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Improvement of the chemical properties and buffering capacity of coastal sandy soil as affected by clay and organic by-product application

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Abstract: The main problem with coastal sandy soil is its low water and nutrient retention due to its low clay and organic matter content. This study was aimed at improving the chemical properties and buffering capacity of these soils by using ameliorants of clay and organic polymers. The leaching experiment was conducted with two factors and three replications. The first factor was a clay ameliorant (5% clay, whether from the soil type Inceptisol (I) and the soil type Vertisol (V)). The second factor was a natural or synthetic organic polymer (tapioca 1% and 2% (T1 and T2), tapioca dregs 1% and 2% (TD1 and TD2), polyvinyl alcohol 0.1% and 0.2% (P1 and P2)). The leaching was carried out at 1-month intervals and the leachate was collected for the analysis of the soluble Ca, Mg, K and Na. The leaching was stopped after all the treatments reached the electrical conductivity values < 100 µS/cm. The ameliorants of clay (I or V) and natural polymer (T or TD) significantly increased the cation exchange capacity, the available cations, and the buffering capacity of the coastal sandy soil. The single treatment of I was better than V in increasing the available Mg, while the combination with organic natural polymers could increase the available Ca and K. The treatment of ITD2 was able to increase the soil buffering and maintain the soluble Ca, Mg and K in the coastal sandy soil. Therefore, TD which is a by-product of the tapioca flour industry when combined with I has the potential to be a prospective ameliorant for coastal sandy soils.

Keywords: ameliorant; Inceptisol, leaching; polymer; tapioca; Vertisol

Nutrient leaching is a serious problem in coastal sandy land because sand is unable to hold water and nutrients for a long time. The weak cohesion between the particles (Shepperd et al. 2002), the low particle binding agents, namely organic matter, clay, oxide, and Ca (Six et al. 2004) causes this soil to have a high permeability, low moisture and nutrient retention (Šimanský et al. 2019). The sandy soil only contains a small amount of clay and organic matter which causes low cation exchange capacity (CEC), soil buffering capacity and easily leached cations (Havlin et al. 2005; Aharonov-Nadborny et al. 2017).

The efforts to increase nutrients and water holding capacity are needed to improve the fertility of the sandy soil, including through the addition of clay and organic matter (Al-Omran et al. 2002, 2004). Additions of clay soil material and organic matter to the sandy soil in East Java, Indonesia significantly

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influence the increase in the available water content (Djajadi et al. 2011). The smectite clay increased the CEC of the sandy soil in Egypt (Sallam et al. 1995). A clay ameliorant also reduced the leaching of N and P in the sandy soil from Penola, South Australia (Tahir & Marschner 2017a). The amelioration of coastal sandy soil using clay ameliorants will be more effective in the presence of organic polymers that function to bond particles. Starch is a glucose homopolymer consisting of two main components namely amylose and amylopectin (Vazquez et al. 2011). Gelatinised starch bonds the sand particles and intensifies the contact between the particles by coating the soil particles and binding them through cementing. Polyvinyl alcohol (PVA) is a synthetic polymer that is water soluble and able to be decomposed biologically (Awada et al. 2014; Mittal et al. 2016). PVA is used as a soil ameliorant with a very low concentration, 0.1% PVA significantly increases the aggregate stability (Kukal et al. 2007). Both starch and PVA have many hydroxyl groups in their chains and this group will easily form hydrogen bonding (Jiang et al. 2016). The soil particles are bonded by clays and natural and synthetic polymers (Xu et al. 2015; Zhou et al. 2019) so that the moisture and nutrient retention increases. This study was aimed at determining the effect of clay ameliorants and natural and synthetic organic polymers on the chemical properties and buffering capacity on coastal sandy soils.

MATERIAL AND METHODS

Soil samples and ameliorants. The coastal sandy soil at a depth of 0–20 cm was obtained from Samas Beach, Yogyakarta, Indonesia. The soil was classified as Udipsamment (Soil Survey Staff 2010) with 98% sand. A mineral ameliorant was applied in the form of Inceptisol (39% clay) and Vertisol (59% clay) derived from the Kretek and Sanden sub-districts, Bantul, Yogyakarta, respectively. The location of the clay soil was about 7 km from the beach. The used adhesives are natural organic polymers in the form of tapioca flour and tapioca dregs which are a by-product of the local tapioca industry about 10 km from the beach, while, as a comparison, polyvinyl alcohol (PVA) synthetic organic polymers have been applied.

Soil and ameliorants properties. The properties of the analysed soil were: organic carbon (OC) was performed using a spectrophotometer method (Page et al. 1982), the soluble cations in the extract from the soil and water suspension of 1 : 5, the available cations and cation exchange capacity was analysed using ammonium acetate 1 N pH 7.0 (Rowell 1994), pH-H_2O, and the electrical conductivity (EC) was measured using a ratio of soil and water of 1 : 5 (Van Reeuwijk 1993). The chemical analysis was also carried out on the soil after the treatment. The properties of the tapioca and tapioca dregs were: amylose by the iodine spectrophotometric method (Juliano 1971), starch by the acid hydrolysis method, OC by the ignition method at 600°C for 4 h, pH in H_2O (1 : 5) using a pH-meter, and total nutrient content (P, K, Ca, Mg and Na) was determined by wet oxidation with HNO_3 + $HClO_4$ (Horwitz 2000). The P content was measured using the phospho-molybdate method and read with a UV-VIS spectrophotometer (Genesys 20, Thermo Scientific, USA). The monovalent cation levels were measured by a flame photometer (PFP 7, Jenway, UK), while divalent cation levels were measured by Agilent 200 Series AA (Agilent Technologies, USA).

Column leaching experiments. The study was conducted using a lysimeter (height 40 cm, diameter 8 cm, and height of soil 25 cm) with a nylon mesh base as filter. The coastal sandy soil used was 2.5 kg in dry weight. The experiment was arranged in a completely randomised design with 2 factors: (1) clay soil ameliorant (5% clay whether from Inceptisol (I) and Vertisol (V), 321 and 212 g, respectively) and (2) polymers consisting of tapioca 1% and 2% (T1 and T2), 25 and 50 g, respectively; tapioca dregs 1% and 2% (TD1 and TD2), 25 and 50 g, respectively; and synthetic polymers consisting of PVA 0.1% and 0.2%, 2.5 and 5.0 g PVA, respectively. The coastal sandy soil, clay soil and tapioca dregs used in the experiment were filtered using 2-mm sieve. The tapioca and PVA were applied in the form of a solution, the tapioca solution was made by dissolving 25 and 50 g tapioca into 2.5 l of boiling water until gelatinisation occurred. The PVA solution was made by dissolving 2.5 and 5.0 g of PVA into 2.5 l of hot water at 90°C. The treatment was made in 3 replications so that the total number of experimental units included 39, including the controls (pure coastal sandy soil without an ameliorant). The mixture of the coastal sandy soil and ameliorant in the lysimeter was incubated for 1 month. Then leaching was carried out every month using 200 ml of the aquadest for 6 months until reaching the value of EC < 100 μS/cm. The leachate that came out was collected in an erlenmeyer flask and the levels of Ca, Mg, K and Na were analysed.

Buffering capacity. The soil buffering capacity was calculated based on the ratio between the changes in the number of exchanged cations (ΔQ) and the changes

Table 1. The properties of the coastal sandy soil from Samas Beach and the soil ameliorants

	pH	OC (%)	EC (µS/cm)	Available cations (mmol$_+$/kg)				CEC (mmol$_+$/kg)	Soluble cations (mg/l)			
				Ca	Mg	K	Na		Ca	Mg	K	Na
CSS	6.92	0.06	18.9	4.5	1.5	3.1	0.4	4.30	76	1.2	3.9	2.3
I	6.29	0.69	135.2	116.1	33.4	7.4	0.8	296.0	144	15.8	3.9	52.9
V	7.3	0.95	238.5	131.9	63.3	6.4	1.7	660.0	110	7.3	19.5	43.7

CSS – coastal sandy soil; I – Inceptisol; V – Vertisol; OC – organic carbon; EC – electrical conductivity; CEC – cation exchange capacity

in the amount of the dissolved cations (ΔI) (Havlin et al. 2005). The Q value (quantity) was approximated by the number of cations extracted using NH_4OAc, while the value I (intensity) was approximated by the number of cations dissolved in water. The formula used to calculate the soil buffering capacity is as follows:

$$BC = \frac{\Delta Q}{\Delta I}$$

where:

BC – soil buffering capacity

$\Delta Q = Q_2 - Q_1$

Q_1 – the amount of the cations exchanged in the control soil

Q_2 – the amount of the cations exchanged in the soil after treatment

$\Delta I = I_2 - I_1$

I_1 – the amount of the cations in leachate from the control soil

I_2 – the amount of the cations exchanged in leachate from the soil after treatment.

Statistical analysis. The obtained data were analysed using the SAS program (Ver. 9.3, 2012) continued with a Duncan multiple range test at $P < 0.05$. The differences between the mean of the treatments and control were compared with the Orthogonal Contrast test at $P < 0.05$.

RESULTS AND DISCUSSION

Chemical properties of the coastal sandy soil and soil ameliorants. The coastal sandy soil does not have acidity and salinity problems, but the very

Table 2. The properties of the tapioca and tapioca dregs

	St	Am	pH	OC (%)	Total (%)			Total (ppm)		
	(%)				N	P	K	Ca	Mg	Na
T	80.2	29.6	5.65	61.59	0.11	0.03	0.04	230	56	4
TD	34.6	18.4	5.68	61.16	0.36	0.04	0.09	1116	383	17

T – tapioca; TD – tapioca dregs; St – starch; Am – amylose; OC – organic carbon

Table 3. The effects of the clay and organic polymers on the pH, EC and CEC of the coastal sandy soil

SC	pH			EC (µS/cm)			CEC (mmol$_+$/kg)		
	I	V	mean	I	V	mean	I	V	mean
T1	7.6^{bc}	7.5^{de}	7.6	115.0^{d}	420.0^{c}	267.5	75.7^{ab}	21.3^{d}	48.5
T2	7.6^{bc}	7.4^{e}	7.5	225.7^{h}	582.3^{a}	404.0	79.4^{a}	23.5^{d}	51.5
TD1	7.6^{bc}	7.5^{de}	7.6	592.0^{a}	508.3^{b}	550.2	65.9^{c}	19.2^{d}	42.6
TD2	7.4^{d}	7.6^{bc}	7.5	285.7^{f}	372.0d	328.8	70.1^{bc}	22.9^{d}	46.5
P1	7.4^{e}	7.7^{a}	7.6	273.3^{g}	324.7^{e}	299.0	71.7^{bc}	23.5^{d}	47.6
P2	7.7^{a}	7.6^{bc}	7.7	280.3^{fg}	198.3^{i}	239.3	65.2^{c}	24.3^{d}	44.8
Mean	7.6	7.4	$7.5^{x(+)}$	295.3	400.9	$348.1^{x(+)}$	71.3	22.4	$46.9^{x(+)}$
C			7.4^{x}			224.0^{x}			14.1^{y}

$^{(+)}$indicates there is an interaction effect; the values in the same column with the same letter are not significantly different at $P < 0.05$; the mean followed by the same superscript letters are not significantly different according to the orthogonal contrast at $P < 0.05$; SC – soil conditioner; I – Inceptisol; V – Vertisol; T1 – tapioca 1%; T2 – tapioca 2%; TD1 – tapioca dregs 1%; TD2 – tapioca dregs 2%; P1 – PVA 0.1%; P2 – PVA 0.2%; C – control; EC – electrical conductivity; CEC – cation exchange capacity low amount of clay and organic material fraction results in low CEC values and nutrient availability (Table 1). The clay amelioration affects the nutrient availability in the sandy soils (Tahir & Marschner 2017b), increase the CEC and the number of available cations of the coastal sandy soil.

The contents of the starch and amylose in the tapioca are 80.2% and 29.6%, respectively. The tapioca dregs as a by-product still contains starch and amylose with 34.6% and 18.4%, respectively (Table 2). Both of these materials can function as cementing agents for the particles, and also have the potential to contribute to the nutrients to the coastal sandy soil. The high contents of Ca^{2+} and Mg^{2+} are probably influenced by the tapioca making process. The industrial location of the tapioca in the limestone hills area causes water to contain quite high Ca and Mg, so that affects the cation levels in the tapioca and tapioca dregs produced.

The change in the chemical properties of the coastal sandy soil after the amelioration. The intake of the alkaline cations derived from the clay and organic polymers has an effect on increasing the pH of the coastal sandy soil (Table 3).

The treatments of VT and VTD showed a higher increase in the EC, but still at a level that plants can tolerate. The highest CEC was observed in the amelioration using a treatment of IT2, the clay fraction of I and the functional groups derived from the organic material (tapioca) increase the soil's ability to exchange cations (Adani et al. 2006; Chaganti & Crohn 2015). The organic molecules and clays interact to bond the soil particles (Fink et al. 2016), tapioca maintains contact with the sand-clay so that the clay is not easily leached and its function in the cation exchange is maintained.

The application of IT2 increased the Ca levels by 171% compared to the controls that were influenced by the increase in the soil CEC and the contribution of Ca^{2+} from the ameliorants (Table 4). The single treatment of I increased the retention of Mg in the coastal sandy soil by 281% compared to the control. The treatment of ITD2 increased the available K by 40% compared to the controls. Inceptisol increased the ability of the sandy soils to exchange cations which affect the increase in the amount of the available K and the tapioca dregs releasing a number of K^+ ions to the soil solutions. The single treatment of I significantly increased the buffering capacity of the coastal sandy soil compared to V. The clay increased the CEC of the coastal sandy soil so that

Table 4. The effects of the clay and organic polymers on the available cations of the coastal sandy soil

SC	Available (mmol₊/kg)												Buffering capacity		
	Ca			Mg			K			Na					
	I	V	mean	I	V	mean	I	V	mean	I	V	mean	I	V	mean
T1	47.9^{a}	9.4^{d}	28.7	24.5	6.6	15.5^{p}	1.3^{c}	1.3^{c}	1.3	1.5	0.7	1.1^{pq}	17.93	2.05	9.99^{q}
T2	51.5^{a}	8.7^{d}	30.1	24.8	7.0	15.9^{p}	1.7^{bc}	1.5^{c}	1.6	1.7	1.1	1.4^{p}	26.88	3.09	14.99^{p}
TD1	33.9^{c}	6.1^{d}	20.0	19.8	6.2	13.0^{p}	2.2^{b}	1.3^{c}	1.7	0.9	0.9	0.9^{q}	18.68	1.32	10.00^{q}
TD2	41.3^{b}	7.1^{d}	24.2	20.2	6.7	13.5^{p}	2.8^{a}	1.2^{cd}	2.0	1.5	0.8	1.2^{pq}	23.49	1.16	12.33^{pq}
P1	39.3^{b}	8.6^{d}	23.9	22.6	6.8	14.7^{p}	0.7^{d}	1.6^{bc}	1.2	1.4	0.8	1.1^{pq}	20.96	2.27	11.62^{pq}
P2	31.1^{c}	11.0^{d}	21.0	18.2	7.3	12.7^{p}	1.4^{c}	1.4^{c}	1.4	1.4	1.1	1.3^{p}	28.41	2.71	15.56^{p}
Mean	40.8	8.5	$24.6^{x(+)}$	21.7^{a}	6.8^{b}	$14.2^{x(-)}$	1.7	1.4	$1.5^{y(+)}$	1.4^{a}	0.9^{b}	$1.1^{x(-)}$	22.73^{a}	2.10^{b}	$12.41^{(-)}$
C			19.0^{y}			5.7^{y}			2.0^{x}			1.0^{y}			

$^{(+)}$ or $^{(-)}$indicates there is an interaction or no interaction effect; the values in the same column with the same letter are not significantly different at $P < 0.05$; the mean followed by the same superscript letters are not significantly different according to the orthogonal contrast at $P < 0.05$; SC – soil conditioner; I – Inceptisol; V – Vertisol; T1 – tapioca 1%; T2 – tapioca 2%; TD1 – tapioca dregs 1%; TD2 – tapioca dregs 2%; P1 – PVA 0.1%; P2 – PVA 0.2%; C – control

Table 5. The balance of Ca^{2+} in the coastal sandy soil after leaching (in mg)

SC	Initial			Leached			Residual		
	I	V	mean	I	V	mean	I	V	mean
T1	238.6^{d}	215.7^{i}	227.2	2.9^{a}	0.7^{d-f}	1.81	235.6^{d}	215.0^{i}	225.3
T2	241.0^{c}	218.1^{h}	229.6	0.9^{c-e}	1.6^{b}	1.23	240.1^{c}	216.5^{h}	228.3
TD1	246.1^{b}	223.3^{g}	234.7	0.6^{f}	0.7^{d-f}	0.64	245.5^{b}	222.6^{g}	234.1
TD2	256.1^{a}	233.3^{f}	244.7	1.0^{c}	0.9^{c}	0.97	255.1^{a}	232.3^{f}	243.7
P1	236.2^{e}	213.3^{j}	224.8	0.9^{cd}	0.7^{ef}	0.77	235.3^{e}	212.7^{j}	223.9
P2	236.2^{e}	213.3^{j}	224.8	0.7^{df}	0.7^{df}	0.67	235.5^{de}	212.6^{j}	224.1
Mean	242.4	219.5	$230.9^{x(+)}$	1.16	0.87	$1.01^{x(+)}$	241.2	218.6	$229.9^{x(+)}$
C			190.0^{y}			0.73^{x}			189.3^{y}

$^{(+)}$indicates there is an interaction effect; the values in the same column with the same letter are not significantly different at $P < 0.05$; the mean followed by the same superscript letters are not significantly different according to the orthogonal contrast at $P < 0.05$; SC – soil conditioner; I – Inceptisol; V – Vertisol; T1 – tapioca 1%; T2 – tapioca 2%; TD1 – tapioca dregs 1%; TD2 – tapioca dregs 2%; P1 – PVA 0.1%; P2 – PVA 0.2%; C – control; initial Ca^{2+} = Ca^{2+} derived from sandy soil+clay+polymers; residual Ca^{2+} = initial Ca^{2+} – leached Ca^{2+}

the buffering capacity increases. Increasing the soil buffering capacity reduces the nutrient loss and prevents the nutrients from leaching (Havlin et al. 2005).

Cation composition in the leachate. Generally, amelioration using natural polymers shows a higher leaching of Ca^{2+} and Mg^{2+} than the PVA (Tables 5 and 6). The cations are leached during the leaching experiment (Pratiwi et al. 2016), a similar trend in comparison between the organic and non-organic ameliorants was found by Chaganti et al. (2015). The release of Ca^{2+} and Mg^{2+} into soil solutions was probably influenced by the mineralisation of the natural ameliorants added (Jalali & Ranjbar 2009; Mahmoodabadi et al. 2013).

The application of ITD2 increased the soil buffering capacity and maintained the soluble Ca and Mg in the coastal sandy soil. The increasing capacity was indicated by the amount of residual Ca^{2+} and Mg^{2+} which was significantly higher than that of the other treatments. Amelioration using ITD2 also had the best effect on maintaining the soluble K in the soil (Table 7). The treatment of ITD2 increased the buffering capacity of the coastal sandy soil so that the K^{+} leaching decreased. The use of tapioca dregs also offers environmental advantages by reducing

Table 6. The balance of Mg^{2+} in the coastal sandy soil after leaching (in mg)

	Initial			Leached			Residual		
	I	V	mean	I	V	mean	I	V	mean
T1	92.0	5.7	7.5^{s}	1.8^{a}	1.1^{eg}	1.48	7.4^{f}	4.6^{j}	5.98
T2	10.4	6.9	8.7^{r}	1.6^{b}	1.1^{eg}	1.38	8.8^{e}	5.8^{i}	7.29
TD1	16.6	13.1	14.8^{q}	1.0^{g}	1.3^{c-e}	1.19	15.5^{c}	11.7^{d}	13.62
TD2	25.1	21.6	23.4^{p}	1.2^{d-g}	1.4^{cd}	1.28	23.9^{a}	20.3^{b}	22.09
P1	8.0	4.5	6.3^{t}	1.2^{e-g}	1.1^{fg}	1.14	6.8^{g}	3.4^{k}	5.12
P2	8.0	4.5	6.3^{t}	1.4^{c}	1.3^{c-f}	1.36	6.6^{h}	3.3^{k}	4.91
Mean	12.9^{a}	9.4^{b}	$11.1^{x(-)}$	1.38	1.23	$1.30^{x(+)}$	11.49	8.17	$9.83^{x(+)}$
C			3.00^{y}			1.15^{x}			1.85^{y}

$^{(+)}$ or $^{(-)}$indicates there is an interaction or no interaction effect; the values in the same column with the same letter are not significantly different at $P < 0.05$; the Mean followed by the same superscript letters are not significantly different according to orthogonal contrast at $P < 0.05$; SC – soil conditioner; I – Inceptisol; V – Vertisol; T1 – tapioca 1%; T2 – tapioca 2%; TD1 – tapioca dregs 1%; TD2 – tapioca dregs 2%; P1 – PVA 0.1%; P2 – PVA 0.2%; C – control; initial Mg^{2+} = Mg^{2+} derived from sandy soil+clay+polymers; residual Mg^{2+} = initial Mg^{2+} – leached Mg^{2+}

Table 7. The balance of K^+ in the coastal sandy soil after leaching (in mg)

SC	Initial			Leached			Residual		
	I	V	mean	I	V	mean	I	V	mean
T1	71.6	74.5	73.1^{s}	7.1^{d}	5.7^{d}	6.39	64.5^{g}	68.8^{f}	66.67
T2	77.9	80.7	79.3^{r}	2.8^{e}	11.7^{c}	7.27	75.0^{d}	69.0^{f}	72.02
TD1	86.1	89.0	87.6^{q}	2.9^{e}	18.4^{a}	10.65	83.2^{c}	70.7^{e}	76.93
TD2	106.9	109.8	108.3^{p}	3.7^{e}	13.9^{b}	8.79	103.2^{a}	95.9^{b}	99.54
P1	65.4	68.3	66.8^{t}	2.8^{e}	10.5^{c}	6.62	62.7^{h}	57.8^{i}	60.22
P2	65.4	68.3	66.8^{t}	2.3^{e}	15.0^{b}	8.63	63.2^{gh}	53.3^{j}	58.21
Mean	78.9^{b}	81.8^{a}	$80.3^{x(-)}$	3.60	12.52	$8.06^{y(+)}$	75.29	69.24	$72.27^{x(+)}$
C			64.2^{y}			12.01^{x}			52.14^{y}

$^{(+)}$ or $^{(-)}$indicates there is an interaction or no interaction effect; the values in the same column with the same letter are not significantly different at $P < 0.05$; the mean followed by the same superscript letters are not significantly different according to the orthogonal contrast at $P < 0.05$; SC – soil conditioner; I – Inceptisol; V – Vertisol; T1 – tapioca 1%; T2 – tapioca 2%; TD1 – tapioca dregs 1%; TD2 – tapioca dregs 2%; P1 – PVA 0.1%; P2 – PVA 0.2%; C – control; initial K^+ = K^+ derived from sandy soil + clay + polymers; residual K^+ = initial K^+ – leached K^+

the potential of the pollutants and these materials are available in abundance and are cheap.

Decomposition of the natural polymers releases a number of Ca^{2+} and Mg^{2+} cations that replace Na^+ on the exchange site (Jones et al. 2012; Mahmoodabadi et al. 2013; Zhang et al. 2015; Batarseh 2017). The high mobility causes Na^+ to be easily carried away by the movement of the vertical water flow (Mahmoodabadi et al. 2013; Wang et al. 2016). The amount of leached Na^+ in the single treatment of I was not different from that in V. However, since the initial Na^+ in the amelioration using I was higher than in V, thus, the amount of residual Na^+ was higher as well (Table 8). The single treatment of T2 had the best effect on increasing the buffering capacity of Na^+ in the coastal sandy soil so that Na^+ leaching decreased, resulting in the highest amount of residual Na^+.

CONCLUSION

Clay and natural polymers had a significant effect on improving the soil buffering capacity of the coastal sandy soil indicated by an increase in the CEC and the number of available cations and a decrease in the amount of the leached cations. The single treat-

Table 8. The balance of Na^+ in the coastal sandy soil after leaching

SC	Initial (mg)			Leached (mg)			Residual (mg)		
	I	V	mean	I	V	mean	I	V	mean
T1	22.8	15.1	18.9^{r}	9.2	8.1	8.65^{p}	13.5	7.0	10.26^{q}
T2	22.8	15.1	18.9^{r}	6.6	7.7	7.16^{q}	16.2	7.4	11.80^{p}
TD1	23.1	15.4	19.2^{q}	7.9	8.8	8.30^{p}	15.2	6.6	10.93^{pq}
TD2	23.5	15.8	19.6^{p}	8.2	9.3	8.71^{p}	15.3	6.5	10.89^{pq}
P1	22.7	15.0	18.9^{r}	8.7	8.3	8.46^{p}	14.1	6.7	10.39^{q}
P2	22.7	15.0	18.9^{r}	8.4	9.1	8.74^{p}	14.3	5.9	10.12^{q}
Mean	22.9^{a}	15.2^{b}	$19.1^{x(-)}$	8.14^{a}	8.53a	$8.34^{x(-)}$	14.78^{a}	6.69^{b}	$10.73^{x(-)}$
C			5.75^{y}			8.62^{x}			-2.87^{y}

$^{(-)}$indicates there is an interaction or no interaction effect; the values in the same column with the same letter are not significantly different at $P < 0.05$; the mean followed by the same superscript letters are not significantly different according to the orthogonal contrast at $P < 0.05$; SC – soil conditioner; I – Inceptisol; V – Vertisol; T1 – tapioca 1%; T2 – tapioca 2%; TD1 – tapioca dregs 1%; TD2 – tapioca dregs 2%; P1 – PVA 0.1%; P2–PVA 0.2%; C – control; initial Na^+ = Na^+ derived from sandy soil+clay+polymers; residual Na^+ = initial Na^+ – leached Na^+

ment of I had a better effect than V on the available Mg. The treatment of IT2 significantly increased the CEC and available Ca in the coastal sandy soil. TD has the potential to be combined with clay as an ameliorant in coastal sandy soils. The treatment of ITD2 significantly increased the available K, the buffering capacity and decreased the leaching of Ca, Mg and K in the coastal sandy soil.

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