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Characterization of biochar obtained from weeds and its effect on soil properties of North Eastern Region of India

S. Mandal[1]*, B.C. Verma[2], G.I. Ramkrushna[2], R.K. Singh[1] and D.J. Rajkhowa[2]
[1]Division of Agricultural Engineering, ICAR Research Complex for NEH Region, Umiam-793 103, India
[2]Division of Natural Resource Management, ICAR Research Complex for NEH Region, Umiam-793 103, India
*Corresponding Authors Email : smandal2604@gmail.com

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Abstract

In the global climate change scenario, application of biochar in soil has become one of the important management practices for carbon sequestration, soil health improvement and climate change mitigation. In this study, an attempt was made to see the effect of biochar prepared from weed biomass on soil properties in subtropical northeast India. Biochar were prepared from seven locally available weed biomass viz. *Ageratum conyzoides, Lantana camera, Gynura sp., Setaria sp., Avena fatua,* Maize stalk, Pine needles and were characterised. A pot experiment was conducted with maize, where biochar was applied alone and in combination with fertilizers. Results revealed that biochar had significant impact on soil pH, SOC, and available nutrients like N, P and K. It also had significant impact on maize biomass yield. All biochar contained more than 50% stable carbon. Increase in soil pH was in the range of 0.26 to 0.3 and that of SOC from 1.62% in control to 1.74% in biochar added treatments. Biochars alone improved the available nitrogen ranging from 4.5 to 21.3 mg kg^{-1}, available P from 3.32 to 3.68 mg kg^{-1} and increased K content by 20% above control. Weed biomass can be potential alternative to enhance soil and crop productivity through conversion into biochar.

Key words

Acid soil, Biochar, Maize, Weed biomass

Introduction

Storage of carbon in soil for long duration has been considered an important mechanism to control increasing level of CO_2 concentration in atmosphere (Lal, 2009). From the Amazonians' primitive technology called "Terra-Preta" of enhancing soil productivity with charred biomass, biochar has emerged as a viable technique for carbon sequestration in soil (Lehmann *et al.,* 2006). Biochar is a carbon rich material produced by incomplete combustion of biological materials in absence or with limited amount of oxygen. Biochar is highly recalcitrant against microbial decay and it is believed that biochar can store carbon in soil for hundreds to thousands of years. Thus level of greenhouse gases (GHGs) like CO_2 and methane can be reduced significantly from atmosphere (Lehmann, 2007a).

Soil fertility and crop productivity in North East India is low due to high-rainfall, soil acidity, low availability of phosphorus, aluminium toxicity, etc. However, soil fertility can be successfully improved using both, inorganic as well as organic fertilizers. The major limitation of using inorganic fertilizers is their low accessibility to resource-poor farmers due to high cost (Diels *et al*., 2004). Hence, manure and compost are viable option but are difficult to get in well decomposed form and contain pathogens, heavy metals and pharmaceuticals, which are harmful for crop as well as environment (Barrow, 2012).

Application of compost and manure in soil is subject to rapid microbial breakdown and it stimulates microbial action and causes emission of methane, N_2O and other GHGs to the atmosphere, resulting in significant air pollution. In contrast to manure or compost, biochar seems to be an alternative option because it is applied to soil as a means of improving soil productivity, carbon storage and filtration of percolating soil water to reduce pollution of surface and groundwater (Barrow, 2012). Further, biochar application stores carbon in soil and this sequestration is likely to be for centuries, possibly thousands of years and more as compared to manure or compost. The importance of biochar for soil improvement seems promising and is probably due to its large surface area, presence of more number of micropores which provide a microhabitat for beneficial soil microorganisms, enable moisture retention and adsorption of nutrients (Blackwell *et al*., 2009; Sohi *et al*., 2010). Addition of Biochar increases the cation exchange capacity (CEC) of soil and changes the soil environment which reduces nitrogen losses. Hence, it increases nitrogen use efficiency by crops which might further reduce GHGs emission (Gaunt and Lehmann, 2008).

Biochar from wood is not a feasible and sustainable option in most farming areas of India. However, biochar can be produced by incomplete combustion from any ligno-cellulosic biomass (Lehmann *et al*., 2006; Lehmann, 2007b) and is a by-product of modern technologies for bio energy production such as gasification and pyrolysis (Laird, 2008). Biochar has been produced from different crop residues and its effects on soil properties and crop productivity has been studied by many researchers (Sohi *et al*., 2010; Peng *et al*., 2011). Further, its incorporation in soil had been proposed to increase water holding capacity (Dugan *et al*., 2010), soil organic carbon stock while improving soil fertility (Deal *et al*., 2012), rice crop yield (Haefele *et al*., 2011) and climate change mitigation (Zhang *et al*., 2012). But, no information is available for conversion of weed biomass to biochar. In high rainfall areas of North East India, weed biomass growth of 12 t ha^{-1} (on dry weight basis) has been observed annually (Mandal *et al*., 2012). Hence, in this study an attempt was made to find out the properties of biochar derived from different weed and forestry biomass and its effect on soil properties as well as growth of maize crop.

Materials and Methods

Biochar production from different biomass : Seven types of biomass viz. *Ageratum conyzoides, Lantana camera, Gynura sp., Setaria sp., Avena fatua,* Maize stalk and Pine needles were collected from experimental farm and nearby areas of ICAR Research Complex for NEH Region (ICAR RC NEH), Umiam, Meghalaya, India. Biomass was naturally dried for 4 weeks after shredding them to a size less than 50 mm. Before charring, each biomass sample was oven dried at 60 ºC for 24 hr. All dried biomass were crushed to <5 mm size and placed in stainless steel containers of 100 mm diameter and 150 mm height and were further pyrolysed in a muffle furnace. Carbonization temperature was maintained at 400 ºC for 4 hours with an initial heating rate of 10 ºC min^{-1}. This temperature was selected because biochars produced at low temperature had predominantly amorphous carbon structure with lower aromaticity and relatively higher nutrient content than high temperature biochars (Joseph *et al.,* 2010) and natural vegetation fire generally produces biochar at less than 450 ºC (Chandler *et al.,* 1983). At the end of pyrolysis reaction, samples were allowed to cool to room temperature inside the furnace overnight and then sealed in plastic container. All biochars were ground, screened to <2 mm and mixed thoroughly to obtain a fine granular consistency that would mix more uniformly into the soil. Biochars were oven dried at 105 ºC prior to application to soil (Kinney *et al*., 2012). Productivity of biochar was calculated by dividing dry weight of biochar by dry weight of the biomass taken.

Biochar characterisation : All biochar samples were analyzed for moisture content, volatile matter, total organic carbon and ash content. Moisture content was determined by drying in an oven at 105 ºC for 24 hr. BSI standard method (BSI, 2009) was followed to find out the volatile matter. The oven dried biochar samples were kept in a ceramic crucible in a muffle furnace at 900 ºC for 6 min to determine the volatile matter and at 750 ºC for 6 hr for ash content. Total organic carbon of biochar was determined by a TOC analyzer (Make: Elementer, Germany).

Experiment with maize : Bulk soil sample was collected from undisturbed field located at ICAR Research Complex experimental farm. The collected soil belonged to sandy clay loam type. Its average bulk density was 1.3 mg m^{-3} and pH was in acidic range (4.96). It was high in organic carbon (1.23%), medium in available N (244 kg ha^{-1}), available potassium (225 kg ha^{-1}) and low in available P (7.74 kg ha^{-1}). Climatically, the location of experimental site was classified as subtropical humid and received an annual average rainfall of 2395 mm. Temperature ranged from 6.9°C to 25.6°C, with an average daily high of 23.8°C and an average low of 10.6°C during the period of experiment. Relative humidity ranged from 54% to 80% and averaged 67%.

To study the effect of biochar and fertilizers as well as their interaction effects, eight level of biochar (one without biochar and seven with biochar from different sources @ 2.1 g kg^{-1}) and two level of fertilizers (without fertilizers and with fertilizers @ 0.15 g kg^{-1} N, 0.1 g kg^{-1} P_2O_5 and 0.15 g kg^{-1} K_2O) was selected. Thus, from a factorial randomized block design, sixteen (16) treatment combinations were created with three replications. In each pot, 2.5 kg soil was taken and treatments were allocated as described above. The soil collected for pot experiment was air-dried and ground to pass through a 2-mm sieve before use in the pot experiment. Biochar and fertilizers were mixed thoroughly with soil as per treatment before filling in the pots.

In each pot, three maize seeds (*Zea maize*) were sown at a depth of 50 mm and after germination only one healthy plant was allowed to grow while the other two were removed. All the pots were arranged in a complete randomized design. Water was added periodically to maintain proper moisture level. After 30 days of sowing, plants were uprooted and oven dried at 65 ºC for 48 hr and dry weight was recorded to get the biomass yield.

Soil analysis : At the end of the experiment, soil samples collected from each pot were air-dried, ground to pass through a 2 mm sieve and analyzed for various parameters. pH of soil sample was determined in 1:2 (soil:water) suspension using combined electrode (glass and calomel electrodes) by digital pH meter, according to Datta *et al*. (1997). Soil organic carbon was determined following the method of Walkley and Black (1934), available N by alkaline potassium permanganate method (Subbiah and Asija, 1956), available P by Bray's method (Bray and Kurtz, 1945) and available K by ammonium acetate extraction method (Jackson, 1967), respectively.

Statistical analysis : Experimental data were analysed using SAS statistical software (SAS Institute Inc., Cary, NC, USA, Version: 9.3) to assess the statistical significance of biochars and fertilizers on soil properties and maize biomass.

Results and Discussion

Characterization of biochar revealed that biochar productivity ranged between 35.9 to 48.3% on dry basis. Highest productivity of biochar was found from pine needles which may be due to uniform size of needles. Lowest productivity of biochar was recorded with *Gynura sp.* There was a little variation in moisture content of the produced biochar and it ranged between 8.1 to 11.2 %. Biochar contained 75.7 to 83.8 % total organic matter, highest in biochar from *Avena fatua* and lowest in maize stalk. Maximum total organic carbon (TOC) content was obtained in biochar from *Avena fatua* (56.2%) which was followed by *Setaria* (55.2%), pine needles (54.6%) and *Gynura* (53.9). This biochar thus produced can be a potential source of soil carbon (Table 1). It was also observed that all biochars contained more carbon than digested and undigested sugar beet trailings but lesser than wood biochar (Major *et al*., 2010; Yao *et al*., 2011).

Application of biochar had positive and significant effect ($p<0.05$) on improvement of soil pH. Irrespective of the sources of biochar, its application improved soil pH by 0.26 to 0.30 units within 2 months (Table 2 and Fig. 1a). Maximum improvement was observed from the biochar of pine needle. All weed biomass biochar had significant impact on soil pH. The results showed that biochar alone, or in combination with fertilizers, increased soil pH. This might be due to the fact that biochar pH in water was in alkaline range and biochar having high surface area as well as charge density helped in retention of basic cations. Novak *et al*. (2009) reported that with the addition of biochar, soil pH increased significantly which implies that it can be an effective liming agent which would neutralize pH solution by reducing exchangeable acidity.

All the biochars had significant ($p<0.05$) impact on soil organic carbon (SOC) and SOC in biochar added treatments was in the range of 1.70 to 1.74% as compared to 1.62 in control. Highest increase in SOC was observed with biochar of *Gynura,* followed by biochar of *Ageratum, Lantana* and *Setaria* (Table 2 and Fig. 1b). Biochar is a carbon rich material containing more than 50% carbon in stabilized form and is an alternative and viable option for carbon sequestration (Lehmann, 2007a). Van Zwieten *et al*. (2010) reported that with the application of biochar, total soil carbon was significantly elevated by 0.5 to 1% depending upon the soil type. Conversion of biomass carbon to biochar carbon leads to sequestration of more than half of the initial carbon as compared to low amount retained after burning and biological decomposition even after 5 to 10 years. Biochar gives more stable soil carbon than burning or direct land application of biomass (Lehmann *et al*., 2006).

Both fertilizer and biochar had direct and interactive effect on significant improvement in soil available nitrogen. Biochars derived from different sources alone improved the available nitrogen ranging from 4.5 to 21.3 mg kg^{-1} over control (110 mg kg^{-1}) while in combination with fertilizers they increased N ranging from 4.5 to 15.7 mg kg^{-1} (Table 2 and Fig. 1c). However, biochar of *Lantana*, *Gynura* and *Setaria* in combination with fertilizers had negative impact on available nitrogen. Biochar had mixed effect on soil available nitrogen. Biochar having high carbon content, when applied in soil might cause immobilization of available nitrogen in soil, but sometimes, if there is less available nitrogen, it simulates mineralization hence the effect might be mixed. A wider C:N ratio along with aromaticity will cause slow biochar de-composition in soil (Lehmann, 2007a) and the rate of decomposition will be so slow that even large additions of biochar to soil will probably not significantly immobilize the nitrogen (Novak *et al*., 2009).

Table 1 : Characteristics of biochars derived at 400°C for 4 hours from seven different sources/ biomasses

Source/ biomasses	Productivity*	Moisture content	Total organic matter	Volatile matter	Total organic carbon	Ash content
Ageratum conyzoides	38.7	10.1	78.8	26.2	52.6	21.2
Lantana camera	41.6	10.2	77.9	25.9	52.0	22.1
Gynura sp.	35.9	10.3	79.9	25.9	53.9	20.1
Setaria sp.	44.9	10.1	80.9	25.8	55.2	19.0
Avena fatua	45.5	8.1	83.8	27.5	56.2	16.3
Maize stalk	47.9	11.2	75.7	23.8	51.9	24.3
Pine needles	48.2	9.0	76.9	22.3	54.6	23.1

*Values are given in % on dry weight basis

Table 2 : Main effect of different biochars and fertilizer on soil pH, SOC, available NPK content and maize biomass yield under pot experiment

*Parameters/Treatments	Soil pH	SOC (%)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Biomass yield (g)
F0	4.70	1.66	93.1	2.72	48.9	1.74
F1	4.70	1.75	143	4.13	69.9	2.29
SEM±	0.003	0.002	0.35	0.01	0.10	0.01
CD (P=0.05)	NS	0.01	1.02	0.02	0.28	0.03
Biochar						
B0	4.46	1.62	111	3.14	51.4	1.76
B1	4.74	1.72	122	3.46	61.6	2.08
B2	4.72	1.73	112	3.32	60.1	1.95
B3	4.76	1.74	111	3.55	62.4	1.99
B4	4.72	1.73	115	3.41	57.6	1.97
B5	4.73	1.72	132	3.44	60.8	2.21
B6	4.73	1.70	117	3.68	60.8	2.02
B7	4.76	1.70	123	3.39	60.4	2.13
S.Em±	0.01	0.01	1.41	0.02	0.39	0.04
C.D. (P=0.05)	0.02	0.01	1.99	0.03	0.55	0.05

*F0 and F1 are without fertilizers and with fertilizers @ 0.15 g kg^{-1} N, 0.1 g kg–1 P_2O_5 and 0.15 g kg–1 K_2O respectively. B0, B1,B2, B3, B4, B5, B6 and B7 are without biochar and biochar from *Ageratum conyzoides, Lantana camera, Gynura sp.*, *Setaria sp,. Avena fatua*, maize stalk and pine needles @ 2.1 g kg^{-1}, respectively

Table 3 : Correlation analysis among different soil parameters and biomass yield

Parameters	pH	SOC	N	P	K	Biomass
Taking all samples together						
pH	1					
SOC	0.35*	1				
N	0.13	0.52**	1			
P	0.13	0.59**	0.89**	1		
K	0.24	0.65**	0.90**	0.94**	1	
Biomass	0.20	0.57**	0.74**	0.77**	0.77**	1
Taking only biochar treated samples						
pH	1					
SOC	0.36	1				
N	0.65**	0.07	1			
P	0.69**	0.38	0.37	1		
K	0.77**	0.49*	0.54**	0.82**	1	
Biomass	0.51*	0.34	0.22	0.36	0.42	1

* and ** : correlation is significant at 0.05 and 0.01 level, respectively

Phosphorus (P) availability was markedly influenced by biochar application. It was observed that P availability varied from 3.32 mg kg^{-1} (*Lantana* biochar) to 3.68 mg kg^{-1} (Maize stalk biochar) as compared to 3.14 mg kg^{-1} in control pot (Table 2). Interactive effect of biochar and fertilizers was also significant ($p<0.05$) and impact of biochar on P availability was more pronounced in the absence of fertilizers as compared to its presence (Fig. 1d). In the presence of fertilizers, P availability increased to 6% only, whereas in their absence, P availability improved from 20 to 37%. Availability of phosphorus in acid soil is correlated with soil pH and is low due to its fixation in soil colloids. As the soil pH increases in acid soil, P availability also increases. Several studies have demonstrated enhanced phosphorus uptake by plants in the presence of biochar because it makes phosphorus more available in soil by modifying soil pH and exchange capacity (Kwapinski *et al.*, 2010).

Available potassium was significantly ($p<0.05$) influenced by the application of all the biochars. Biochar derived from weed and other biomass increased available K content in soil by an average of 20% over control (Table 2). Biochars have significant amount of available potassium due to the presence of ash. Hence, application of biochar might have significant positive effect on available potassium in soil. In most of the studies, potassium availability was increased by biochar application even during second year of its application (Major *et al.*, 2010).

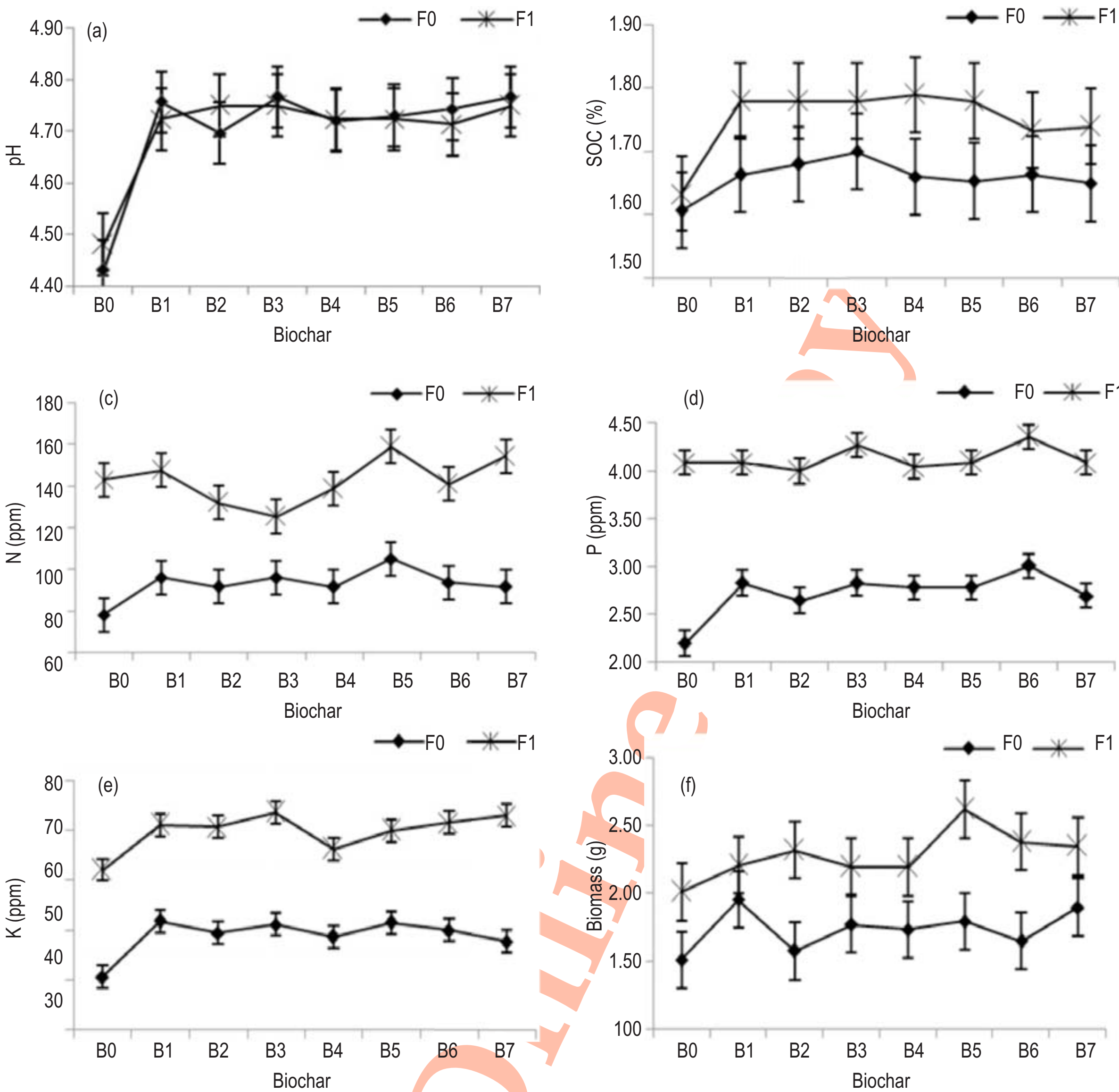

Fig. 1 : Interactive effect of fertilizers and different biochars on (a) soil pH, (b) soil organic carbon (SOC), (c) available N, (d) available P, (e) available K and (f) biomass yield

Biochar application had significant effect ($p<0.05$) on biomass yield of maize. Fertilizers alone increased biomass yield up to the level of 31%, while the effect of biochar was variable and increased the yield ranging from 10 to 26% (Table 2). Application of biochar from *Avena* gave maximum biomass yield followed by pine needle, maize stalk and *Ageratum*. However, interaction of biochar and fertilizers had non-significant effect on plant biomass (Fig. 1f). Fertilizers statistically had superior effect on plant growth as it provides plant nutrients in available form. Application of biochar had positive effect on soil pH as well as nutrient availability. Hence, this positive environment increased the biomass yield of maize. Kimetu *et al*. (2008) reported that application of biochar derived from eucalyptus to degraded soils in Kenya doubled maize yields and opined that it might be due to increase in soil pH and CEC. There was an increase in yield with biochar application in controlled environment as well as in field condition (Lehmann *et al*., 2006; Blackwell *et al*., 2009). It was also observed that with the varied rate of application of biochar (from less than 1 to over 100 t ha^{-1}) percent yield increased over comparable control ranged from less than 10% to over 200%. This variable response might be due to variation in nature and properties of biochar, its application rate, soil and crop type.

Several authors have reported that increase in crop yield with biochar addition was due to its effect on soil pH (Yamato *et al*., 2006; Rondon *et al*., 2007; Van Zwieten *et al.,* 2007) and too often pH-related increase in nutrient availability (Lehmann *et al*., 2003; Yamato et al., 2006; Rondon *et al*., 2007). Results showed that maize biomass was significantly correlated with the soil properties related with fertility. Biomass yield had significant positive correlation with soil organic carbon and soil available nitrogen, phosphorus and potassium (r = 0.57^{**}; 0.74^{**}; 0.77^{**} and 0.77^{**}, respectively). These soil fertility parameters were also significantly correlated with each other (Table 3).

As biochar application is intensely meant to see the effect on soil pH and carbon status, as well as different related properties, so by taking all the samples together it was difficult to correlate the effect of biochar alone. For this purpose, samples treated with biochar were separately correlated (Table 3). It was observed that pH had positive correlation with soil fertility. It also revealed that the yield of maize biomass was significantly correlated with soil pH, whereas, it showed non-significant positive correlation with other soil fertility parameters. It was recorded that yield was significantly correlated with soil fertility parameters when all samples together were correlated but contrast figure came when biochar alone was correlated where, only pH was significantly correlated. It may be explained with the fact that with the application of fertilizers, the sole effect of biochar was masked and biomass yield showed non-significant correlation with soil fertility. Biochar application improved soil pH that caused improvement in soil nutrient availability as well as maize biomass yield. It was well reported that application of biochar improved soil pH, soil fertility as well productivity of maize biomass.

It is concluded that weed biomass can be a better alternative source of biochar containing more than 50% organic carbon. It has significant impact on soil pH, soil fertility and crop biomass yield. Biochar certainly can be a good alternative for acid soil amelioration to increase soil pH.

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