatment of 1000 kg ha$^{-1}$ dolomite, which reached 5.30 tons ha$^{-1}$. Improvements in land quality and rice production due to the application of Ca-based soil ameliorants indicate that saline soil can be used for rice cultivation to support agricultural extensification as an adaptation to climate change.

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