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Acidic soil, Environmental extent, and different strategies of reclamation– A Review

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ABSTRACT

Soil is a crucial ingredient in the creation of agricultural goods. The production of this soil diminishes whenever it loses its fertility, regardless of whether the cause is acidity or alkalinity. This review focuses on the issues crops face due to soil acidity. The soil's acidity represents the most significant challenge confronting the worldwide food producing business. Acidic soil can occur in every geographical region worldwide. This review primarily examines global regions characterized by acidic soils. This page extensively discusses the chemical and biological approaches for reclaiming acid soils, accompanied by various examples and case studies.

INTRODUCTION

General properties of acidic soil

Soil is a biologically active and permeable substance that functions as a reservoir of water and nutrients. Fundamental salts, including Calcium, Magnesium, Potassium, and Sodium, are extracted from the soil in regions experiencing the most significant precipitation through drainage. Insoluble oxides and silicates of iron, silicon, and aluminium accumulate in significant quantities in the soil. The salt residues exhibit an acidic response, so rendering the soil acidic. Soils with a pH below 7 are classified as acidic.

Soils with a pH below 5.5 exhibit significant shortages in phosphorus (P), calcium (Ca), magnesium (Mg), and molybdenum (Mo), alongside toxicities of aluminium (Al) and iron (Fe) (Panda, N. & Chamuah, G.S. 2002). Aluminium toxicity in acidic soils with a pH below 5.5 adversely impacts the cultivation of staple food crops, vegetables, and cash crops globally (Nidhi Gupta et al. 2013). Excessive aluminum damages the root apex and impedes root extension (Sivaguru M & Horst WJ. 1998). Soil acidity impairs root development in crops, consequently diminishing water and nutrient absorption, which leads to decreased agricultural yields (Wang J et al. 2006; Marschner H. 2011).

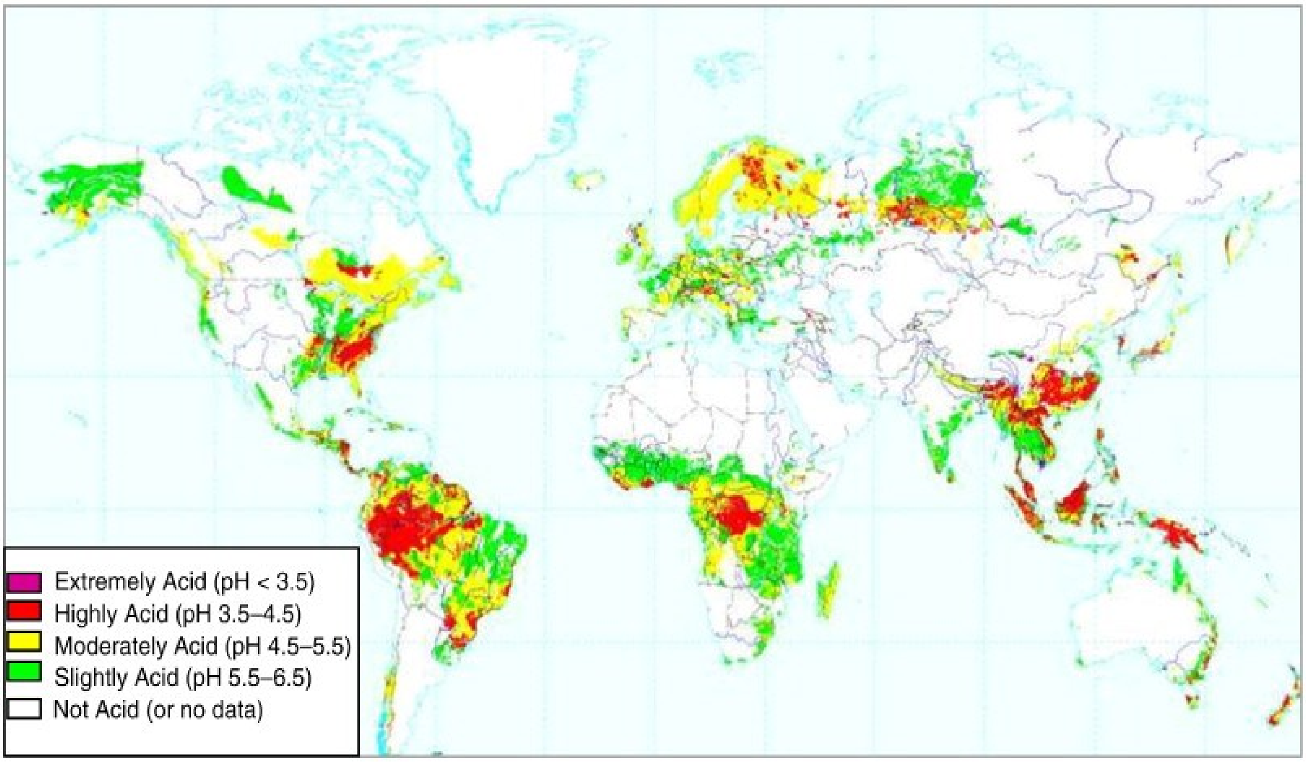
Sources of acid soil include leaching from heavy rains, acidic parent material, alumina silicate minerals, acid-forming fertilizers, humus and other organic acids, carbon dioxide and hydrous oxides, as well as acid rain (M.R. Latha and P. Janaki). Acidic soils can readily form in temperate zones and hilly areas (C. Bloomfield, 1953).

1. Geographical distribution of Acidic soil

1.1. Global

Acidic soils comprise over 60% (3,950 million hectares) of the Earth's surface area. Approximately 38% of cropland in Southeast Asia, 31% in Latin America, 20% in East Asia, 56% in Sub-Saharan Africa, and certain regions of North America are impacted (S. Wood et al. 2000; O.A. Hoekenga et al. 2006). In the Americas, 1616 million hectares are impacted, predominantly in South America. In Australia and New Zealand, 239 million hectares of agricultural land exhibit acidity. In China and India, 212 million hectares, or 12% of agricultural land, are designated as acidic. Africa constitutes the third largest contributor to acidic soils globally, accounting for 16.7% (659 million hectares) of all acid soils (H R von Uexkull & E. Mutert, 1995). They originate in humid climatic circumstances from carbonaceous, less soil-forming rocks over nearly all thermal belts of the Earth.

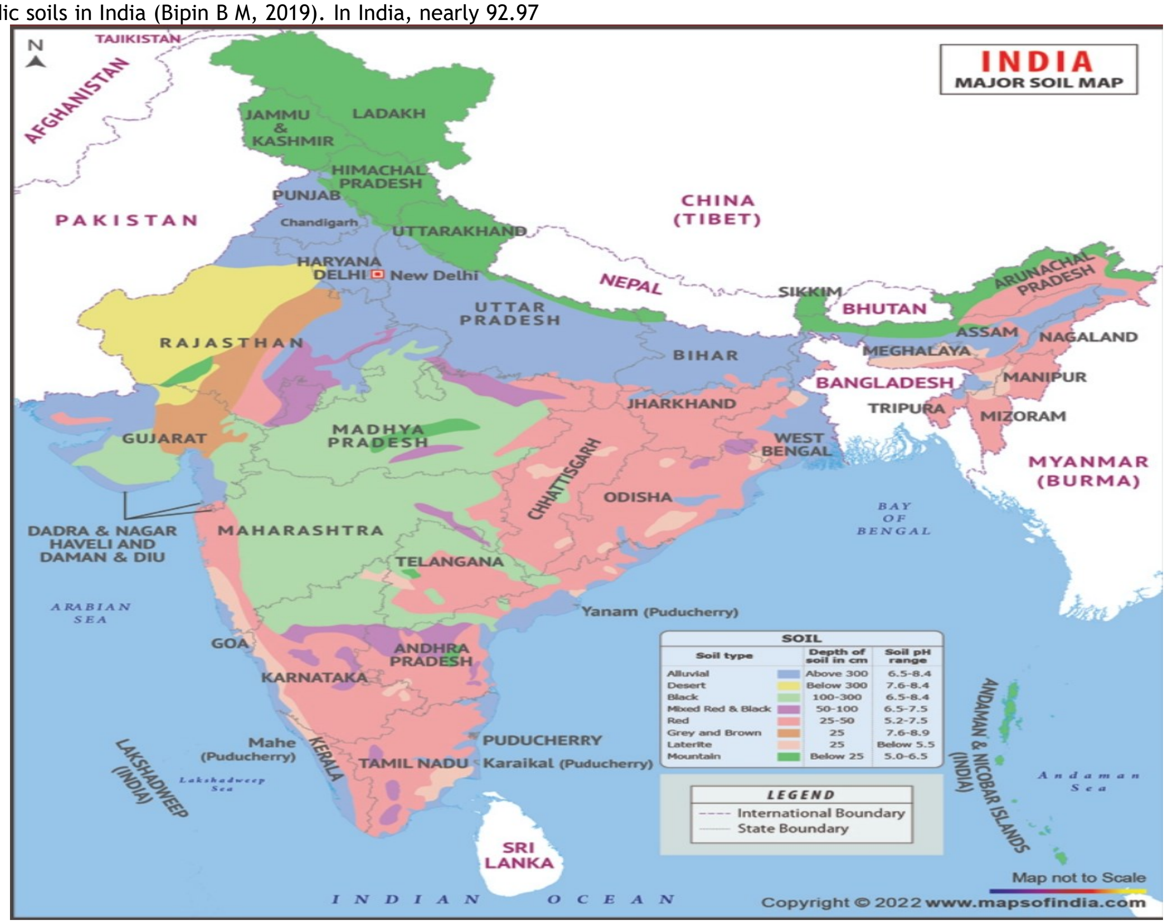
Sub-Saharan Africa exhibits notable regions impacted by soil acidity, encompassing East and Central Africa (Ethiopia, Kenya, Tanzania, Uganda, Rwanda, Burundi, Malawi, Central African Republic, Democratic Republic of Congo), West Africa (Ghana, Nigeria, Ivory Coast, Liberia, Sierra Leone, Guinea), and Southern Africa (South Africa, Zimbabwe, Mozambique) (Leenaars JG et al. 2014).



Source: World distribution of acid soils (USDA, NRCS, world soil resources, Washington, D.C.)

1.2. India

Assam, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, NEFA, Manipur, Tripura, West Bengal, Bihar, Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir, Madhya Pradesh, Maharashtra, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh have acidic soils in India (Bipin B M, 2019). In India, nearly 92.97 Mha of land is exposed to different magnitudes of soil acidity and soil fertility-related problems. Chemical degradation in soils leads to the development of acidity. It was estimated that about 6.98 Mha areas are affected by soil acidity **(Dk Mandal et al, 2019).**



Source: Maps of India.com

Strong and very strongly acid soils (pH 4.5- 5.5) have been reported in the north-eastern, eastern, and peninsular regions, including the Bihar plateau, sub-plateau areas of Bengal and significant parts of Odisha, Andhra Pradesh, Telangana, Tamil Nadu, Kerala, Maharashtra, and the Bay Islands. Moderately acid soils (pH 5.6-6.5) are found in the states, namely, Gujarat, Karnataka, Madhya Pradesh (parts), Chhattisgarh (hills), Uttar Pradesh and Uttarakhand (Panda et al., 1996). Severely acidic soils like acid sulphate soils (pH 4.5) are found in parts of Kuttanad area of Kerala, Goa, Maharashtra and Andaman and Nicobar Islands (Ganeshamurthy, A.N et al. 2000).

State-wise distribution of acid soils of India (Area in '000ha)

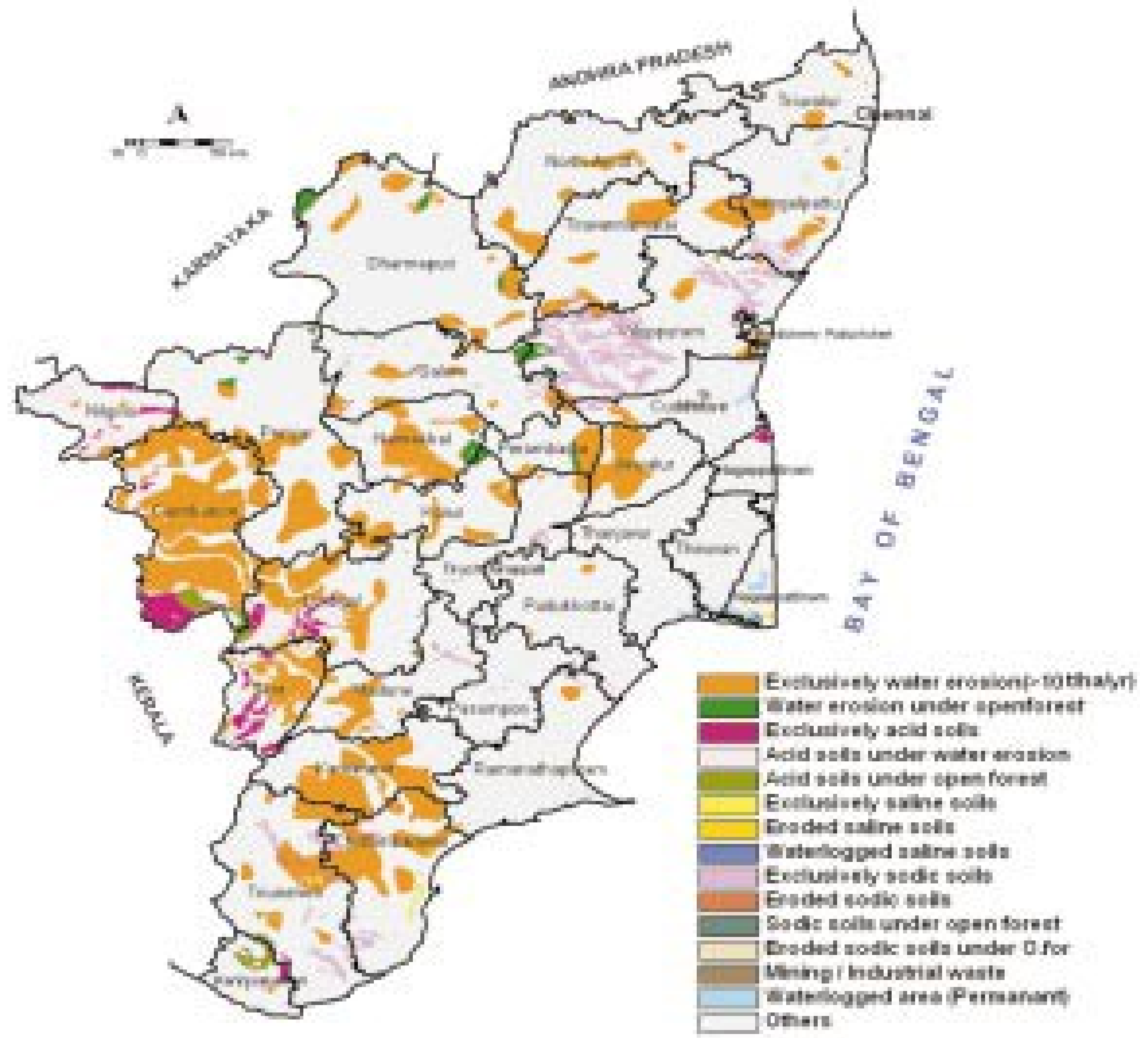
S.No	District	Strongly acidic pH<4.5	Moderately acidic pH<4.5-5.5	Slightly acidic pH<5.5-6.5	Total	TGA	% to TGA
		Area	Area	Area	Area	Area	
1	Andra Pradesh	0.0	0.0	2827.5	2827.5	27504.504	10.3
2	Arunachal Pradesh	4775.9	1742.7	268.8	6787.4	8374.3	81.1
3	Assam	23.5	2331.2	2332.7	4687.5	7843.8	59.8
4	Bihar	0.0	36.7	2324.9	2361.6	9416.3	25.1
5	Chhattisgarh	156.4	5930.1	4386.6	10473.0	13480.0	77.7
6	Goa	3.6	113.7	191.1	308.3	370.2	83.3
7	Himachal Pradesh	0.0	157.0	1620.6	1777.6	5567.3	31.9
8	Jammu & Kashmir	0.0	93.3	1480.1	1573.4	22223.6	7.1
9	Jharkhand	0.0	999.6	5772.1	6771.7	7971.4	84.9
10	Karnataka	0.0	61.4	3254.7	3316.1	19179.1	17.3
11	Kerala	138.0	2789.6	753.2	3680.7	3886.3	94.7
12	Madhya Pradesh	0.0	1124.7	10601.8	11726.5	30864.1	38.0
13	Maharashtra	0.0	240.0	4332.6	4572.6	30771.3	14.9
14	Manipur	426.9	1437.2	325.1	2189.2	2232.7	98.1
15	Meghalaya	0.0	1186.3	1054.4	2240.7	2242.9	99.9
16	Mizoram	0.0	1267.6	777.3	2044.9	2108.1	97.0
17	Nagaland	118.9	1483.3	55.7	1657.9	1657.9	100.00
18	Orissa	0.0	261.6	8409.7	8671.3	15570.7	55.7
19	Sikkim	278.9	323.4	2.8	605.0	709.6	85.3
20	Tamil Nadu	264.0	347.3	4294.5	4905.8	13005.8	37.7
21	Tripura	56.6	749.0	237.2	1042.8	1048.6	99.5
22	Uttar Pradesh	0.0	0.0	337.5	337.5	24104.6	1.4
23	Uttarakhand	0.0	1183.6	2300.6	3484.2	5336.5	65.3
24	West Bengal	0.0	555.6	4199.7	4755.3	8875.2	53.6
25	Others*	0.0	0.0	0.0	0.0	64381	0.0
	Total	6242.6	24414.6	62141.2	92798.4	328726.3	28.2
	Area (%)	1.9	7.4	18.9	28.2	100.0	

Others*: Delhi, Gujarat, Haryana, Punjab, Rajasthan, A & N islands, Chandigarh, D & N Haveli, Daman & Diu, Lakshadweep and Pondicherry.

Courtesy: NBSS & LUP, Publ. No. 145

1.3. Tamil Nadu

The laterite zone in Tamil Nadu is covered with acid soil (M.R. Latha and P. Janaki). In Tamil Nadu, Acidic soils cover 427 thousand ha (4% of TGA), and the affected districts in order are Coimbatore (126 thousand ha), followed by Dindigul (107 thousand ha), Nilgiris (97 thousand ha) and Teni (58 thousand ha). (G. P. Obi Reddy)



Source: NBSS & LUP

2. Usage and utilization of acid soil:

2621 mill, ha (66%) of the world's acid soils are forests and woodlands, while 699 mill, ha (18%) are used for pastures; (H R von Uexkull & E. Mutert, 1995) maize and soybean have been adapted to acid soil. Acid soils have a significant effect on plant productivity once the soil pH falls below 5. Soil with a pH of 6.5 is close to neutral and optimum for many acid-sensitive plants. Some trace elements may become unavailable, while soil with a pH of 5.5 is slightly acidic and has an optimal balance of major nutrients and trace elements available for plant uptake.

3. Economic importance of Acid soils

Two-thirds of the acid soils support forests and woodlands, and 18% is estimated to be under savanna, prairie and steppe vegetation. Only 4.5% (179 million ha) of the acid soils are used for arable crops, and 33 million Ha for perennial tropical crops (H R von Uexkull & E. Mutert, 1995). Most of the vegetable crops require moderately acidic to neutral pH values (5.5-7.0) for normal growth and development. This pH range can ensure the high bioavailability of most nutrients essential for vegetable growth and development (Ronen, E. 2007). Bean (*Phaseolus vulgaris* L.) absorbed 93.3% more P, 53.8% more Fe, and 44.1% more Zn at pH 5.4 than at pH 7.3, respectively (Thomson, C. J et al. 1993).

Relative tolerance of crops to soil acidity

Crops	Optimum pH range
Cereals	
Maize, sorghum, wheat, barley	6.0-7.5
Millets	5.0-6.5
Rice	4.0-6.0
Oats	5.0-7.7
Legumes	
Field beans, soybeans, peas, lentils etc.	5.5-7.0
Groundnut	5.3-6.6
Others	
Sugarcane	6.0-7.5
Cotton	5.0-6.5

The mid-altitudinal zone in the Himalayas has Podzols, which are acidic with low humus and are found in Assam, Darjeeling, Kashmir, Uttaranchal, and Himachal Pradesh. Maize, barley, wheat, and temperate fruits are grown in this soil in the Himalayan region. Plantation of crops like tropical fruits, coffee, tea, or spices in the states of South India, like Kerala, Tamil Nadu, and Karnataka, is undertaken in this type of soil. In the drier areas or deciduous forest belt, deep soil, brown in colour and rich in humus, is found. It is perfect for orchard crops.

Laterite soil supports crops like Rice, Ragi, Sugarcane, rubber, coconut, tea, coffee and Cashew nuts.

4. Reclamation of Acid Soils:

Acid soil reclamation should be carried out to improve crop productivity, either through the addition of certain neutralizers as amendments to correct the soil acidity or by adjusting the agronomic practices depending upon the climatic and edaphic conditions.

4.1. Lime

Preponderance of H^+ ions over OH^- ions leads to soil acidity, because the bulk of H+ ions are held in close association with the clay-organic colloid complex. Strong acid soils are unfertile for agricultural purposes and are not very productive. This problem of less production due to acidity can be overcome by the addition of Lime to such soils. Roots of cultivable crops can penetrate the surface soil in search of water and nutrients; in turn, they face the catastrophe of acidity. In every part of soil depth in India, pH prevails below 5.0, so under such episodes, application of lime to enhance the soil acidity is needed (Bhattacharyya, T. et al. 1993; 1999; 2006; Pal, D.K., et al. 2006; 2014).

When lime is added to moist soil, the soil solution becomes charged with cations, and the exchangeable hydrogen and aluminium ions on the clay-organic colloid complex and the H+ ions in the soil solution are displaced by calcium ions. Hydrogen combines with OH—to form neutral water or with CO3 or HCO3—to form unstable H_2CO_3, which readily dissociates to form CO_2 and water. The application of lime causes soil pH to increase, which causes Al and Fe sediment to increase (Arthanur Rifqi Hidayat and Arifin Fahmi, 2020).

Commonly used liming materials are as follows: (M.R. Latha and P. Janaki)

- Calcic limestone ($CaCO_3$), which is ground limestone.
- Dolomite ($CaCO_3$. $MgCO_3$).
- Quick lime (CaO), which is burnt limestone.
- Hydrated (slaked) lime [Ca $(OH)_2$].
- Coral shell lime.
- Marl or chalk ($CaCO_3$).

Liming soils below pH 4.5 is not economical; thus, integrated approaches (a Combination of chemical, engineering and agronomic measures) are required to enhance the productivity of acid soils under such a situation (Gouranga Kar et al. 2010).

4.2. Biomass

The principal mechanisms involved in increasing soil pH by organic matter vary depending on the type of materials. Composts, manures, peat, and coal products are more stable to decomposition than un-decomposed plant materials and contain humic-type substances. The functional groups of these humic substances confer metal binding and pH buffering capacities, which are essential in determining the pH of the treated soil (Wong M.T.F., Swift R.S. 2003).

Soil organic matter could be increased by the addition of Green manure, compost, farmyard manure (FYM), biochar and crop residues, which also add nutrients to the soil. Organic matter can increase microbial activity, improve soil structure, aeration, nutrient retention and water holding capacity (Vanlauwe B et al. 2015; Agegnehu G, Amede T. 2017; Amede T et al. 2021). Crop residues help recycle nutrients that have been removed from the soil. Green manures provide a considerable amount of N to succeeding crops and also control soil erosion (Xu R et al. 2002; Kumar S, Sukul P. 2020). organic matter like crop residues, green manures, FYM, compost or biochar extract toxic elements from the soil solution, thereby reducing the effect of harmful components and incorporating them into organic compounds (Sharma PK et al. 1990; Luo X et al. 2017; Cornelissen G et al. 2018).

The mechanisms postulated for explaining their effect on soil pH include the specific adsorption of organic anions on hydrous Fe and Al surfaces and the corresponding release of hydroxyl ions (Hue N.V. 1992; Hue N.V. et al. 1986), proton consumption during reduction of metallic ions due to oxygen consumption during compost decomposition, and ammonification of labile organic nitrogen in composts (Wong M.T.F., Swift R.S. 2003).

4.3. Biochar

Biochar is a carbonaceous solid material obtained from thermally degrading biomass in the absence of oxygen or presence of little oxygen. It is commonly defined as charred organic matter, produced with the intention to apply in the soils to sequester carbon and improve soil physical and chemical properties (Lehmann, J. and Joseph, S. 2009).

S.No	Types of Biochar	Reclamation studies	Reference
1.	Maize straw, Rice straw, Sugarcane baggase biochars	Immobilize Cd, Pb, Cu, Cr, Increase soil pH	Myra Nazeer et al, 2022
2.	Coffee ground and parchment biochar	Remediation of Cd, Zn, Pb, Increase soil pH, Re-vegetation with Jack bean	Ruan Carnier et al, 2022
3.	Rice husk biochar	Increase soil pH, Re-vegetation with mint	Jiang w et al, 2022
4.	Corn stover derived biochar	Improves soil physio-chemical properties, increase soil resistance to acidity, reduces Ni bioavailability	Evelyn Becerra-Agudelo et al, 2022
5.	Vineyard prunings and wood chips biochar	increased the nutrient content of the Swiss chard leaves, enhanced the soil properties	Anna Rita Rivelli and Angela Libutti, 2022

Biomass ashes can be used as a lime substitute for amelioration of acid soils by increasing pH, providing nutrients for crop development and stimulating microbial activity. However, ash application might increase N-mineralization and induce nitrate losses via leaching (Marina Fernández-Delgado Juárez et al. 2020).

Pyrolytic biochar can be used as a soil amendment to improve soil fertility and reduce soil acidity (Chan KY et al. 2018; Steiner C et al. 2007). Biochar is recalcitrant and might persist for hundreds of years in soils (Rebecca R. 2007).The combined application of biochar with vermicompost and NPK fertilizers was found to be most effective in increasing tomato yield in acid soil than sole application of biochar or biochar in combination with recommended doses of chemical fertilizers (Oguboyana Srikanth Yadav and Sanjay Swami 2019).

4.4. Industrial sludges

The dross or scoria of a metal obtained as derivative from iron and steel plants are used in agriculture for reclaiming acid soils. The slags are of three types:

- Blast furnace slags,
- Basic slag and
- Electric furnace slag.

These slags are well-heeled in phosphorus and mixture of CaO and CaC$(OH)_2$. Futhurmore, Ca, Mg, Al, silicates are also present in them (M.R.Latha and P. Janaki). Basic slag with <1% of free iron content and ground to 80 mesh can be foster as affordable supplement material whose requirement is almost 1.0 to 1.5 times of lime requirement (D.K. Mandal et al. 2019).

Lime concentrations present in the by-product of paper mills, tanneries, water softening plants, and by product in the form of $CaCO_3$ from fertilizer factories which use gypsum in its process are good enhancers of soil neutrality.

4.4.1. Paper Mill Sludge (PMS)

Lime sludge is a solid waste produced while converting wood/bamboo chips into pulp in the paper industry. Its major component is CaCO3; it contains low levels of potentially toxic heavy metals and can be a cheap source of amelioration of soil acidity. Paper Mill Sludge (PMS) has been tested for its suitability and found to be a good and cheap source compared to calcite and dolomite (Antaryami Mishra et al. 2020). Amending acid soil with PMS at 50% lime requirement (LR), and 100% NPK, gives higher yield in crops like groundnut, maize, sunflower and black gram from rain fed acidic upland (Gouranga Kar et al. 2010).

4.4.2. Press-mud

Clarification of Sugarcane juice leads to the separation of clear liquid and mud, this residual solid by-product obtained from sugar mills are called as Press mud. Strength of the lime-stabilized soil could be increased by amending press-mud to lime (Jijo James and P. Kasinatha Pandian, 2017). Commonly it is used as fertilizer. Fertilizer value of press mud could be increased by composting and treatment with microbes and distillery effluents (Nasir,N. M., 2006)

4.5. Molecular approach

Aluminium (Al) is one of the most abundant metals in the earth's crust and prevails in acid soils all over the world. Due to the increasing world population, there is an urgent need to ameliorate Al toxicity to increase plant production on acid soils (Miao Biana et al. 2013).

Progress in explaining mechanisms and detection of genes responsible for Al tolerance are made possible only through the molecular level of approach. Many researchers have shown that an external mechanism, especially organic acid exudation, plays a major role in detoxifying Al. Wheat malate transporter gene ALMT1 significantly improved Al tolerance in transgenic barley (Miao Biana et al. 2004). It was reported that citrate exudation is the main mechanism and HvAACT1 is the responsible gene for Al tolerance in barley (M. Bian et al 2013).

4.6. Integrated approach

Improved management (IM) practices developed through sustained researches to upgrade and maintain their nutrient status and make efficient use of soil water to sustain crop productivity at an enhanced level. The improved management system package includes improved seeds, NPK fertilizers, micronutrients, FYM and use of legumes in the cropping sequence, lime, improved water management, land development and the implementation of the soil conservation practices (Datta, M., 2013).

5. Soil vegetation types

The solubility and availability of nutrients to plants is closely related to the pH of the soil (Marschner 2011). Acid-tolerant plants can survive in acid soils by setting up several tolerance mechanisms, such as the increase of soil pH around the root apices (Kochian LV et al. 2004; Vitorello VA et al. 2005). The effects of acid soils on plant growth change according to plant species because Al-tolerant mechanism of plants depends on the species (Shinji Matsumoto).

Blueberries, potatoes and watermelons tend to be more acid tolerant crops. Wheat has proven to be up to 10-fold difference in Al tolerance among its genotypes compared to other cereals (Prochnow BL. 2014). Paddy is a good choice because flooding neutralizes the acidity and associated negative effects. Wheat, barley, maize, clover, and beans grow well on mildly acid to neutral soils (pH 6–7). Grasses tend to tolerate acid soils better than legumes (Getachew Agegnehu et al. 2021). Crops tolerant to acid soils are millet, sorghum, sweet potato, potato, tomato, flax, tea, rye, carrot and lupine (Somani LL. 1996).

Major Vegetable crops of acid soils (Ganeshamurthy, A. N et al. 2016)[a]

S.No	Vegetables	Major producing state having acid soil	pH range
1.	Brinjal	Odisha, Karnataka, West Bengal, Andhra Pradesh	5.5-8.5
2.	Cabbage	Odisha, Assam, West Bengal, Chhattisgarh, Uttaranchal, Himachal Pradesh and Karnataka	5.8-7.0
3.	Cauliflower	Odisha, Assam, West Bengal, Chhattisgarh, Uttaranchal, Himachal Pradesh and Karnataka	6.0-7.0
4.	Okra	Andaman & Nicobar, Odisha, West Bengal, Karnataka, Jharkhand, and Assam	5.5-8.5
5.	Onion	Odisha, Karnataka, Tamil Nadu	6.0-6.7
6.	Peas	Himachal Pradesh, Odisha, Jharkhand, West Bengal and Karnataka	6.0-7.5
7.	Tomato	Bihar, Karnataka, Odisha, and Assam	5.5-6.8
8.	Potato	Himachal Pradesh, Karnataka, and Assam	4.5-7.5

Organic residues from nitrogen fixing trees such as *Albizia zygia* and *Gliricidia sepium* ameliorate acid infertile rice soils. These trees increased the pH of the soil from 4.4 to 5.1 and 5.3, respectively after four weeks of incubation, as these species exude basic cations into the rhizosphere (Baggie I et al. 2000).

There are many fruit crops like Banana, citrus, mangostene, pineapple, guava, sapota that grow well on acid soils (Ganeshamurthy, A. N et al. 2016)[b].

6. Lacunae in different methods of reclamation

Both logistic and economic reasons make it impractical for resource poor farmers to apply high quantities of lime in acidic soils. Over-liming: affects soil permeability, destabilize soil structure and increased binding tendency of ferrous and aluminum oxides in soil particles (Antaryami Mishra et al. 2020) and also may lead to severe deficiency of Fe, Zn, B, P, Mg and K as well as permit molybdenum toxicity in some of the fruit crops like citrus, banana and pine apple (Ganeshamurthy, A. N et al. 2016)[b].

The addition of organic material is often associated with efforts to control metals that are toxic to plants and increase nutrient availability, but in reality, the application of organic matter can also acidify the soil and increase $Fe2+$ solubility if not managed appropriately (Arthanur Rifqi Hidayat and Arifin Fahmi, 2020). The decomposition of organic material in the early stages produces a lot of acetic acids. The oxidation of acetic acid always coincides with the reduction of $Fe3+$ (K. Kyuma, 2004).

One of the main problems encountered when considering the use of composts products to treat acid soils was their compositional variability. This meant that their acid-ameliorating properties were uncertain and the use of these materials for ameliorating acid soils was risky because of insufficient knowledge of the mechanisms involved and unpredictable benefits (Jean Jacques M. Mbonigaba & Marc Culot, 2009).

7. Case Study - Success story of low cost liming material in acid soil management in Odisha

A project on “Agricultural diversification for enhancing productivity of acidic uplands of eastern India”, sponsored by Technology Information Forecasting and Assessment Council (TIFAC) was executed by Directorate of Water Management, Bhubaneswar from 2006-07 to 2009- 10 in representative acid soil areas of Orissa. Lime in the form of paper mill sludge (PMS) was applied every year in ploughed layer, 4 - 6 weeks before sowing. Study revealed that after ameliorating soil with PMS @ 50% lime requirement (LR), and 100% NPK, higher net returns were obtained from rain-fed acidic upland during kharif season. During rabi season also higher crop productivity, net returns and water use efficiency were obtained with PMS @50% LR and 100% NPK (Gouranga Kar et al. 2010).

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