Обзор / Review

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Acidic soil-tolerant tree species identification

Melkamu Terefe Asmare

Ethiopian Forestry Development
Addis Ababa, Ethiopia

***Corresponding Author:** melkamu1122@gmail.com

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ABSTRACT

Previously, surface soil acidity was amended by the application of lime, gypsum, and acidic soil-tolerant crop species. However, their effectiveness in subsurface soil acidity reduction is limited. Thus, this review paper aimed to screen the tree species that easily overcome such problems. Scopus, Science Direct, Google Scholar, African journals online, and Google search engine databases were used. A total of 60 acidic soil-tolerant tree species were identified. *Acacia auriculiformis, Acacia crassicarpa, Arbutus unedo* L., *Casuarina junghuhniana,* and *Erythrina abyssinica* were among the extremely acidic soil-tolerant tree species. Whereas *Acacia cincinnata, Acacia mangium, Pinus patula, Albizia saman, Citrus x paradisi,* and *Cassia reticulata* were belongs to some of the strong acidic soil tolerant tree species. Generally, the species' acidic tolerance capacity and planting site compatibility should be considered for the success of amendment works. Scaling out these species and large-scale plantations should be done in addition to estimating their relative percent of acidic soil amendment roles. Producing stable food in line with reclaiming acidic soil is achieved through the integration of stress tolerant fruit trees. Research on large-scale plantations, domestication, skilling up and comparative evaluation of their levels of acidic soil amendment capacity should be performed in the future.

KEYWORDS:

Agroforestry; Fruit, Legumes tree; pH; subsurface soil acidity

М.Т. Асмаре*

Развитие лесного хозяйства Эфиопии
Аддис-Абеба, Эфиопия

***Автор для переписки:** melkamu1122@gmail.com

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Определение видов деревьев, устойчивых к кислой почве

РЕЗЮМЕ

Раньше подповерхностную кислотность почвы корректировали путем внесения извести, гипса и кислых почвоустойчивых культур. Однако их эффективность в снижении кислотности почв ограничена. Таким образом, цель данного обзора – отобрать породы деревьев, которые легко преодолевают подобные проблемы. Были использованы источники Scopus, Science Direct, Google Scholar, африканские онлайн-журналы и базы данных поисковых систем Google. Всего выявлено 60 видов деревьев, устойчивых к кислым почвам. *Acacia auriculiformis, Acacia crassicarpa, Arbutus unedo* L., *Casuarina junghuhniana* и *Erythrina abyssinica* относились к числу чрезвычайно устойчивых к кислотности почв видов деревьев. В то время как *Acacia cincinnata, Acacia mangium, Pinus patula, Albizia saman, Citrus x paradisi* и *Cassia reticulata* принадлежали к видам деревьев, устойчивым к сильно кислым почвам. Как правило, для успеха корректирующих работ следует учитывать кислотоустойчивость вида и совместимость с местом посадки. Увеличение и закладка крупномасштабных плантаций плодовых деревьев должна осуществляться с учетом оценки их относительной роли как улучшителей кислой почвы. Таким образом, производство стабильных продуктов питания и восстановление кислой почвы достигается за счет выращивания устойчивых к стрессу плодовых деревьев. В будущем должны быть проведены исследования крупномасштабных плантаций, интродукции и сравнительная оценка их уровня способности улучшать почву.

КЛЮЧЕВЫЕ СЛОВА:

Агролесомелиорация; плодовые деревья; бобовые деревья; pH; подповерхностная кислотность почвы

1. Introduction

In rain fed agricultural areas, the absence of diversified livelihood assets boosted the forest-to-agricultural area conversion process. Such anthropogenic factors, along with the associated natural events, cause substantial soil acidification on land [1]. Alvarez, Gimenez [2] reported that soil acidification may result from acid parent materials, leaching of basic cations (calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), hydrolysis reactions within soil exchange sites, rainfall containing nitric and sulfuric acids, cations absorbed by the crop over the course of long-term cultivation, removal of crop residue, and the addition of soluble salts and fertilizers (mineral and organic). Generally, the worry of soil acidification can be seen from different angles. Reduction of land productivity, change in vegetation cover, global warming, and migration are the major perspectives that express the consequences of acidification. Increasing acidification on land influences the essential mineral absorption capacity of tree and crop root systems, resulting in vegetation cover reduction. Land productivity is strongly influenced. Unable to sustain food and feed production later on influences the health system of people and other living organisms. Therefore, famine occurred, and the migration of living organisms to other areas occurred. In addition to this ending of poor acidic soil management, the area will be exposed to desertification since the vegetation cover is strongly influenced (degraded). Once erratic rainfall occurs in those areas, the remaining minerals are easily leached by floods and create higher sedimentation on the riverbank. The Accommodation of large sedimentation reduces the sea level water content and aggravates the emission of carbon dioxide, which was previously stored at sea level, to the atmosphere. The process finally creates global warming. Areas covered by acidic soil vary across the continent. For instance, in tropical regions, which are the largest agricultural production area, 43% of the land is covered by acidic soil [3]. Sumner and Noble [4] reported that the total topsoil acidic area of the world is approximately 30% (3.777 to 3.95 billion ha) of the total ice-free land area. They also reported that 22% of the total land of Africa (3.01 billion ha) is exposed to acidic soil. In Ethiopia, 47% of the total and 45% of the rainfed area of land is covered by the most hazardous acidic soil [5, 6]. The cultivated to the total area of the above mentioned continent is much lower than the acidic areas. The extent of acidity in the total and rainfed lands of Ethiopia was categorized as extreme to strong, moderate, and slight. In the rainfed agricultural areas of Ethiopia, the extreme to strongly acidic (higher concentration of hydrogen ions H+ in the soil) soil cover area is twice its content in the total area of the country [6]. To avoid the above mentioned consequences, different acidic soil amendment techniques were implemented in the different parts of the country. The application of lime (CaCO3) and acid-soil-compatible microbes, Al-tolerant crop genotypes, and gypsum are among the most commonly used acidic soil amendment techniques [7-9]. Liming is well known to reduce surface soil acidity, although it increases soil pH, native phosphorous, and molybdenum [10, 11]. Subsurface soil acidity, which occurs in a soil zone of 10-35 cm due to aluminum toxicity, is not easily reduced via the application of lime, gypsum and other usual treatments. Leaving this area free from any activity without amendment practice couldn't reduce the content of acidity. It rather aggravates the expansion rate to other nearby area. Its impact on reducing vegetation cover of less tolerance species and land productivity enhances unless appropriate amendment techniques applied on time. To overcome such problems, deep banding lime treatment has been implemented in different areas [12-14]. However, such practice is cost demanding and needs additional skill. As a result, sustainable and cost-effective surface and subsurface soil acidity amendment options are needed. Thus, this review focuses on the screening of various tropical acidic soil-tolerant species for future skilling-up and domestication-based research work. This is claimed by Nair, Kumar [15] in that there is little availability of surface and subsurface acidity in the forest and coffee landscape as compared to rubber and coconut land use practices. Abure [16] reported that acidity of soil under home garden was better than eucalyptus plantation land use. This indicated that proper species screening for acidity amelioration technique is pertinent issues.

2. Literature searching method

Formerly published data were used. Databases such as Scopus, Science direct, Google scholar, African journals online and Google search engines were used. Hand picking, citation and reference tracking manual searching techniques were used to compile relevant published papers. Papers that were published in English language alone were used. To avoid missing relevant information and compiling sufficient evidence, the timeline of publication was not considered.

3. Results and discussion

3.1. The extent of acidity on soil type, Agroecology and its effect on species composition

There are three main categories of soil based on textural size: small-sized clay, medium-sized silt, and larger-sized sandy soil. The class's sandy-textured soil types are primarily known for their acidity. Clay-textured soil types, on the other hand, have a high alkaline content. Acidity growth is constrained by the ecology and the type of soil. Among the 12 soil orders, acidity is more frequently occur in Oxisols in Africa and Ultisols in South America. According to Sanchez P.A. et all. [17], Oxisols and Ultisols make up roughly 43% of the tropics. Around 205 million hectares, or 23% of the nation, make up the tropical savannah known as the cerrado in central Brazil. Because of their high aluminum saturation, high P fixation capacity, and low natural soil fertility, the majority of the soils in this region are Oxisols (46%), Ultisols (15%), and Entisols (15%) [18]. Acidity varies across agro ecological zones. Factors like parent material, climate variability, vegetation cover type, drainage type, organic matter content, weather of rocks, management practice and other agricultural activity influence the extent of acidity across Agroecology [19-21]. Volcanic soil dominated highland and coastal lowland ecology have higher level of acidity than other areas [22-25]. The plant root required favourable soil nutrient content besides other essential things for their growth and development. The absence of nutrient or essential element toxicity or deficiency and active and abundant relevant microorganisms activities directly influence the plant root growth and development. In areas with higher level of aluminum toxicity, the root tip's cell elongation and division is inhibited[26]. In other words, it creates unfavourable environment for bacteria, earth warm and other essential microorganisms besides leaching of essential nutrients below the root zones of the plant. In such cases the plant root water and other essential nutrient uptake capacity reduces significantly. This creates the critical role in their development and reproduction rate. Thus, the species diversity and abundance in particular and species composition in general in acidic soil dominated area reduces as compared with other fertile soil area [27, 28].

3.2. Effect of soil acidity on biomass or yield of crops species

Increases in crop yields have been shown to dramatically lower poverty and enhance food security. A number of factors, including technological ones (managing decisions, agricultural practices or tillage system etc.), biological ones (crop verity, diseases, insects, pests, weeds), and environmental ones (climatic conditions, soil fertility, acidity, salinity, alkaline, topography, water quality, etc.) can affect yield, or the mass of harvested crop product in a given area [29-31]. Acidity is influence crop and vegetation growth across soil types. Combining such factors with acidity strictly declined the crop yield and exposed the community for conical famine season. Crop requires favourable phosphorus and other essential elements. In acidic soil areas' the tillage system influence these essential nutrients. In a 19 years study, Calegari, Tiecher [7] found that, up to 10 cm of soil depth, proper liming and other soil management techniques provided better acidity, P, and K availability for winder crop species growth in no tillage systems than in conventional tillage systems. They also reported that below a depth of 10 cm, lime treatments in small amounts on the soil's surface were ineffective in mitigating the hazards of aluminum. Their findings indicate that applying lime to the soil surface on a regular basis under the no tillage system for crop yield improvement can only be a feasible substitute tactic if the subsurface's acidity and aluminum toxicity have been previously eradicated by applying a sufficient quantity of lime and blending it with the growing layer. Crop growth is greatly impacted by low soil pH, which lowers yield. According to Ngoune Tandzi, Mutengwa [32] soil acidity in maize can result in up to 69% yield loss. The maize (*Zea mays* L.) grain yield negatively correlated with the level of acidity [31, 33-35]. For instance, Hayati, Sutoyo [33] find out that the mean maize yield obtained in acidic soil was 38 times lower than the control environments.

3.3. Major acidic soil amelioration techniques used

Liming or Working horse of crop [36], gypsum, coffee husk manure, acid resistant cover crops, organic matters and dolomites are some of the main methods we use to treat acid soil. By increasing the availability of calcium and magnesium, enhancing microbial activity, increasing plant nutrient uptake efficiency, and lowering phosphorus immobilization, solubility, and heavy metal leaching, liming improves soil structure and lowers acidity [8, 24, 31, 36]. Though liming has such importance, its acidity or Al toxicity reduction capacity is limited until 10-20 cm soil depth alone during the first three successional years of its application [37]. Therefore, amending subsoil acidity with liming alone requires so long year and other techniques like gypsum and deep ripping. The extremely slow vertical and lateral movement of lime in the usual soil disturbance (small window) in deep ripping using tyne of 5 to 8 cm width results to big amounts of untreated soil [38]. Because of this, it seems unlikely that the subsurface acidity constraint will be lifted quickly. More research is necessary to determine whether complete tillage at depth is a feasible solution for subsoil acidity amendment as claimed by Li [39]. He also reported that In the short term, the alkalinity in the lime may move downward more easily when combined with organic materials. Nevertheless, over time, nitrification brought on by the heavy application of organic materials may cause the soil to become acidic.

Gypsum is applied to reduce Al toxicity and raise Ca^{2+} levels in the subsoil. The latter result has been linked to $SO4^{2-}$'s involvement in either Al precipitation [36]. However, its usual treatment slowly reduces the subsoil acidity. Another treatment was used to rapidly ameliorate subsoil acidity. Accordingly, Oates and Caldwell [40] reported, that using hydrofluorogypsum and phosphorgypsum gypsum by-product in place of the standard gypsum treatments were considerably and quickly reduced subsoil acidity because of the fluoride impurity found, which have an amount of 21 cmol(+) per kg of KCl- exchangeable Al. Applying gypsum to acid Andosols seemed to be more effective when soil humus contents and minor variations in soil pH levels were taken into account. This also resulted in a decrease in Al release rates when the consistent segmentation method was employed [41]. Generally, the use of inorganic acidic soil amendment techniques in a sustainable way request huge capital. The better less costly and sustainable crop production option in acidic soil dominated area needs further research. In the long and short run the use of acidic soil tolerant tree species better reclaimed the aluminium toxicity and level of soil pH in sustainable and cost efficient ways.

3.4. What makes tree species acidic soil tolerant?

Generally, techniques used in microbial biotechnology are derived from the organic interactions found in ecosystems. *Rhizobacteria*, one type of bacteria that is particularly important for plant growth, offer agricultural crops a counterbalance to the detrimental effects of abiotic stress, such as those brought on by salinized environments [42]. Microbial communities have developed a variety of defences' mechanisms to address numerous environmental obstacles. Because their survival and growth depend on quick, insufficient control over genetic expression and metabolic reactions, bacteria must be dynamic to overcome such unfavourable conditions [43-45]. Certain members of the diverse microbial populations can thrive in settings that are strictly unacceptable, while others may suffer negative consequences. A significant rise in expression occurs when bacteria are exposed to unfavourable conditions such as heat, heavy metals, salt, and nutritional shortages, among others [46]. A few of the diverse microbial populations can survive in completely unfavourable environments, while others are negatively impacted under stressed conditions. When bacteria are exposed to harsh environments such as heat, heavy metals, salt and nutrient limitations, their expression level skyrockets. The highly acidic environment is another significant unfavourable factor that inhibits bacterial growth. However, rhizobia species have evolved mechanisms to cope with such harmful environmental factors, and proteomics can help identify the proteins responsible for tolerance to high acidity[46]. Most legume agroforestry species are well adapted in stress-dominated areas. The presence of *arbuscular mycorrhizal fungi* in legume tree species allows them to adapt and grow well in stress-like acidity, salinity, and alkaline tropical areas [46].

Table. The acid-tolerant multipurpose tree species

No.	Scientific Name of species	Suitable pH(H_2O) range	Reference
1.	***Acacia auriculiformis***	3-9	[48-50]
2.	***Acacia cincinnata***	4-5	[51, 52]
3.	***Acacia crassicarpa***	3.4-5.4	[51-53]
4.	***Acacia koa* A.Gray**	4-7.4	[54]
5.	***Acacia mangium***	4.5-6.5	[51, 52, 55, 56]
6.	***Acacia mearnsii* De Wild.**	5-6.5	[57]
7.	***Acer pseudoplatanus* L.**	5-8	[58-61]
8.	***Albizia lebbeck***	5.5-7.5	[52]
9.	***Albizia saman***	4.6-7	[52]
10.	***Annona squamosa****	6.5-8	[62]
11.	***Arbutus unedo* L.***	3-7.2	[63-66]
12.	***Azadirachta indica***	5-8	[67, 68]
13.	***Betula pendula***	4-5	[69, 70]
14.	***Calliandra calothyrsus***	4.5-6.5	[52, 71, 72]
15.	***Calliandra calothyrsus* Meisn.**	4.5-6.5	[52, 73, 74]
16.	***Cassia abbreviate***	5.5-6.9	[52, 75]
17.	***Cassia reticulata***	4.2-4.7	[76]
18.	***Casuarina junghuhniana***	2.8-8	[52]
19.	***Citrus aurantiifolia****	5-8	[77]
20.	***Citrus limon****	5.5-6.5	[78, 79]
21.	***Citrus sinensis****	6-8	[52]
22.	***Citrus x paradisi****	4.3-8	[80]
23.	***Delonix regia***	4.5-7.5	[81]
24.	***Dialium guineensis***	5-7.5	[73]
25.	***Dodonaea viscosa***	4.5-8.5	[82]
26.	***Eneste ventricosum***	5-7.5	[83]
27.	***Enterolobium cyclocarpum***	4.5-8	[52]
28.	***Erythrina abyssinica***	3.5-5.5	[84]
29.	***Erythrina variegate* L.**	4.5-8	[52]
30.	***Fagus sylvatica* L.**	3.5-8.0	[85-87]
31.	***Ficus Carica****	5.5-6.5	[88]
32.	***Flemingia macrophylla***	4-8	[52]
33.	***Fraxinus excelsior* L.**	5-8.	[89]
34.	***Gliricidia sepium***	4.5-6.2	[90-92]
35.	***Harungana madagascariensis***	5.5-6.5	[73, 93, 94]
36.	***Inga edulis****	4-8	[95]
37.	***Japanese Maples (Acer palmatum)***	5.5-6.5	[96]
38.	***Juniperus horizontalis***	4-6	[97]
39.	***Leucaena leucocephala***	6-7	[76]
40.	***Liquidambar styraciflua***	5-7.4	[98, 99]
41.	***Malus domestica****	5.5-7	[100, 101]
42.	***Mangifera indica****	5.5-7.5	[102]
43.	***Mimosa scabrella***	4.8-5.1	[52]
44.	***Oxytenanthera abyssinica* A.Rich.**	5-6	[103]
45.	***Paraserianthes falcataria***	5.5-7	[104]
46.	***Persea americana****	5-7	[105, 106]
47.	***Pinus patula***	4.5-5.5	[107, 108]
48.	***Pinus strobus***	4.5-6.5	[109]
49.	***Pithecellobium dulce***	5.5-7.5	[110]
50.	***Prunus persica****	6-6.5	[111]
51.	***Prunus persica* var. *nectarine****	5.5-6.5	[111, 112]
52.	***Pterocarpus indicus***	5-7.5	[110]
53.	***Pyrus communis* L.***	5-6.5	[113]
54.	***Punica granatum* L.***	5.5-7.2	[114]
55.	***Quercus palustris***	5-7	[115]
56.	***Sinorhizobium medicae***	5-7	[116-118]
57.	***Taxodium distichum***	5.5-6.8	[119]
58.	***Tetrapleura tetraptera***	4-7	[73]
59.	***Vachellia abyssinica***	5-7.5	[52]
60.	***Vitellaria paradoxa****	5.5-8	[120]

*Note * indicated that the palatable fruit produced species*

3.5. Acidic soil-Tolerant tree species

The logarithm of a solution's reciprocal of its hydrogen ion concentration is known as pH. Practically speaking, pH is the relative acidity or alkalinity of a solution. The pH scale ranges from 0 to 14, with 7 denoting a neutral pH. Coffee (pH=5) and grapefruit juice (pH=3) are typical examples of acidic solutions, whereas saltwater (pH=8) and oven cleaning (pH=13) are typical alkaline solutions. Potential of Hydrogen (pH) is significant in soils because it affects the availability of essential nutrients for plants. When the pH rises, some soil nutrients, such as iron and manganese, become less available.

Chesworth [47] reported that four (extremely acidic ($0 \leq pH < 4$), strongly acidic ($4 \leq pH < 5$), moderately acidic ($5 \leq pH < 6$), and slightly acidic ($6 \leq pH < 6.5$)) categories of soil acidity were observed in agricultural landscapes. Taking into account these classifications, the identification of acidic soil-tolerant tree species was summarized. In this review paper, a total of 60 tree species were identified. Tree species *Acacia auriculiformis, Acacia crassicarpa, Arbutus unedo* L. (from fruit tree), *Casuarina junghuhniana, Erythrina abyssinica*, and *Fagus sylvatica* L. *were* identified as extremely acidic soil-tolerant tree species. 45 percent of the identified species (*Acacia auriculiformis, Acacia cincinnata, Acacia crassicarpa, Acacia koa* Gray, *Acacia mangium, Albizia saman, Arbutus unedo* L., *Betula pendula, Calliandra calothyrsus, Calliandra calothyrsus* Meisn., *Cassia reticulata, Casuarina junghuhniana, Citrus x paradisi, Delonix regia, Dodonaea viscosa, Enterolobium cyclocarpum, Erythrina abyssinica, Erythrina variegate* L., *Fagus sylvatica* L., *Flemingia macrophylla, Gliricidia sepium, Inga edulis, Juniperus horizontalis, Mimosa scabrella, Pinus patula, Pinus strobus* and *Tetrapleura tetraptera*) were able to grow in strongly acidic soil conditions (Table). All the listed species have direct and indirect ecosystem services (provision, regulation, cultural and support services). Of the screened species 16th were fruit tree species. Three of them (*Arbutus unedo* L., *Citrus x paradisi* and *Inga edulis*) can withstand a strong acidic soil (Table).

4. Conclusion and recommendation

Soil is a vital component for the growth of tree species. Inappropriate management of this essential resource reduces land productivity. Overutilization of inorganic fertilizer enhances the acidity level of surface and subsurface soil. A combined application of lime, gypsum and acidic soil-tolerant crop species is an essential tool for the amelioration of surface soil acidity. Reducing inorganic input and producing crop sustainably required other alternatives. Overall soil acidity (surface and subsurface acidity) is amended sustainably and is environmentally friendly at a high cost through the proper alignment of acidic soil-tolerant legume tree and fruit tree species with specific levels of acidic soil areas. Generally, planting the species (*Acacia auriculiformis, Acacia crassicarpa, Arbutus unedo L., Casuarina junghuhniana, Citrus x paradisi, Erythrina abyssinica and Fagus sylvatica* L.) that have the ability to absorb and recycle the subsurface mineral extreme acidic soil dominated area should be the priority issue for land managers. Producing stable food in line with reclaiming acidic soil is achieved through the integration of stress tolerant fruit trees. Research on large-scale plantations, domestication, skilling up and comparative evaluation of their levels of acidic soil amendment capacity should be performed in the future.

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About the Author:
Melkamu Terefe Asmare – Researcher,
https://orcid.org/0000-0002-8535-2800,
Corresponding Author, melkamu1122@gmail.com

Об авторе:
Мелкаму Терефе Асмаре – научный сотрудник,
https://orcid.org/0000-0002-8535-2800,
автор для переписки, melkamu1122@gmail.com