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RESEARCH ARTICLE

Eco-friendly utilization of rice husk ash for amending acid soils

P Malathi[1*], K Preetha[1], D Selvi[1], E Parameswari[2], SP Thamaraiselvi[3] & KM Sellamuthu[1]

[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Nammazhvar Organic Farming Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[3]Department of Floriculture and Landscape Architecture, Horticulture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: malathi.p@tnau.ac.in

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Abstract

Rice husk ash (RHA) contains appreciable amounts of exchangeable cations and plant nutrients which can be used as liming material for acid soil reclamation. Hence, the present study was carried out to assess the potential of rice husk ash for soil acidity reclamation and its effect on related soil properties. RHA was collected from a modern rice mill and its physical and chemical properties were assessed. The results confirmed the alkaline nature of RHA with a pH of 8.30 at 1:10 RHA-to-water suspension. An incubation experiment was conducted with five levels of RHA *viz.,* 10, 20, 30, 40 and 50 t ha^{-1}; compared with the treatments without liming material and the lime application as per lime requirement. Soil sampling was performed at 15, 30, 45 and 60 days after incubation (DAI) and analysed. The results indicated that the application of RHA 50 t ha^{-1}, 40 t ha^{-1},30 t ha^{-1}and lime (100 % lime) were comparable in enhancing the soil pH, effective cation exchange capacity and percent base saturation and reduced the total acidity and exchangeable Al. With all levels of RHA and lime application, favourable effects on soil properties related to acidic soil reclamation were observed over time. Exchangeable Ca and Mg were the highest in the 100 % lime requirement, followed by RHA at 50 t ha^{-1}. Exchangeable K and Na were the highest in rice husk ash at 50 t ha^{-1}. The results emanated from this study ensured the potential of rice husk ash as a source of lime for acidic soils reclamation.

Keywords

acid soil reclamation; base saturation percentage; exchangeable cations; rice husk ash; soil pH

Introduction

Rice is a staple food in many countries especially India and its production continues (1) During rice milling, the husk and bran layers are removed to yield the edible portions for consumption. The major agricultural waste in rice producing countries is rice husk (2). It is a potential waste material with many uses in its raw or ash forms.

Rice husk residue can be converted into many different forms based on the need for rice husk biochar (RHB), rice husk ash (RHA) and rice husk compost (RHC). Among rice husk products, the most readily available one is RHA. Modern rice mills are emerging in every place and by combustion these rice husks are converted into RHA. In modern rice mills, for parboiling paddy rice husks are used as fuel.

RHA may have favourable effects on the soil by correcting soil acidity (3). About 31 million tons of rice husk is produced in India which generate 4.65-5.58 million tons of RHA (15-18 % of rice husk) (4). Approximately, 3000 modern rice mills are currently operating in Tamil Nadu that generate considerable quantity of husk and RHA. From the controlled combustion of rice husks in the form of charcoal, RHA is produced. In South India, on average, 50 percent of the rice husks obtained are used as a source of fuel in rice mills, hotels and brick-making industries. As RHA is voluminous, transport for disposal is difficult and costly. Because of the low bulk density of RHA, it's disposal in open fields can cause serious human health and environmental problems. Owing to the difficulty in disposing of RHA, reuse in agriculture will be the best solution. Thus, RHA can be used as a liming material for acidic soils.

As RHA can act immediately on soil, reducing soil acidity and thereby improving nutrient supply. The efficiency of RHA to neutralize soil acidity and as a source of phosphorus and potassium in plants has been widely reported; however, the quantity required was high (3). Due to the alkaline nature of RHA such effects are expected and it also has the essential elemental reserve. The chemical composition of RHA depends on its composition of rice husk, combustion conditions, temperature of burning and duration of burning. During combustion, most evaporable materials in rice husks are released, leaving behind silicates.

The extent of use of RHA in farm lands as a soil amendment is limited, despite its ability to enhance the properties of the soil. The RHA not only supplies nutrients but also functions as a soil conditioner that can hold nutrients, preventing nutrients from being lost through leaching (5). RHA has a high Cation Exchange Capacity (CEC), which leads to increase in CEC of soil (6). RHA can reduce the acidity when used as a mixture (7). This potential was owing to the higher specific surface area of RHA. Hence, the present study aimed to assess the efficiency of RHA in neutralizing soil pH and other related soil properties of acid soils.

Materials and Methods

To determine the suitability of RHA as an amendment to acidic soil and to study the influence of RHA on the properties of acidic soil, an incubation experiment was conducted in the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. For conducting the incubation experiment, soil was collected from a Block of Woodhouse Farm, Horticultural Research Station, Ooty, Nilgiris District. The surface layer (0-15 cm) of soil was collected, processed, homogenized and sieved through a 2 mm sieve. Representative subsamples were drawn for analysis of various physical, chemical and physicochemical properties using standard procedures (Table 1). RHA was characterised for physical and chemical properties using standard procedures (Table 2). The experiment was conducted during 2022-23 with seven treatments replicated four times in a completely randomized block design. Treatments included absolute control (T_1), 100 % lime requirement as lime (T_2), ice husk ash 10, 20, 30, 40 and 50 t ha^{-1}(T_3, T_4, T_5, $T_6$and T_7, respectively).

Approximately 100 g of soil, passed through a 2 mm sieve was filled in clean plastic containers. Treatments were imposed according to the treatment schedule. Soil moisture was maintained at field capacity throughout the experiment.

Table 1. Analytical methodologies adopted for soil analysis

Properties	Methodology	Reference
Physical properties		
Particle size analysis	International pipette method	(24)
Field capacity moisture content	Pressure-plate apparatus	(25)
Physico-chemical properties		
Soil reaction (pH)	Potentiometry (1:2.5 soil: water suspension)	(26)
Electrical conductivity (EC)	Conductometry (1:2.5 soil: water suspension)	(26)
Effective cation exchange capacity (ECEC)	1N NH_4OAc at field pH	(26)
Chemical properties		
Organic carbon	Chromic acid wet digestion	(27)
Available nitrogen	Alkaline $KMnO_4$	(28)
Available phosphorus	Bray No.1 extractant (0.03 N NH_4F and 0.025 N HCl)	(29)
Exchangeable potassium and sodium	Neutral Normal NH_4OAc	(30)
Exchangeable calcium and magnesium	Versenate titration	(26)
Available sulphur	Turbidimetry	(31)
Available micronutrients DTPA- Zn, Fe, Mn and Cu	DTPA extraction- Atomic Absorption Spectrophotometer	(32)
Total acidity	1 N CH_3COONa extract	(33)
Exchangeable aluminium	1 N KCl extract	(34, 35)
Available Si	0.5 M CH_3COOH	(36)
Lime requirement of acid soil	SMP buffer	(37)

Table 2. Analytical procedures followed for the analysis of rice husk ash

Parameter	Methodology		Reference
	Extraction	Estimation	
pH	RHA: Water suspension in 1:10 ratio	Potentiometric method using pH meter	(38)
Si	Microwave digestion system (70% HNO_3: 30% H_2O_2: 40% HF in 7:2:1 ratio)	Spectrophotometer with reducing agent 1-amino, 2-napthol, 4-sulfonic acid (ANSA)	(39)
K, Na, Ca, Mg, Fe, Mn, Cu, Zn and Al	Microwave digestion system (HNO_3: HCl: HF in 6: 2: 2 ratio)	ICP-OES	(40)
P, S		Spectrophotometer	
Total Calcium carbonate equivalent (TCCE)	0.5 M HCl	Titrimetric method	(41)
C, N	EDAX (Energy Dispersive X-ray Analysis)		(42)
Bulk density	Cylinder method		(24)

Soil samples were collected at 15, 30, 45 and 60 DAI and analysed for pH, total acidity, Exchangeable cations (Ca, Mg, K, Na and Al), Effective Cation Exchange Capacity (ECEC), following the methods provided in Table 1. The percent base saturation of the soil, calculated as the percentage of ECEC occupied by the basic cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) was determined.

The data collected on various parameters were subjected to statistical analysis (8). Critical differences were computed at five percent probability level, to assess the significance of the difference among the treatments. Non-significant comparisons were denoted as NS. Simple correlation was computed using MS-Excel to assess the relationships exist among different parameters.

Results and Discussion

Characteristics of experimental soil

The experimental soil had clay loam texture, strongly acidic (pH 4.92) with permissible levels of salinity (EC 0.26 dS m^{-1}), high content of organic carbon (30 g kg^{-1}) and ECEC of 5.20 c mol (p+) kg^{-1} (Table 3). Regarding soil fertility, the experimental soil was medium in available N (442 kg ha^{-1}) and P (45.7 kg ha^{-1}), high in available K (568 kg ha^{-1}) and $CaCl_2$-S (18.2 mg kg^{-1}) and sufficient in available Zn (1.30 mg kg^{-1}), Cu (1.92 mg kg^{-1}), Fe (43.2 mg kg^{-1}) and Mn (10.3 mg kg^{-1}).

The exchangeable cations in the experimental soil were 1.85, 0.95, 0.59, 0.14 and 1.71 c mol (p+) kg^{-1} for Ca, Mg, K, Na and Al, respectively. Percent base saturation and total acidity of the soil were 67.9 % and 4.45 c mol (p+) kg^{-1} respectively.

Table 3. Physico chemical characteristics of experimental soil

Properties	
Physical properties	
Mechanical analysis (%)	
Clay	38.2
Silt	26.2
Sand	32.5
Texture	Clay loam
Field capacity moisture content (%)	30.0
Physico-chemical properties	
pH	4.92
EC (dS m^{-1})	0.26
Effective cation exchange capacity (ECEC) (cmol (p+) kg^{-1})	5.20
Chemical properties	
Organic Carbon (g kg^{-1})	30.0
Available Nitrogen (kg ha^{-1})	442
Available Phosphorus (kg ha^{-1})	45.7
Available Potassium (kg ha^{-1})	568
Available Sulphur (mg kg^{-1})	18.2
Available Zinc (mg kg^{-1})	1.30
Available Copper (mg kg^{-1})	1.92
Available Manganese (mg kg^{-1})	10.3
Available Iron (mg kg^{-1})	43.2
Available Silicon (mg kg^{-1})	28.5
Exchangeable Calcium (cmol (p+) kg^{-1})	1.85
Exchangeable Magnesium (cmol (p+) kg^{-1})	0.95
Exchangeable Potassium (cmol (p+) kg^{-1})	0.59
Exchangeable Sodium (cmol (p+) kg^{-1})	0.14
Exchangeable Aluminium (cmol (p+) kg^{-1})	1.71
Per cent base saturation (%)	67.9
Total acidity (cmol (p+) kg^{-1})	4.45

Properties of rice husk ash

The properties of the RHA were analyzed and are presented in Table 4. Acid soils found to reduce the use efficiency of elements like phosphorus and fixed as insoluble compound. RHA found to be a good source of nutrients and it can enhance soil pH. The most important characteristic of an amendment for acidic soil is pH. In this study, the pH of the RHA (1:10 RHA: water suspension) was 8.30. The elemental compositions of carbon (3.49 %), Si (40.5 %), N (0.09 %), P (0.26 %), K (0.72 %), Ca (0.39 %), Mg (0.27 %), S (0.15 %), Na (1.22 %) and Al (0.88 %) were determined. RHA also contains significant levels of micronutrients, such as Fe (1591 mg kg^{-1}) and Zn (49.4 mg kg^{-1}), Mn (426 mg kg^{-1}) and Cu (13.2 mg kg^{-1}). RHA was having a bulk density of 0.27 Mg m^{-3}. The RHA used in this study had Total Calcium Carbonate Equivalent (titration method) and Effective Calcium Carbonate Equivalent (determined by incubation with the soil) of 10.3 % and 6.41 %, respectively.

Table 4. Characteristics of rice husk ash used in the study

Properties	
Physical properties	
Bulk density Mg m^{-3}	0.27
Physico-chemical properties	
pH	8.30
Chemical properties	
Carbon (%)	3.49
Silicon (%)	40.5
Nitrogen (%)	0.09
Phosphorus (%)	0.26
Potassium (%)	0.72
Calcium (%)	0.39
Magnesium (%)	0.27
Sulphur (%)	0.15
Sodium (%)	1.22
Aluminium (%)	0.88
Iron (mg kg^{-1})	1591
Zinc (mg kg^{-1})	49.4
Manganese (mg kg^{-1})	426
Copper (mg kg^{-1})	13.2
Neutralizing value or TCCE (%)	10.3
Effective calcium carbonate equivalent (%)	6.41

Soil pH

At all stages of incubation, statistically significant variations in soil pH were found among treatments (Fig. 1). Higher soil pH was recorded with the application of RHA 50 t ha^{-1} (T_7), which showed par values with 100 % lime requirement as lime (T_2), RHA 40 t ha^{-1} (T_6) and 30 t ha^{-1} (T_5) at 15, 30, 45 and 60 DAI. The lowest was recorded in the control (T_1).

At different stages of incubation, the highest soil pH values of 5.88, 5.99, 6.17 and 6.28, respectively, were recorded in RHA 50 t ha^{-1} (T_7), followed by 100% lime requirement as lime (T_2) (5.83, 5.96, 6.12 and 6.24, respectively), RHA 40 t ha^{-1} (T_6) (5.81, 5.91, 6.10 and 6.19, respectively) and RHA 30 t ha^{-1} (T_5) (5.77, 5.85, 6.05 and 6.12, respectively). The lowest values registered in the control (T_1) were 4.84, 4.86, 4.95 and 4.92 at 15, 30, 45 and 60 DAI, respectively. Over time, soil pH gradually increased in all treatments except the control. An increase in soil pH was observed at all stages of incubation with increasing levels of RHA.

RHA is alkaline in nature and increase in pH with its addition to acid soils, might be due to the presence of appreciable quantities of bases, such as Ca, Mg, K and Na. These bases can neutralize soil acidity by reacting with hydrogen ions (3), which aligns with the previous findings (6, 8).

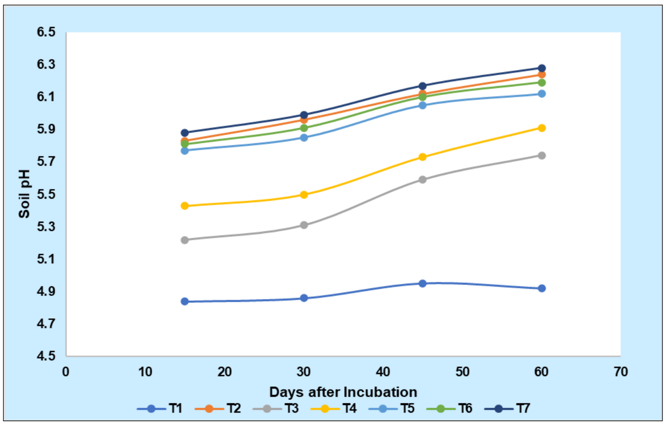

Fig. 1. Soil pH at different stages of incubation.

Total acidity

The total acidity values decreased with the application of lime and RHA at different levels (Fig. 2). With increasing RHA levels, the total acidity of the soil decreased. In all treatments, a reduction in total acidity over time was observed, except the control. The treatment received RHA at 50 t ha^{-1} registered significantly lowest total acidity values (3.67, 3.56, 3.40 and 3.31 cmol (p$^+$) kg^{-1} at 15, 30, 45 and 60 DAI, respectively), which was statistically on par with the 100 % lime requirement as lime (T_2) (3.71, 3.58, 3.42 and 3.33 cmol (p$^+$) kg^{-1}), RHA 40 t ha^{-1} (T_6) (3.74, 3.60, 3.43 and 3.36 cmol (p$^+$) kg^{-1}) and RHA 30 t ha^{-1} (T_5) (3.78, 3.63, 3.46 and 3.39 cmol (p$^+$) kg^{-1}). The highest value of 4.42, 4.38, 4.37 and 4.32 cmol (p$^+$) kg^{-1} at 15, 30, 45 and 60 DAI, respectively was noticed in control (T_1).

With increasing levels of RHA, the total acidity of the soil decreased. The alkaline nature of RHA increases the soil pH from an acidic level (3). This resulted in a decrease in soil acidity (9, 10). Total acidity is a measure of the total amount of hydrogen ions in the soil, which were neutralized by bases from the RHA. The slow dissolution of bases in RHA (3) might be the reason for the decrease in total acidity and increase in soil pH over time. A negative and highly significant correlation was observed between soil pH and total acidity at all stages of incubation (Table 6).

Exchangeable aluminium

Compared to the control, exchangeable aluminium was significantly reduced with the application of RHA and lime at all stages of incubation (Fig. 3). The treatment that received RHA 50 t ha^{-1} (T_7) recorded a minimum values of 1.31, 1.23, 1.14 and 1.09 cmol (p$^+$) kg^{-1}, followed by 100 % lime requirement as lime (T_2) (1.32, 1.23, 1.15 and 1.10 cmol (p$^+$) kg^{-1}), RHA 40 t ha^{-1}(T_6)(1.33, 1.24, 1.16 and 1.11 cmol (p$^+$) kg^{-1}) and RHA 30 t ha^{-1} (T_5) (1.33, 1.26, 1.17 and 1.11 cmol (p$^+$) kg^{-1}) at all the stages of incubation. The highest values of exchangeable Al found in the control (T_1) were 1.69, 1.72, 1.74 and 1.73 cmol (p$^+$) kg^{-1}respectively, at 15, 30, 45 and 60 DAI. Exchangeable aluminium values decreased in the liming material received treatments over time. A reduction in exchangeable Al was observed with an increase in the levels of RHA at all stages of sampling.

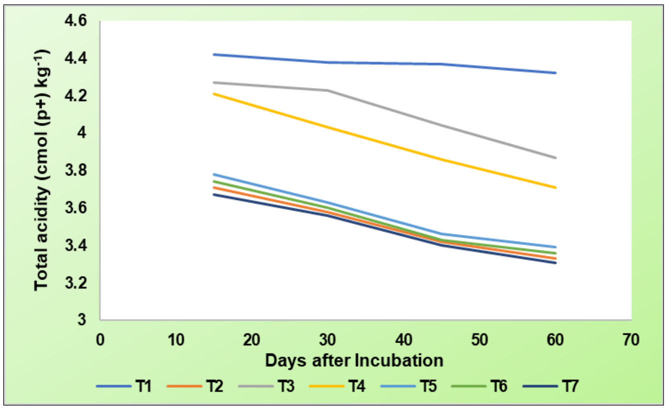

Fig. 2. Total acidity at different stages of incubation.

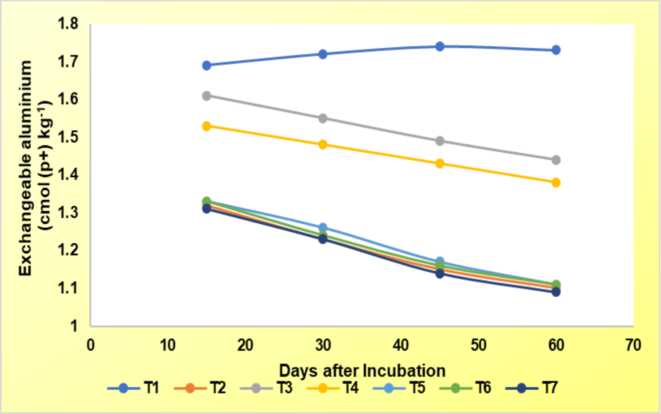

Fig. 3. Exchangeable aluminium at different stages of incubation.

When soil pH increases, exchangeable aluminium decreases because Al is soluble only at acidic pH. At pH values above 6.0, aluminium exists in the soil in an insoluble form (11). Similar findings were already reported in previous studies (9, 10, 12). This is further supported by the negative and highly significant correlation between soil pH and exchangeable aluminium at all stages of incubation (Table 6).

Exchangeable calcium

Among the treatments, significant variation was observed in exchangeable calcium at all stages of incubation (Fig. 4). Application of 100 % lime requirement as lime (T_2) recorded significantly highest exchangeable Ca (2.44, 2.69, 2.85 and 3.16 cmol (p$^+$) kg^{-1}) followed by RHA 50 t ha^{-1} (T_7) (2.24, 2.52, 2.76 and 2.93 cmol (p$^+$) kg^{-1}) at 15, 30, 45 and 60 DAI, respectively. Control (T_1) registered significantly lowest values of 1.82, 1.85, 1.88 and 1.84 cmol (p$^+$) kg^{-1} at all the stages of incubation. All treatments, except the control, registered increasing exchangeable Ca with the advancement of time. At all stages of incubation, an increase in exchangeable Ca was noticed with a hike in the levels of RHA.

Liming material application increases the dissociation of H$^+$ from hydroxyl groups which increases the negative variable electric charges on the surface of colloids and enhances retention of basic cation (Ca^{2+}) resulting in increase in soil pH (13).

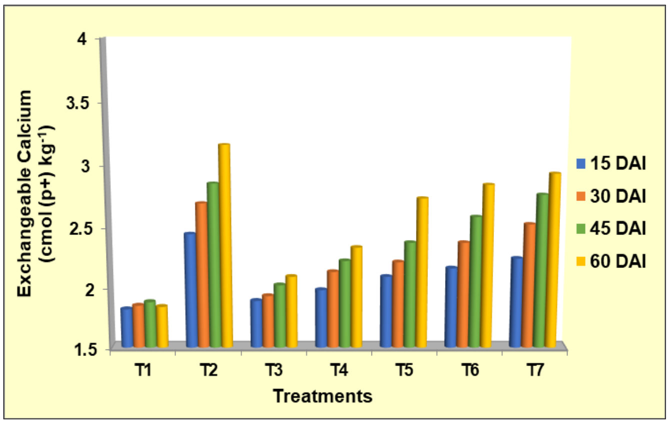

Fig. 4. Exchangeable calcium at different stages of incubation.

In increasing soil pH and Ca levels, application of lime was most effective and similar results were already reported (14, 15). In addition to lime, RHA at 50 t ha^{-1}(T$_7$) registered maximum exchangeable Ca. This might be due to the Ca added to the soil from the RHA, as reported in the previous study (12). Decreased exchangeable acidity and increased soil pH had an indirect effect on the availability of Ca (9). The relationship between soil pH and exchangeable Ca at all incubation stages was highly significant and positive (Table 6). The gradual increase in exchangeable Ca over time may be due to the slow dissolution of bases from RHA (3).

Exchangeable magnesium

The values obtained from the experiment revealed a significant variation in exchangeable Mg among the treatments (Table 5). At all the stages of incubation, highest exchangeable Mg was observed in 100 % lime requirement as lime (T$_2$) (1.46, 1.87, 2.29 and 2.42 cmol (p+) kg^{-1}) followed by RHA 50 t ha^{-1} (T$_7$) (1.29, 1.69, 1.93 and 2.11 cmol (p+) kg^{-1}). The lowest values (0.93, 0.96, 0.95 and 0.91 cmol (p+) kg^{-1}was registered in the control (T$_1$) at 15, 30, 45 and 60 DAI, respectively. With increasing time, the application of lime and different levels of RHA increased soil exchangeable Mg. Increasing the RHA levels increased exchangeable Mg at all sampling stages. Slow solubility of exchangeable bases in RHA (3) might be the reason for the increasing exchangeable Mg with time.

An increase in exchangeable Mg with lime application was noticed which might be due to the increased pH-dependent charge density on the exchange sites (16). The results could be further strengthened by the highly significant and positive correlations between soil pH and exchangeable Mg at all stages of incubation (Table 6).

Reduced Al saturation and increased Ca and Mg with lime application was reported earlier (17). The present study is akin to the results of previous studies (18, 19). RHA also increases exchangeable Mg because it contains exchangeable bases (12, 20). The low solubility of exchangeable bases in RHA may be the reason for the increase in exchangeable Mg with time (3).

Exchangeable potassium

Significant variation was observed among treatments with respect to exchangeable K (Table 5). The highest exchangeable K values of 0.85, 0.93, 1.06 and 1.13 cmol (p$^+$) kg^{-1} at 15, 30, 45 and 60 DAI, respectively, were observed in the treatment application of 50 t ha^{-1} RHA (T$_7$), followed by 40 t ha^{-1} RHA (T$_6$) and 30 t ha^{-1} RHA (T$_5$). The treatment control (T$_1$) registered the lowest exchangeable K of 0.57, 0.60, 0.62 and 0.58 cmol (p$^+$) kg^{-1}at 15, 30, 45 and 60 DAI, respectively. With the advancement of incubation, exchangeable K increased in treatments that received lime and different levels of RHA. With an increase in RHA levels, an increase in exchangeable K was observed.

Increasing negative charges due to increased pH with the application of liming materials might have contributed to enhance exchangeable K. In the present study, a significant positive relationship was observed between soil pH and exchangeable K at 15, 30, 45 and 60 DAI (Table 6).

Potassium supplied by RHA also could have increased exchangeable K in the soil, as reported previously (6, 9, 12). Exchangeable K increased from 15 to 60 DAI, which could be attributed to the slow dissolution of the bases (3).

Exchangeable sodium

Exchangeable Na increased with time in treatments that received lime and different levels of RHA (Table 5). At all the stages of incubation, RHA 50 t ha^{-1} (T$_7$) registered the highest values with statistical significance of 0.48, 0.63, 0.72 and 0.84 cmol (p$^+$) kg^{-1}at 15, 30, 45 and 60 DAI respectively which was followed by the application of RHA 40 t ha^{-1} (T$_6$) and RHA 30 t ha^{-1} (T$_5$). The lowest value of 0.14, 0.13, 0.16 and 0.15 cmol (p$^+$) kg^{-1} was noticed in control (T$_1$) at 15, 30, 45 and 60 DAI, respectively. Exchangeable Na increased at all stages of incubation with hikes at RHA levels.

Increasing the charge density with increasing soil pH and the addition of Na from RHA might have increased exchangeable Na with increasing levels of RHA. This was further supported by the significant positive correlation observed between soil pH and exchangeable Na at all stages of incubation (Table 6). These findings align with those of previous studies (19-21), which confirmed an increase in exchangeable Na following the addition of ashes.

Effective cation exchange capacity

Notable variation was observed among the treatments with respect to effective cation exchange capacity (ECEC) (Table 5). ECEC was significantly highest with RHA 50 t ha^{-1} (T$_7$) (6.23, 6.76, 7.34 and 7.86 cmol (p$^+$) kg^{-1}) followed by 100% lime requirement as lime (T$_2$) (6.21, 6.73, 7.29 and 7.83 cmol (p$^+$) kg^{-1}) which were comparable. The lowest ECEC values of 5.28, 5.33, 5.35 and 5.32 cmol (p$^+$) kg^{-1}at 15, 30, 45 and 60 DAI respectively were recorded in control (T$_1$). With the advancement of incubation, ECEC values

Table 5. Effect of RHA on exchangeable magnesium, potassium, sodium, effective cation exchange capacity and base saturation percentage (15, 30, 45 and 60 days after incubation)

Treatments	**Exchangeable. Magnesium (cmol (p$^+$) kg^{-1})**				**Exchangeable. Potassium (cmol (p$^+$) kg^{-1})**				**Exchangeable sodium (cmol (p$^+$) kg^{-1})**				**Effective cation exchange capacity (cmol (p$^+$) kg^{-1})**				**Base Saturation (%)**			
	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60
T$_1$- Control	0.93	0.96	0.95	0.91	0.57	0.6	0.62	0.58	0.14	0.13	0.16	0.15	5.28	5.33	5.35	5.32	65.5	66.4	67.5	65.4
T$_2$- 100% lime requirement as lime	1.46	1.87	2.29	2.42	0.65	0.69	0.76	0.80	0.28	0.32	0.38	0.42	6.21	6.73	7.29	7.83	77.8	82.8	86.2	86.9
T$_3$- RHA 10 t ha^{-1}	0.98	1.05	1.12	1.18	0.6	0.63	0.65	0.68	0.17	0.19	0.2	0.22	5.32	5.44	5.61	5.74	68.4	69.9	71.2	72.6
T$_4$- RHA 20 t ha^{-1}	1.06	1.18	1.28	1.41	0.62	0.66	0.71	0.73	0.2	0.22	0.25	0.28	5.54	5.75	5.97	6.26	69.7	72.9	74.7	75.9
T$_5$- RHA 30 t ha^{-1}	1.15	1.35	1.48	1.65	0.71	0.78	0.84	0.91	0.31	0.39	0.48	0.57	5.66	5.98	6.31	6.70	75.3	79.1	82.0	87.5
T$_6$- RHA 40 t ha^{-1}	1.22	1.47	1.68	1.87	0.77	0.86	0.95	1.02	0.38	0.47	0.64	0.71	5.95	6.41	6.88	7.31	76.1	80.7	85.1	88.1
T$_7$- RHA 50 t ha^{-1}	1.29	1.69	1.93	2.11	0.85	0.93	1.06	1.13	0.48	0.63	0.72	0.84	6.23	6.76	7.34	7.86	78.0	85.4	88.2	89.2
SEd	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.003	0.01	0.03	0.08	0.09	0.09	0.80	1.18	1.31	1.57
CD (P= 0.05)	0.02	0.03	0.0	0.05	0.0	0.02	0.03	0.02	0.01	0.01	0.01	0.02	0.07	0.16	0.19	0.19	1.7	2.4	2.7	3.3

Table 6. Correlation between soil pH and exchangeable cations, effective cation exchange capacity and base saturation percentage at 15, 30, 45 and 60 days after incubation (DAI)

Correlation		Total acidity	Exchangeable calcium	Exchangeable magnesium	Exchangeable potassium	Exchangeable sodium	Exchangeable aluminium	Effective cation exchange capacity	Base Saturation (%)
Soil pH	15 DAI	-0.967**	0.883**	0.887**	0.796*	0.848*	-0.984**	0.997**	0.973**
	30 DAI	-0.978**	0.893**	0.879**	0.784*	0.830*	-0.994**	0.998**	0.965**
	45 DAI	-0.980**	0.886**	0.891**	0.773*	0.797*	-0.986**	0.999**	0.934**
	60 DAI	-0.980**	0.895**	0.894**	0.792*	0.760*	-0.968**	0.998**	0.929**

Simple correlation was computed using MS-Excel

increased in treatments that received liming materials. At all sampling stages, increases in ECEC were recorded with increasing levels of RHA.

As the pH increases, hydrogen dissociates and the number of negative exchange sites increases. Hydrogen is replaced by cations such as Ca, Mg, Na and K, which, in turn, become exchangeable. The addition of RHA increased the soil pH, which would in turn increased the exchange capacity of the soil (22). ECEC showed a highly significant and positive correlation with soil pH at all stages of incubation (Table 6). These results are in line with the previous observations which reported that RHA increased the concentration of exchangeable bases, thereby increasing the ECEC (21). Addition of RHA resulted in high CEC of soil because RHA had high CEC probably due to the negative charge arising from the carboxyl groups of the RHA (6).

Percent base saturation

Different levels of RHA showed a significant variation in the percent base saturation (BS %) (Table 5). Among the various treatments, the application of RHA 50 t ha^{-1} (T$_7$) recorded the highest BS % (78.0, 85.4, 88.2 and 89.2 %), followed by 100 % lime requirement as lime (T$_2$) (77.8, 82.8 86.2 and 86.9 %), RHA 40 t ha^{-1} (T$_6$) (76.1, 80.7, 85.1 and 88.1 %) and RHA 30 t ha^{-1} (T$_5$) (75.3, 79.1, 82.0 and 87.5 %) at 15, 30, 45 and 60 DAI, respectively. The control (T$_1$) recorded the lowest BS % of 65.5, 66.4, 67.5 % and 65.4 % at 15, 30, 45 and 60 DAI, respectively. The percentage base saturation increased with time with the application of lime and different levels of RHA. An increase in BS % was observed with an increase in RHA levels.

RHA application increases exchangeable bases, which further increases % BS (12) and an increase in pH also increases % BS (23). A positive and highly significant correlation was observed between % BS and soil pH at 15, 30, 45 and 60 days after application (DAI) (Table 6). The slow dissolution of bases from RHA might be the reason for the increase in % BS with time (3).

Conclusion

RHA was alkaline in nature, with a pH of 8.3 and contains appreciable quantities of plant nutrients such as N, P, K, Ca, Mg, S, Na, Si and micronutrients. The results indicated that significantly higher soil pH was observed with the application of RHA 50 t ha^{-1}, which was on par with the 100 % lime requirement as lime, RHA 40 t ha^{-1} and RHA 30 t ha^{-1}. Total acidity and exchangeable aluminium were lowest in the treatment received RHA 50 t ha^{-1} which was statistically on par with the 100 % lime requirement as lime, RHA 40 t ha^{-1} and RHA 30 t ha^{-1}. The highest exchangeable Ca and Mg contents were observed with the application of 100 % lime, followed by RHA at 50 t ha^{-1}. RHA at 50 t ha^{-1} recorded the highest exchangeable K and Na. The effective cation exchange capacity was significantly higher in RHA 50 t ha^{-1} followed by lime (100 % lime). With respect to the percent base saturation, the highest value was recorded in RHA at 50 t ha^{-1}. Application of RHA from 30 t ha^{-1}onwards registered comparable performance with lime application as per lime requirement in terms of neutralising the acidity of the soil. The results of this study revealed that there is lot of scope for using RHA for acid soil reclamation and plant growth promotion in acid soils.

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Authors' contributions

PM conceived the original, contributed to the design of experiments, implementation of the research, data analysis and writing of the manuscript. KP conducted the experiments and analysis of the samples. EP, SPT, KMS and DS edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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