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Effect of Ameliorants on Nutrient Uptake and Maize Productivity in Peatlands

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ABSTRACT

Peat, when used as a growing medium, must be optimally managed to improve its soil chemical properties. One alternative to increasing soil pH and available nutrient is by applying coastal sediment and salted fish waste which are easily obtained and relatively inexpensive. This study examined the effect of different amounts of coastal sediment and salted fish waste on nutrient uptake and production of maize on the peatlands of West Borneo (West Kalimantan). One control and three dosing regimes were tested on three types of peatlands as follows : (1) control case (farmers' standard practice without additional dosing);(2) 20 Mg ha^{-1} of coastal sediment + 0.75 Mg of salted fish waste ha^{-1}; (3) 40 Mg $ha^{-1}$of coastal sediment + 1.5 Mg of salted fish waste ha^{-1}; and (4) 60 Mg ha^{-1} of coastal sediment + 2.25 Mg of salted fish waste ha^{-1}. The peatlands that were improved were Typic Haplohemist, Typic Sulfisaprist and Typic Haplosaprist. A combination of 40 Mg ha^{-1} of coastal sediment and 1.5 Mg ha^{-1} of salted fish waste was found to be the best dosing regime for each peat type, increasing nutrient uptake (N, P and K) and improving the production of maize. Typic Haplosaprists (13.36 Mg ha^{-1}) was found to have the highest maize production, followed by Typic Haplohemists (13.06 Mg ha^{-1}) and Typic Sulfisaprists (12.96 Mg ha^{-1}).

Keywords: Coastal sediment, salted fish waste, nutrient uptake, correlation study

INTRODUCTION

Maize (*Zea mays* L.) is not only a staple food for people, but also a major component of feeds for the animal industry (Reddy *et al*., 2013). It is also being increasingly used in biofuels (Koçar and Civas, 2013). Indonesia targeted maize production of 29,000,000 tons in 2014. Haryono (2012) estimates that the area of production and productivity had to be increased to approximately to 4,999,000 ha and 5.82 t ha^{-1}, respectively to meet the production target. With mineral soils for agricultural expansion becoming less available, the role of peatlands is

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increasingly important, especially in a country where there is abundant peatlands (Agus *et al*., 2012). Page et al., (2011) estimate Indonesia's peatland area as being 206.95 km^2 or 47% of global peatland area, covering almost 10% of the land surface of the country. Indonesia's peatlands are mostly at low altitudes in the coastal and sub-coastal areas of Sumatra, Papua and Borneo (Kalimantan) islands (Jaenicke *et al*., 2008).

The peatland area in Borneo is about 5.77 million ha, of which 1.73 million ha are in West Kalimantan (Wahyunto *et al*., 2010) with peat thickness ranging from 0.5 to 20 m (Page *et al*., 2002). The bulk of the peatland is covered by peat swamp forests (64%), whilst a small portion is being used with smallholder farmers accounting for 4% and 11% of the peatland, respectively (Miettinen and Liew, 2010). Peat is mostly acidic to very acidic and naturally accumulates under anaerobic conditions (Sabiham *et al.*, 2012). In addition, peat soils have limitations with regard to the non-availability of potassium (K), sulphur (S), zinc (Zn), and copper (Cu) (Masud *et al*., 2011; Abat *et al*., 2012). Peat with low fertility may have reduced decomposition rates because of the lack of available cations which are usually strongly bound to the negative exchange sites within peat (Gogo and Pearce, 2009).

Two methods for improving the fertility and productivity of peatlands is by adding ameliorants (Nurzakiah *et al*., 2013) or by reducing the rate of peat decomposition (Husen and Agus, 2011). The alternative ameliorants applied to maize farms in West Borneo peatlands are coastal sediment and salted fish waste which are easily obtained and relatively cheap. The addition of coastal sediment to the peat soil can raise the pH due to the neutralising of hydrogen ions (H+) or cations from peat by hydroxide ions (OH^-) of base cations contained in the coastal sediments (Suyadi, 1995). An increase in the pH of the peat soil to 6 or 7 will increase the activity of its microorganisms (Błońska, 2010; Sullivan *et al*., 2013).

The fishing industry produces a large amount of waste which may be of potential use for agricultural activities (Mosquera *et al*., 2011). These large quantities of fish waste have not been used efficiently, and the disposal of fish waste can have negative impacts on the local environment (Kim, 2011). Fish waste has also traditionally been used as a fertiliser in coastal areas, as it is rich in nutrients, particularly nitrogen (N) and phosphorous (P) (Arvanitoyannis and Kassaveti, 2008). Hudsom (2008) found that corn plants grow faster and look better when planted in soils mixed with germinated fish compost compared to plants grown without the compost. Fish waste in West Kalimantan is readily available because the region's marine fisheries produced 89.77 tonnes yr^{-1} of products and about 20% (17.96 tons yr^{-1}) of it is considered as waste (Department of Marine and Fisheries of West Kalimantan, 2009). This study aimed to determine the effect of application of coastal sediment and salted fish waste as ameliorants on nutrient uptake productivity of maize in the peatlands of West Kalimantan.

MATERIALS AND METHODS

Study Site and Ameliorants

The research was conducted at three different sites of Rasau Jaya III subdistrict in Kubu Raya District of West Kalimantan, Indonesia from April to June 2012, on peatlands classified as Typic Haplohemist (109^o 20' 52.653" E, 0^o 14' 59.431" S), Typic Sulfisaprist (109^o 20' 56.675" E, 0^o 15' 40.304" S) and Typic Haplosaprist (109^o 21' 17.824" E, 0^o 14' 11.131" S) (Suswati *et al*., 2011).

Salted fish waste used in this study was obtained from local markets. Coastal sediments were sourced from Kijing Beach,West Kalimantan. The fertiliser dosing was based on the recommended requirements of N, P, and K for maize plants. The Pioner 21 hybrid variety of maize seed was used in this experiment.

Field Sudy

The trial was a factorial experiment with five replications conducted using randomised complete block design (RCBD) (Gomez and Gomez, 1984). The first factor of the experiment consisted of four levels: (1) farmers'practice; (2) 20 Mg ha^{-1} of coastal sediment + 0.75 Mg of salted fish waste ha^{-1}; (3) 40 Mg ha^{-1} of coastal sediment + 1.5 Mg of salted fish waste ha^{-1}; and (4) 60 Mg ha^{-1} of coastal sediment + 2.25 Mg of salted fish waste ha^{-1}. The second factor consisted of three types of peat: (1) Typic Haplohemists; (2) Typic Sulfisaprists; and (3) Typic Haplosaprists.

The study comprised 20 plots (each sized 6 m x 3.8 m) for every peat type with a 1 m protection zone framing the experimental field. The maize was planted at a spacing of 75 cm x 20 cm, resulting in 152 plants per plot. Six plant samples were taken randomly for measurement outside of swath for N, P and K uptake, whilst 44 plants (grown in the size 3 m x 2.2 m swath) were used to determine maize productivity per hectare at the end of the study. Measurement of nutrients uptake was carried out on samples at the maximum vegetative phase (Gangwar and Kalra, 1988). For this study, the maximum vegetative phase was at 54 days after planting which was indicated by the appearance of male flowers for as much as 60% of the plant population.

Ameliorants and Nutrient Uptake Analyses

Selected physical and chemical properties of ameliorants were determined using standard procedures. The coastal sediment texture analysis was carried out using the pipette method (Sarkar and Haldar, 2005). The ameliorants' pH values were determined in a 1:2.5 soil to distilled water suspension using a glass electrode. The content of organic carbon was determined using the Walkley and Black method. Ameliorant cation exchange capacity (CEC) was determined by leaching with 1M ammonium acetate buffer adjusted to pH 7.0 followed by steam distillation (Pansu and Gautheyrou, 2006). Available phosphorus in the ameliorants were extracted with $NaHCO_3$ (0.5 M) at pH 8.5 and determined colorimetrically after treatment with ammonium molybdate and stannous chloride at a wave length of 660 nm.

The exchangeable base cations were extracted with 1.0 mol L^{-1} ammonium acetate (Pansu and Gautheyrou, 2006). After extraction, the cations were measured using an atomic absorption spectrophotometer (AA-6200 Shimadzu).

Plant macronutrients (N, P and K) content were established after 1 g of plant samples (previously dried at 60°C for 24 h) were digested with concentrated H_2SO_4 (for the determination of N) and a mixture of concentrated HNO_3 and $HClO_4$ (for the determinations of nutrients other than N), after which the extraction was adjusted using up to 50 mL of deionised water. The determination of N, P and K was done using semi-micro Kjedahl, P with vanadomolybdate yellow and K with the atomic absorption spectrophotometry (AAS) method (Temminghoff and Houba, 2004).

Statistical Analysis

The data obtained were subjected to two-way analysis of variance (ANOVA) followed by a Tukey's test at 5% level. For some parameters, the correlations were computed. The data were analysed using the Statistical Analysis System package (SAS Institute, 2003).

RESULTS AND DISCUSSION

The Characteristic of Peatlands and Ameliorants

The soil characteristics of the three peat soilshave been described by Suswati *et al.* (2011). Based on the standards for determining soil chemical properties described by Hazelton and Murphy (2007), the three peat soils studied were very acidic (3.26 - 3.76), had high total N content (> 0.5%) and organic-C (29.74 - 43.85%). Available P in Typic Sulfisaprist (8.72 mg P kg^{-1}) was high, where as in Typic Haplohemist (3.36 mg P kg^{-1}) and Typic Haplosaprist (1.63 mg P kg^{-1}) the levels were relatively low. The exchangeable K varied between 0.84 - 1.23 mg K kg^{-1}. Cation exchange capacity was very high (57.37 - 88.57 $cmol_{(+)}$ kg^{-1}) but base saturation (BS) was low (8.17 - 11.26%), which could inhibit equilibrium of nutrients, especially K, Ca and Mg. The content of K, Ca and Mg nutrients was low, which resulted in the plants beign deficient in these macronutrients. This is similarto the study of Simbolon (2009) which reported low peat soil's fertility, characterised by high acidity and low availability of N, P, K, Ca and Mg.

Coastal sediment and salted fish waste samples were analysed for chemical properties (Table 1). Coastal sediment had a high pH value (8.13),very high base saturation (135.17%) and electrical conductivity (EC) of 9.57 mS/cm. It comprised 10.20% sand, 51.85% silt and 37.95% clay (silty clay loam texture). It had very low available P and exchangeable K with levels of 1.51 mg P kg^{-1} and 1.42 mg K kg^{-1}, respectively. The addition of coastal sediment on peat soil might raise soil pH due to neutralising of H^+ ions from peat soil by OH^- ions from coastal sediment. Coastal sediment also contained high amounts of alkali cations. A high content of alkali cations will cause CEC to decrease, increasing BS and availability of cations Ca^{2+}, Mg^{2+}, Na^+ and K^+. The CEC decline occurs because

TABLE 1
The chemical characteristics of coastal sediment and salted fish waste

Parameter	Coastal sediment	Parameters	Salted fish waste
Texture			
Sand (%)	10.20		-
Silt (%)	51.85		-
Clay (%)	37.95		-
pH	8.13	pH	6.08
Organic -C (%)	1.96	Organic- C (%)	41.95
Total N (%)	7.26	Total N(%)	7.66
C/N	0.27	C/N	5.48
Available P (mg kg^{-1})	3.45	Total P(%)	1.26
Exch. K($cmol_{(+)}$ kg^{-1})	1.71	Total K(%)	0.59
Exch. Ca ($cmol_{(+)}$ kg^{-1})	14.62	Total Ca(%)	0.82
Exch. Mg ($cmol_{(+)}$ kg^{-1})	1.73	Total Mg(%)	0.30
Exch. Na ($cmol_{(+)}$ kg^{-1})	2.65	Total Na(%)	0.29
CEC ($cmol_{(+)}$ kg^{-1})	15.33		-
Base saturation (%)	135.17		-
Fe (mg kg^{-1})	5239.64		
Cu (mg kg^{-1})	29.16		
Mn (mg kg^{-1})	16.54		
Zn (mg kg^{-1})	11.49		

of the peat soil's organo-cation complex formation between organic acids with cations from coastal sediment (such as Fe, Cu, Mn and Zn) (Table 1). Husen *et al.* (2013) explained that these high valence cations might form a ligand complex with organic acids in peat. Tan (2011) explained that organic acids in peat soils are capable of forming complex metal ions, particularly for transition metal such as Al, Fe, Cu, Zn and Mn. The coastal sediment was formed from complex organo-cation compounds resulting in cations that are strongly bound and difficult to exchange. This is consistent with the findings of Wulandari *et al*. (2014) showing that the addition of sea water can decrease the CEC of peat.

Meanwhile, salted fish waste hada high plant nutrient content. Content of total N, P, K, Ca, Mg and Na were 7.66, 1.26, 0.59, 0.82, 0.30 and 0.29%, respectively. Salted fish waste was neutral and the organic matter content was very high (72.33%) with a carbon/nitrogen ratio of 5.48. Additionally, the application of salted fish waste may inhibit acidity increases in peat soil, as well as enhance BS and availability of cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (Suswati, 2006). The EC value of salted fish waste was 4.02 dS m^{-1} (very high), but due to the relatively small amount applied to the peat soil, it did not impede plant growth. The soil EC after addition of coastal sediment and salted fish waste at the highest dose (60 Mg ha^{-1} of coastal sediment + 2.25 Mg ha^{-1} of salted fish waste) was only 1.22 dS/m (Table 2).

TABLE 2
Electrical conductivity of peat soils after ameliorant application

Variable of observation	Dose of ameliorant (Mg ha^{-1})	Peatland type			Mean	Standard error
		Typic Haplohemists	Typic Sulfisaprists	Typic Haplosaprists		
EC (dS m^{-1})	0	0.06	0.07	0.07	0.07a	0.003
	20 + 0.75	0.51	0.41	0.41	0.44b	0.033
	40 + 1.50	1.16	0.74	0.70	0.87c	0.147
	60 + 2.25	1.43	1.26	0.96	1.22d	0.137
	Mean	0.79	0.62	0.53	(-)	
	Standard error	0.311	0.253	0.191		

Notes: (-) no interaction and (+) interaction.Meanvalues followed by the same letter in the column and the same treatment groups did not differ by Tukey's test at 5% probability level.

Plant Nutrient Concentrations andUptake

The effect of costal sediment and salted fish waste on N, P, and K concentrations and their uptake through each peat soil type is presented in Tables 3 and 4. Concentrations of N, P, and K, in the tissue of maize that received treatments

TABLE 3
Nutrient concentrations in foliar tissue at maximum vegetative phase with ameliorant application and peatland type

Variable of observation	Dose of ameliorant (Mg ha^{-1})	Peatland type			Mean	Standard Error
		Typic Haplohemists	Typic Sulfisaprists	Typic Haplosaprists		
N (%)	0	1.61	1.77	1.52	1.63 a	0.072
	20 + 0.75	1.74	1.91	1.75	1.80 b	0.053
	40 + 1.50	1.85	1.82	1.83	1.83 b	0.007
	60 + 2.25	1.68	1.88	1.81	1.79 b	0.058
	Mean	1.72	1.84	1.73	(-)	
	Standard error	0.051	0.031	0.071		
P (%)	0	0.22	0.23	0.18	0.21 a	0.016
	20 + 0.75	0.33	0.33	0.29	0.32 b	0.013
	40 + 1.50	0.37	0.35	0.31	0.34 b	0.018
	60 + 2.25	0.35	0.36	0.31	0.34 b	0.016
	Mean	0.32	0.32	0.27	(-)	
	Standard error	0.032	0.030	0.031		
K (%)	0	1.38	1.45	1.42	1.41 a	0.020
	20 + 0.75	1.88	1.82	1.89	1.86 b	0.021
	40 + 1.50	2.01	1.89	2.20	2.03 c	0.090
	60 + 2.25	1.74	1.96	2.29	2.00 c	0.159
	Mean	1.75	1.78	1.95	(+)	
	Standard error	0.136	0.114	0.196		

Notes: (-) no interaction and (+) interaction.Mean values followed by the same letter in the column and the same treatment groups did not differ by Tukey's at 5% probability level.

TABLE 4
Nutrients uptake maximum vegetative phase with ameliorant application and peatland type

Variable of observation	Dose of ameliorant (Mg ha^{-1})	Peatland type			Mean	Standard error
		Typic Haplohemists	Typic Sulfisaprists	Typic Haplosaprists		
N (mg plant^{-1})	0	660.11	768.64	833.42	754.06a	50.559
	20 + 0.75	2238.58	2120.4	2140.82	2166.6b	36.470
	40 + 1.50	2902.48	3091.56	3735.26	3242.1c	252.061
	60 + 2.25	2258.76	2324.86	2129.44	2237.6b	57.388
	Mean	2014.98	2076.37	2209.74	(-)	
	Standard error	477.210	483.430	593.904		
P (mg plant^{-1})	0	91.82	98.12	98.71	96.22 a	2.205
	20 + 0.75	429.72	363.52	353.01	382.08 b	24.011
	40 + 1.50	577.65	592.76	654.96	608.46 c	23.657
	60 + 2.25	472.71	443.32	361.94	425.99 b	33.130
	Mean	392.98	374.43	367.16	(-)	
	Standard error	105.082	103.634	113.696		
K (mg plant^{-1})	0	569.01	627.13	786.37	660.84 a	64.970
	20 + 0.75	2419.27	2030.51	2289.25	2246.34 b	114.257
	40 + 1.50	3132.32	3197.42	4787.50	3705.75 c	541.203
	60 + 2.25	2339.76	2407.93	2701.00	2482.90 b	110.813
	Mean	2115.09	2065.75	2641.03	(+)	
	Standard error	545.292	537.636	825.351		

Notes: (-) no interaction and (+) interaction.Mean values followed by the same letter in the column and the same treatment groups did not differ by Tukey's at 5% probability level.

of coastal sediment and salted fish waste were significantly increased compared to the control case (Table 3). Nitrogen concentration in plant tissues of maize grown without the addition of coastal sediment and salted fish waste was 1.63%. Nitrogen concentration in plant tissues of maize grown with coastal sediment and salted fish waste ranged from 1.79 to 1.83%. Both coastal sediment and salted fish waste had high N contents of 7.26 and 7.66%, respectively (Table 1).

The concentration of P in maize tissue in the control was 0.21%. The treatment of coastal sediment and salted fish waste increased the concentration of P in the plant tissue. Increasing the dose of coastal sediment and salted fish waste did not significantly increase P concentration in plant tissue as the treatment amounts tested, 20 Mg ha^{-1} + 0.75 Mg ha^{-1}, 40 Mg ha^{-1} + 1.5 Mg ha^{-1} and 60 Mg ha^{-1} + 2.25 Mg ha^{-1} produced P concentrations of 0.32, 0.34 and 0.34%, respectively.
The use of ameliorant materials significantly increased N uptake whilst the soil factor as well as the interaction between those factors did not significantly impact on the variables (Table 4). The treatment of 20 Mg ha^{-1} of coastal sediment + 0.75 Mg ha^{-1} of salted fish waste increased N uptake compared to untreated coastal

sediment + salted fish waste. Nitrogen update further increased with the treatment of 40 Mg ha^{-1} of coastal sediment + 1.5 Mg ha^{-1} of salted fish waste, but did not increase further with the application of 60 Mg ha^{-1} of coastal sediment + 2.25 Mg ha^{-1} of salted fish waste. Increased availability of N caused maize to absorb more N than the control. Jones *et al.* (1991) state that N uptake by plants is affected by soil pH, temperature and the presence of other ions in the soil solution. Increasing soil pH increases activity of soil microorganisms, which are active at a pH range of 6 to 7 (neutral soil). Due to the increased activity of microorganisms in the soil, it would lower the ratio of C and N in peat soil, so that N would be available to plants. Kakei and Clifford (2000) found that liming can increase the pH in peat and thus increase N availability in the peat.

There was a declining trend in N uptake with the addition of 60 Mg ha^{-1} of coastal sediment + 2.25 Mg ha^{-1} of salted fish waste compared to addition of 40 Mg ha^{-1} of coastal sediment + 1.50 Mg ha^{-1} of salted fish waste on each peatland. From Table 2, it can be seen that the EC value of 60 Mg ha^{-1} of coastal sediment + 2.25 Mg ha^{-1} of salted fish waste (1.22 dS m^{-1}) is significantly higher than the addition of 40 Mg ha^{-1} of coastal sediment + 1.50 Mg ha^{-1} of salted fish waste (0.87 dS m^{-1}). According to Magan *et al*. (2005), the increase in EC reduces the uptake of macronutrients due to the increase in osmotic pressure.

The treatment of 20 Mg ha^{-1} coastal sediment + 0.75 Mg ha^{-1} of salted fish waste significantly increased P uptake at the maximum vegetative phase compared to untreated coastal sediment + salted fish waste (Table 4). The treatment of 40 Mg ha^{-1} coastal sediment + 1.5 Mg ha^{-1} of salted fish waste further increased P uptake, but the treatment level of 60 Mg ha^{-1} coastal sediment + 2.25 Mg ha^{-1} of salted fish waste significantly decreased the uptake of P compared to the 40 Mg ha^{-1} treatment (i.e., from 608.46 to 425.99 mg $plant^{-1}$).

A similar trend was seen for P and K uptake. The application of ameliorant increased P uptake on each peatland type up to a certain rate. The P uptake tended to decline with the addition of coastal sediment + salted fish waste on each peatland due to the decrease in soil pH, thus decreasing the available soil N. The analysis showed a highly significant correlation (r = 0.95*) between N uptake with the uptake of P (Table 5). According to Jones *et al*., (1991), P uptake interacts with N uptake and the uptake of other micro-elements such as Cu, Fe, Mn and Zn. The uptake of N stimulates P uptake through improvement in shoot and root plant growth and therefore changing the metabolism of plants, and increasing the solubility and availability of P for plants (Havlin *et al*., 2005).

The treatment of 20 Mg ha^{-1} coastal sediment + 0.75 Mg ha^{-1} of salted fish waste increased K uptake compared to untreated coastal sediment + salted fish waste (Table 4). Treatment of 40 Mg ha^{-1} of coastal sediment + 1.5 Mg ha^{-1} of salted fish waste further increased K uptake. Potassium uptake was not changed with the application of 60 Mg ha^{-1} coastal sediment + 2.25 Mg ha^{-1} of salted fish waste over the 40 Mg ha^{-1} of coastal sediment + 1.5 Mg ha^{-1} of salted fish waste treatment. Use of ameliorant materials significantly increased K uptake whilst the soil factor did not show a significant effect on the variables. The effect of soil

TABLE 5
Coefficients of linear correlation between nutrient uptake and some soil properties

Parameters	pH	EC	BD
N uptake	0.76**	0.62**	0.67**
P uptake	0.80**	0.57**	0.77**
K uptake	0.79**	0.61**	0.71**
Ca uptake	0.78**	0.63**	0.75**
Mg uptake	0.71**	0.72**	0.61**
Na uptake	0.77**	0.71**	0.60**
S uptake	0.76**	0.62**	0.67**

Notes : * = significant at $\alpha = 0.05$; **= significant at $\alpha = 0.01$
EC = Electrical conductivity; BD = Bulk density

factors was not significantly different because the three peat soils were very acidic (i.e., pH values ranging from 3.26 to 3.76). According to Diana *et al*., (2007), these characteristics reduce the availability of nutrients especially K, Ca, and Mg that are bound in such way that it is difficult for them to be utilised by plants. Painter (1991) suggests that cations are so strongly bound to negative exchange sites within peat that plants in that soilwill eventually lack nutrients and thus have sub-optimal growth.

Potassium uptake tended to diminish with the addition of ameliorants on all peat types because of a significant decrease in soil density; as K might also leach out, absorption by maize plant will also decrease. The analysis showed a significant correlation (r = 0.71*) between the bulk density of the soil with K uptake (Table 5). In most soils, loss of K is due to leaching in organic soils (Havlin *et al.*, 2005). On the otherhand Nurani *et al.* (2007) state that it is generally accepted that a high CEC value in peat soils decreases nutrient absorption and especially reduces the uptake of K and Ca.

Maize Yield

Analysis of yield per hectare after harvest is shown in Table 6. The harvesting was done 105 days after transplanting (DAT). ANOVA results indicated that application of ameliorant, soils, and their interaction significantly affected plant yield. Coastal sediment and salted fish waste of each peat soil increased plant yield per hectare (Table 6). In all soils, 60 Mg ha^{-1} of coastal sediment + 2.25 Mg ha^{-1} of salted fish waste were able to increase maize yield per hectare. Treatments of 20 Mg ha^{-1} coastal sediment + 0.75 Mg ha^{-1} of salted fish waste and 40 Mg ha^{-1} of coastal sediment + 1.5 Mg ha^{-1} of salted fish waste increased maize yield per hectare compared to the untreated, coastal sediment + salted fish waste.

The highest maize yield on each type of peatland was obtained with 40 tons ha^{-1} coastal sediment + 1.5 tons ha^{-1} salted fish waste treatment. The increase in maize yield could also be due to increased N, P, and K uptake in all the treated

TABLE 6
Effect of ameliorant and soils on maize yield per hectare

Dose of ameliorant (Mg ha^{-1})	Peatland type			Mean	Standard error
	Typic Haplohemists	Typic Sulfisaprists	Typic Haplosaprists		
	Maize yield (ton ha^{-1})				
0	2.12 f	3.75 e	3.82 e	3.23 a	0.555
20 + 0.75	11.04 cd	9.96 d	10.68 cd	10.56 b	0.317
40 + 1.50	13.06 ab	12.96 ab	13.36 a	13.12 d	0.120
60 + 2.25	12.86 ab	11.92 bc	11.49 c	12.09 c	0.405
Mean	9.77	9.64	9.84	(+)	
Standard Error	2.590	2.062	2.083		

Notes: (-) no interaction and (+) interaction. Mean values followed by the same letter in the column and the same treatment groups did not differ by Tukey'sat 5% probabilitylevel.

TABLE 7
Coefficients of linear correlation between maize plant parameters

Parameters	N uptake	P uptake	K uptake	Ca uptake	Mg uptake	Na uptake	S uptake	Plant height	Weight dry plant	Maize yield
N uptake	1									
P uptake	0.95**	1								
K uptake	0.97**	0.91**	1							
Ca uptake	0.98**	0.96**	0.96**	1						
Mg uptake	0.96**	0.94**	0.96**	0.97**	1					
Na uptake	0.82**	0.86**	0.75**	0.84**	0.81**	1				
S uptake	0.91**	0.94**	0.87**	0.93**	0.92**	0.88**	1			
Plant height	0.80**	0.80**	0.75**	0.83**	0.80**	0.88**	0.82**	1		
Weight dry plant	0.98**	0.96**	0.98**	0.99**	0.97**	0.80**	0.91**	0.76**	1	
Maize yield	0.83**	0.85**	0.81**	0.85**	0.85**	0.88**	0.85**	0.91**	0.83**	1

Notes:* = significant at α = 0.05; **= significant at α = 0.01

peatlands. Additionally, the high nutrient uptake in the treatment supposedly was in accordance with the plants' nutrient requirements in a sufficient and balance state which helped to increase crop production. However, ameliorants at a low dose (20 Mg ha^{-1} of coastal sediment + 0.75 Mg ha^{-1} of salted fish waste) and a high dose (60 Mg ha^{-1} of coastal sediment + 2.25 Mg ha^{-1} of salted fish waste) showed low yield, because uptakes of N, P and K were low on each type of peatland. Nitrogen is an essential element in the plant cell (Taiz and Zeiger, 1991). According to Uhart and Andrade (1995), N deficiency delays development of vegetative and reproductive organs of maize plants, reducing the rate of leaf appearance and reducing light interception, thus decreasing the growth rate when the plants is flowering. Phosphorous is an essential nutrient, a component of certain enzymes and proteins, and a component of ATP, RNA, DNA, and phytin (Fageria, 2009). Phosphorous deficiency in maize generally reduces dry matter accumulation, which slows down the appearance of the leaves, reducing the width of the leaf, and reduces the life of the leaf (Colomb *et al*., 2000). Potassium in the plant acts as an activator of enzymes in the process of photosynthesis, and the metabolism of protein and carbohydrate. Protein synthesis improves crop resilience to disease and increases the size of the seed (Jones, 2012). Plants with excess K suffer from Mg and Ca insufficiency (Barker and Pilbeam, 2007). Maize production per hectare was positively correlated to the uptake of N, P and K; the value of correlation coefficient (r) for the nutrients considered were N = 0.83**, P = 0.85** and K = 0.81** (Table 7).

CONCLUSIONS

It was shown that a combination of coastal sediment and coastal sediment with salted fish waste had a positive effect on the uptake of nutrients and maize productivity in peatlands, which could be potentially exploited using various soil amelioration strategies without risking agricultural sustainability in a tropical area. Results showed that the combination of 40 Mg ha^{-1} coastal sediment and 1.5 Mg ha^{-1} of salted fish waste was the best treatment combination to increase the uptake of N, P, and K and improve the production of maize per hectare. In the tropical peatlands, where lime is not affordable for most farmers, the balanced application of coastal sediment and salted fish waste could alleviate problems of peat soil infertility, provide a solution for salted fish waste disposal and reduce the amount of lime needed to increase production of maize per hectare. This research needs to be further extended to other sites and the long-term effects such as salt accumulation or increase in EC due to continuous application of these treatments.

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