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IMBALANCED NUTRIENT ACCUMULATION IN THE COASTAL SOILS INDUCED BY SALINITY INTRUSION

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Abstract. Salinity intrusion worldwide is a problem of consideration for the global food production and ensuring food security. In this investigation, we focused to find out the key chemical elements for this salinity problem. In this paper, the authors reported the high accumulation of sodium (Na^+) and increased EC (6.9 dS/m) values than that of the previous year (4.67 dS/m). We found the highest EC, Na^+ and ESP of 6.9 dS/m, 2.6 meq/100 g of soil and 19.1%, respectively at Dumki, Potuakhali. The highest increase of exchangeable Na^+ was found in Tojumuddin, Bhola. The result is 55% more when compared to the previous investigated result. Contrary to the Na^+ increase, we found 84–91% decrease of the organic matter (OM) in the investigated samples. The excessive increase of exchangeable Na^+ and decrease of OM in this investigation indicates the salinity intrusion and low nutrient content, respectively in the coastal soils of Bangladesh.

Keywords: nutrient imbalance, sodium accumulation, salinity intrusion, coastal soils

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INTRODUCTION

Being one of the alarming issues worldwide, salinization is causing reduction of agricultural production remarkably all over the world. Nowadays, salinity is one of the most considerable problems in coastal belts of Bangladesh. Henceforth, the agriculture sector (as the dominant livelihood) in Bangladesh should be given the highest priority and it is the responsibility of the government at different levels – semi government, non-government, and personal research sectors – in order to increase food production.

Alam *et al*. (2017) have mentioned 20% yield reduction owing to salinity as one of the major environmental problems in agriculture sector of coastal regions (Clermont-Dauphin *et al*. 2010, Mass and Hoffman 1977). The causes of salinization belong to either environmental or anthropological. Environmental factors such as potential impact of climate change, sea level rising, cyclones, floods, tidal storms as well as anthropogenic reasons like intensive agriculture of high yield variety crop production, prolonged chemical fertilization, usage of poor-quality irrigation water, degradation of ground water quality, improper soil management, growing aquaculture and infrastructural development favor the risk of salinization in coastal soils of Bangladesh. Salinity intrusion induced by sea level rising and anthropogenic activities are very common for central Asia, arid and semi-arid areas and even the Russian Federation (Shahid *et al*. 2013).

Bangladesh is a part of the Ganges Delta and meets the Bay of Bengal at the southern edge of the country with a gentle slope from the north. Ganges floodplains, mostly the southwest part of Bangladesh, are facing the risk of saline intrusion due to continuous contact to the sea (Sarwar 2005). Because of having very flat topography, the regions sometimes experience strong tidal effects even up to 200 km from the coast (Dasgupta *et al*. 2015). In addition, these tidal effects sometimes inundate the coastal area causing the salinity intrusion to ground water.

About 30% of the cultivable lands of the country are covered by these coastal regions (Islam 2006). Despite the unstable and altered shape and surface area of the coastal zones, about half of the cultivable coastal regions are affected by salinity (Haque 2006) and different degrees of salinity limit the effective use of land in those areas (Petersen and Shireen 2001).

The crop production in the coastal zone is declining not only due to salt accumulation problem but also secondary effects of salinization such as soil quality degradation, soil erosion and conversion of agricultural land to shrimp ponds. In that circumstance, excessive use of inorganic fertilizers and converting agriculture to aquaculture is increasing in these areas (Khanom 2016).

Saline soil is a type of problem soil but the issue of the accumulation of element that cause salinity of soils has not been sufficiently studied. While other types of special soils in Bangladesh have been studied and evaluated (Uddin *et al*. 2013, 2014), the coastal salinity intrusion through sodium (Na^+) accumulation needs to be evaluated as early as possible.

Accordingly, the authors believe that it is important to routinely check the current nutrient status of some coastal areas to evaluate the ionic imbalance in coastal soils as a factor of salinity intrusion. To the best of authors' knowledge, this is the first approach to link a sodium accumulation with a nutrient imbalance.

Therefore, the goal of this study is to investigate the present condition of salinity and future risk of salinity intrusion in relation to cationic enrichment in salt-affected soils of Bangladesh. In addition to that, this study aims to explore the nutrient enrichment behavior of soils regulated by salinity intrusion regarding crop production. The authors tried to describe this phenomenon based on existing relationship among soil salinity, base cations and soil nutrients that influence soil physical and chemical properties in terms of crop production.

MATERIALS AND METHODS

Literature search and site selection

The most dynamic and active part of coastal zones in Bangladesh is the central coastal zone having a large volume of discharge from the Ganges-Brahmaputra-Meghna river system forming high volume of silty deposition (more than 70% silt and 10% sand – Coleman 1969, Allison *et al*. 2003). On the other hand, soil characteristics of the western coastal zones covered by greater Khulna and part of Patuakhali district are silty loams or alluvium in nature. Based on the previous literature and saline soils map of Bangladesh, the authors decided to collect soils from three *upazilas* (regions), namely Muladi, Tojumuddin and Dumki of three central coastal districts of Barisal, Bhola and Patuakhali, respectively, and one *upazila* named Terokhada of the western coastal district Khulna. Sampling locations with geographic coordinates are presented in Table 1.

Table 1. Samplings sites with adjacent river and geographic coordinates

District	*Upazila*	River	Coordinates
Barishal	Muladi	Payra	23°00'42.3"N, 90°20'47.4"E
Bhola	Tojumuddin	Meghna	22°25'0.12"N, 90°50'54.96"E
Khulna	Terokhada	Chitra	22°56'30.12"N, 89°40'9.84"E
Patuakhali	Dumki	Lebukhali	22°27'39.5"N, 90°20'24.6"E

Collection and preparation of soil samples

Twelve composite soil samples, three from each *upazila*, were collected from agricultural fields with no rice fields but local vegetation located just next to the respective rivers (Table 1). The samples were collected from a depth up to 15 cm. Approximately 1 kg of soil from three locations within 600 m (200 m apart) was collected in a polythene bag to make the representative composite sample of the specific site. We select the winter season to avoid rainfall effect on the nutrient concentration and salinity. Collected soil samples were properly processed and prepared as necessary for analysis in the laboratory.

Soil sample analysis

Soil samples were analyzed for the physico-chemical and chemical parameters. Soil pH, EC and salinity were detected by Multimeter (Hach sensION156). To determine organic matter (OM %), the wet oxidation method of Walkley and Black (1934) was followed. Total N (%) was analyzed by the Kjeldahl digestion method (Jackson 1967, Sparks *et al*. 1996) with the assistance of Potentiometric Titrator (906 Titrando, Metrohm, Swiss Mode). Exchangeable Na, K (meq/100 g) were determined by the ammonium acetate extraction method (Jackson 1967, Sparks *et al*. 1996) using a flame photometer (Jenway PFP7). Exchangeable Ca and Mg and total Zn and Fe were measured by Atomic Absorption Spectrophotometer (AA-7000, Shimadzu), followed by APHA (1998) guidelines using certified reference materials (CRMs; SSSA, 1996). Total P and S were measured by vanadomolybdophosphoric acid (yellow color method) and turbidimetric method, respectively, using UV Visible Spectrophotometer (Jackson 1967, Hunt 1980, Sparks *et al*. 1996). Exchange sodium percentage (ESP) was determined from the given relationship:

$$ESP = (Na^+/CEC) \times 100$$

where: ESP = exchangeable sodium percentage; Na^+ = measured exchangeable Na ion (meq/100 g soil); CEC = cation exchange capacity by bases (meq/100 g soil).

RESULTS AND DISCUSSION

The soil samples were analyzed to determine pH, EC (dS/m), salinity (%), OM (%), available nutrients (meq/100 g soil) like Na, K, Ca, and Mg. The total content of important nutrient elements (%) such as N, P, K, S, Zn and Fe were measured for the evaluation of total nutrient trends due to salinization process.

The texture of the studied soil samples are clay loam, loam, and clay loam of Muladi, Tojumuddin, and Dumki, respectively (SRDI, 1999, 2001, 2009). The values of pH, EC, salinity, OM, exchangeable cations (Na, K, Ca and Mg) of the soil samples are presented in Table 2. The calculated values of ESP and CEC by bases are also mentioned in Table 2 and 3, respectively. The soils were neutral to alkaline in reaction (pH ranges from 7.8 to 8.4) except Dumki *upazila* where the soil was slightly acidic in pH (5.8). The soil reaction values of current study coincided with the previous results where pH of coastal soils ranged from 6.0 to 8.4 (Anwar 1993, Haque 2006, Naher *et al*. 2011, Shil *et al*. 2016, Azad and Bala 2011).

Table 2. Values of pH, EC, salinity, OM, exchangeable cations (Na, K, Ca, and Mg), CEC, and ESP of soil samples collected from four coastal *upazilas* (Bangladesh)

District	*Upazila*	pH	EC (dS/m)	Salinity (%)	ESP (%)
Barisal	Muladi	8.2±0.04	0.72±0.09	0.03±0	15.4
Bhola	Tojumuddin	7.8±0.36	2.4±1.3	0.16±0.01	18.6
Khulna	Terokhada	8.4±0.29	3.7±0.60	0.19±0.04	14.0
Potuakhali	Dumki	5.8±0.24	6.9±3.4	0.38±0.20	19.1

Table 3. Values of organic matter (OM), exchangeable cations (Na, K, Ca, and Mg), and CEC of soil samples collected from four coastal *upazilas* (Bangladesh)

Upazila	OM (%)	Exchangeable cations (meq/100 g soil)				CEC by bases (meq/100 g soil)
		Na^+	K^+	Ca^{2+}	Mg^{2+}	
Muladi	0.25±0.07	0.7±0.02	0.1±0.02	1.8±0.19	1.9±0.11	4.5
Tojumuddin	0.32±0.01	1.6±0.05	1.3±0.05	2.4±0.32	3.1±0.25	8.3
Terokhada	0.37±0.05	1.8±0.25	1.3±0.13	6.2±0.02	3.3±0.29	12.6
Dumki	0.22±0.01	2.6±0.15	2.1±0.04	4.9±0.97	4.1±0.28	13.8

The values of EC of the samples placed between 0.72 to 6.9 dS/m. The soil of Dumki *upazila* exceeded the level of EC, to be treated as strongly affected by salinity (EC > 4). The result was comparable with the previous experiment of Anwar (1993). Azad and Bala (2011) mentioned the EC of Dumki around 4.67 dS/m. The highest salinity (0.38%) was determined in soil of Dumki *upazila*, which corresponded with its EC value. Horneck *et al*. (2007) proposed soil EC ranging from 0.75 to 4 (dS/m) for sustainable environment. A salinity distribution varies from location to location in the coastal regions of Bangladesh. During the rainy season, the severity of the salinity could be reduced due to dilution of the salt in the root-zone of the existing crops, whereas the condition could be opposite in the summer season.

Low amount of organic matter ranging from 0.22 to 0.37% represents the low quality of soil in nutrient status, threatening to crop production. The results of OM in this investigation are comparable with the previous studies of Anwar

(1993), Haque (2006), Azad and Bala (2011), Akter *et al*. (2012) and Shil *et al*. (2016), but in some cases, the deviation indicates the changing of agricultural practices.

As mentioned in a report of SRDI (2012), the ionic dominance of cations in the most saline soils decreased in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. However, in the soils under prolonged cultivation of shrimp in the brackish water condition in local agricultural land in this investigated area induce the salinization and has an order of ionic dominance as follows: $Na^+ > Mg^{2+} > Ca^{2+} > K^+$. On the other hand, Ondrasek *et al*. (2011) found a general distribution of exchangeable basic cations in most agricultural soil. These were $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ with a pH of 5.8 or more. Regarding the current study, the order of cation concentration of two saline soils collected from Muladi and Tojumuddin *upazila* were $Mg^{2+} > Ca^{2+} > Na^+ > K^+$, whereas soils collected from Terokhada and Dumki *upazila* showed the order of cation concentration as $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. This order followed almost the distribution of general agricultural soils although the monovalent cation Na^+ was always higher than K^+. The increase of Na^+ indicates the dominance of saline water intrusion in the agricultural field. The basic cations are loosely held to the edge of the clay particles or to the soil OM though they differ depending on the nature and conditions of the soils and are in equilibrium with the concentration of cations in the soil solution (Ondrasek *et al*. 2011). Therefore, the farmer might apply the potassium fertilizer to minimize the potassium deficiency.

The CEC values mentioned in Table 3 (4.5 to 13.8 meq/100 g soil) were obtained by summation of the base ions (Na, K, Ca, and Mg). This summation method gives a slightly lower value than those obtained by direct measurement. However, the value of CEC of the experimental soils in current study is lower than that (13.18 to 30.92 meq/100 g soil) of some coastal soils of Bangladesh reported by Azad and Bala (2011). The long-term changes towards a lower CEC value could be explained by the low amount of OM in the experimental soils. However, the OM concentration reflected a poor fertility status of soils. Despite having low amount of OM, comparatively higher values of CEC (> 12.5 meq/100 g soil) were found in soils collected from Terokhada and Dumki than those (CEC < 8.5 meq/100 g soil) found in soils from Muladi and Tojumuddin. The higher values of CEC in Terokhada and Dumki indicate the higher pH and higher clay contents, respectively in these two sites (Chorom and Rengasamy 1995). The other possible mechanism could be the cation enrichment in sampling sites. This base cation enrichment is also another example of saline water intrusion (Kaushal *et al*. 2021) and imbalance nutrient status due to salinity in the present sampling area. The higher the CEC, the more supply of nutrients to plants, however, the excess of Na can cause toxicity to them. Notably, the two highest concentrations of Na^+ corresponding to the highest two values of CEC were observed in the soils from Terokhada and Dumki.

Calculated percentage of ESP ranging from 14 to 19% (Table 2) was supported by the ESP range (3.5 to 48.8) found in some salt-affected area of Astaranga as reported by Azad and Bala (2011). A higher value of ESP indicates a hazard of salinity intrusion. Large accumulation of exchangeable Na affects soil pH which subsequently affects the soil chemical processes. This kind of chemical reaction is causing soil salinization and/or sodification and retardation of crop growth.

Total nutrient analyses among four *upazilas* were performed to understand the present fertility status and accumulation patterns of nutrients in soils. The obtained results of total nutrients were presented in Fig. 1. The total N contents of the soils were very low, 0.3% to less than 1%, while Haque (2006) reported around 1% of total N in some coastal soils of Bangladesh. However, a recent study by Shil *et al.* (2016) stated the lowest total N (0.049%) in Barisal Clay Loam soil at Babuganj, Barisal, one of the coastal lands in Bangladesh. Very lower amount of total N and P content indicates N deficiencies in all the investigated soils which is very common in saline soils. This low amount of N and P content induces the salinization due to the accumulation of sodium for the net ionic balance.

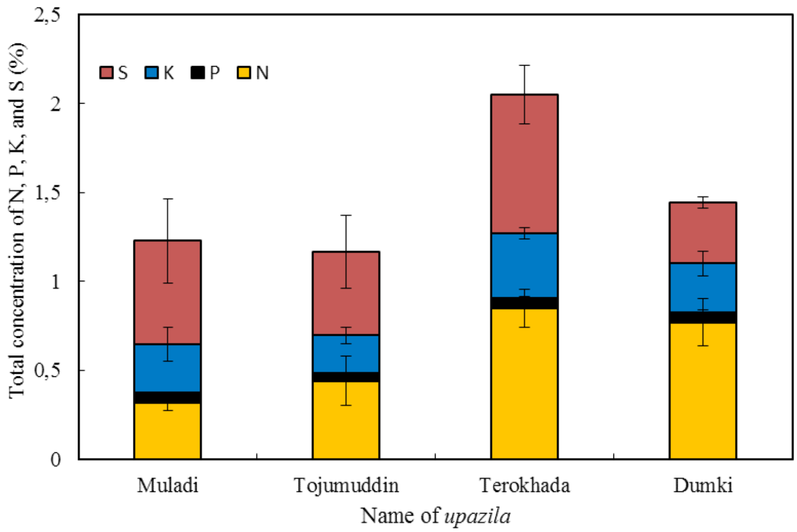

Fig. 1. Total concentration of macro- (N, P, K, and S) nutrients of coastal soils of four upazilas (Bangladesh)

The low amount of total N content induces the usage of high amount of N fertilizer in the studied area. Incorporating large amount of N fertilizer into the soil could reduce the sustainability of crop production and cause water pollution. Additionally, among the four *upazilas*, the total N, K and S were higher in Terokhada, Khulna (N – 0.85%, K – 0.36%, and S – 0.78%) when compared to the other three. Nevertheless, total P content was almost the same in all four *upazilas* (around 0.05%) but the lowest value was reported in Tojumuddin (0.04%; Fig. 1).

Measured values of some parameters such as EC, OM, and exchangeable cations (Na, Ca, and Mg) are compared to the previously available data to evaluate the accumulation or removal percentage of base cations and other parameters in relation to increasing salinity. The increased or decreased percentages of these parameters are presented in Table 4.

Table 4. Comparison of past and present results of EC, OM, exchangeable cations (Na, Ca, and Mg) of soils at the studied areas to evaluate the salinity intrusion trend

Parameters	Muladi[1]		Tojumuddin[2]		Terokhada[3]		Dumki[4]	
	increase (%)≈	decrease (%)≈	increase (%)≈	decrease (%)≈	increase (%)≈	decrease (%)≈	increase (%)≈	decrease (%)≈
EC	40		14		85		49	
OM		84		84		86		91
Na	15		55					
Ca		88		11		73		32
Mg		16	145			55	3	

The superscript numbers 1, 2, 3, and 4 indicate the sources of previously available data in *Upazila* Nirdeshika of respective *upazila*, published by SRDI in 1999, 2001, 1998, and 2009, respectively.

In case of micronutrient, the concentration of Zn ranged from ≈0.004 to 0.006% having the highest value in Dumki and the lowest value in Terokhada, whereas Fe concentration in all four *upazilas* ranged from ≈0.28 to 1.85% having the highest value in Muladi and the lowest value in Dumki (Table 5). These results of micronutrients ranged from 0.002 to 0.008% for Zn and 0.82 to 2.53% for Fe of some salt-affected soils of Punjab in India reported by Sharma *et al*. (2009). Both macro- and micronutrients play an indispensable role for plant growth. Due to high pH, the deficiency of micronutrients is very common in salt stressed soils (Zhu *et al*. 2004, Zayed *et al*. 2011) which is the reason why we evaluated the two important micronutrients in the study area. Different level of salinity can affect the micronutrient concentrations in soils and furthermore influence crop growth (Oertli 1991). The availability of micronutrients in saline soils depends on soil pH, redox potential of the soil solution, organic matter, and other binding sites of inorganic particles and all the factors that influence the solubility of micronutrients as well. Continuous growing of high yielding crop varieties without having organic fertilization might deplete the levels of micronutrients in the studied area.

Table 5. Total iron (Fe) and zinc (Zn) concentration of soil samples collected from four coastal *upazilas* (Bangladesh)

District	*Upazila*	Zn (%)	Fe (%)
Barisal	Muladi	0.004±0.00	1.062±0.07
Bhola	Tojumuddin	0.004±0.00	0.864±0.85
Khulna	Terokhada	0.004±0.00	0.381±0.15
Potuakhali	Dumki	0.005±0.00	0.423±0.11

Surprisingly, there was an irregularity of exchangeable cations enrichment with the increased percentage of EC of the soil samples of four *upazilas*. The increased percentage of exchangeable Na in two *upazilas*, Muladi and Tojumuddin (data for soils of current location at Terokhada and Dumki were not found in previous literature), might show a clear indication of salinity intrusion. However, the increase of EC (85%) in soil of Terokhada showed an alarming indication of cation enrichment which might contribute to sodicity problem in the soils where a decrease in divalent cations was found. An imbalanced accumulation of exchangeable cations as well as their irregular increase and decrease were noticed in each of four *upazilas*. EC increased, and OM decreased in all soils of four *upazilas*, whereas Ca had decreased in all soils. On the other hand, Mg was shown to increase at a greater percentage in soil of Tojumuddin, whereas in the soil of Dumki the increasing trend is lower than that of Tojumuddin. Such an uneven nature of cation enrichment is also supported by the findings of Alam *et al*. (2017). In these circumstances, it could be mentioned that the imbalanced nutrient accumulation in the study sites was due to salinity intrusion, which is clearly supported by Na^+ accumulation and the increased EC values of the soils than that of previous years. A recent investigation suggested the intrusion of salt-water affect the nutrient concentration in soil pore water (Weissman and Tully 2020). The best fit regression model for exchangeable Na with salinity and exchangeable Na with EC represents a coefficient of determination (R^2) value around 0.98 and 0.95, respectively (supporting information).

Hanson *et al*. (1999) reported that Ca and Mg strive for the exchange sites occupied by sodium to reduce the amount of sodium bound to soil particles. Henceforth, it could be certainly explained that, in the present investigation, the decreased percentage of Ca and Mg induce the further accumulation of Na exerting a serious problem of crop production. Nutritional imbalance is very common when excessive amounts of sodium chloride accumulate in soil. Accumulation of excess Na^+ ion can dilute and displace other plant nutrients reducing soil fertility. Plants under salt stress may suffer from oxidative and mechanical stress, or poor health because of nutritional imbalances. Different degrees of salinity have already remarkably reduced agricultural productivity in some areas of Satkhira, Patuakhali, Borguna, Barisal, Jhalakathi, Pirojpur, Jessore, Narail, Gopalganj and Madaripur districts.

The extreme salinity condition limits the livelihood of the people in the studied area and encourage them to rely on shrimp farming. However, shrimp farming has a multilevel negative impact on soil and crop production by increasing the salinity through brackish water intrusion, further decreasing rice production (Bala and Hossain 2009, Karim 2006). In addition, increasing the use of inorganic fertilizers, pesticides, irrigation are necessary for high yielding variety (HYV) crop cultivation to minimize salinity effects in arable lands (Hossain 1988). However, the prolonged use of inorganic fertilizers causes further threat of soil salinization and degradation of soil quality and fertility (Hossain and Kashem 1997, Rahman and Thapa 1999). Thus, salinity intrusion is a major problem of food security for agriculture-based countries like Bangladesh. It is an indisputable fact to avoid and mitigate the soil salinity for sustainable agricultural development. The findings of the present investigation depicted the possibility of salinity intrusion in the studied area. The increasing Na^+ concentration contributes to the imbalance in the accumulation of other basic cations in soils. The imbalanced accumulation of exchangeable cations in soils and additional use of chemical fertilizers have a negative effect on the soil fertility and quality.

CONCLUSIONS

Salinity is a global issue these days. Bangladesh is facing the salinity intrusion problem likewise the other coastal regions in the world. In this study, the salinity intrusion is clearly manifested in the coastal soils inducing an excessive sodium accumulation. The sodium accumulation and concentration of sodium are increasing tremendously, causing a nutrient imbalance in the studied soils. In addition to the Na accumulation, the EC of the four studied areas is increasing when compared to the previous investigation, which indicates a clear presence of salinity intrusion in the investigated soils. The low total nitrogen content will increase the use of nitrogen fertilizers which do not contain the right proportion of nutrients and will contribute to the environmental problems in the near future.

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SUPPORTING INFORMATION

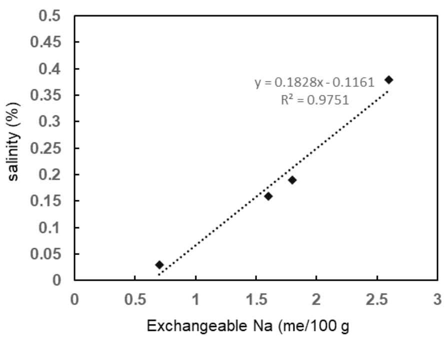

Fig. S1. The regression model of exchangeable Na and salinity representing the R^2 value 0.975

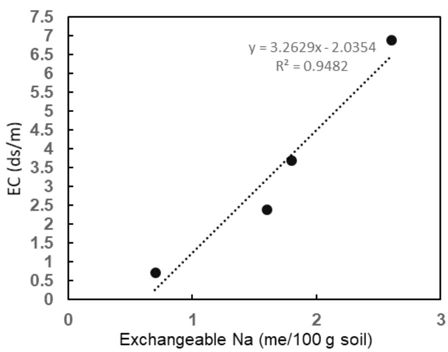

Fig. S2. The regression model of exchangeable Na and EC representing the R^2 value 0.948