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1. Introduction

Soil acidification occurs in high rainfall areas, where soil is relatively enriched with H^+ ions, while other positive ions (Ca^{++}, K^+ etc) are leached. Soil acidification is a natural process but can be greatly accelerated by cultivation practice, for example application of acid fertilisers or removal of organic material. Acid soil is soil with a low pH. The pH is defined as the negative logarithm to the H^+ concentration. pH 7 is neutral, pH < 7 is acidic and pH > 7 is alkaline. The pH range goes from 0 to 14. In practice, soils rarely have pH below 3 or above 9. We consider a soil to be strongly acidic if the pH is less than 5.5. Soil acidity influences dissolution of minerals and nutrients, and thereby influences their tendency to leaching and / or availability to plants. In acid soil, iron, aluminium and sometimes manganese can reach toxic levels, while calcium, potassium and the micro-nutrients magnesium, boron and molybdenum may become deficient.

pH		Description
< 5.5	=	Strongly acid
5.5 - 5.9	=	Medium acid
6.0 - 6.4	=	Slightly acid
6.5 - 6.9	=	Very slightly acid
7.0	=	Neutral
7.1 - 7.5	=	Very slightly alkaline
7.6 - 8.0	=	Slightly alkaline
8.1 - 8.5	=	Medium alkaline
> 8.5	=	Strongly alkaline

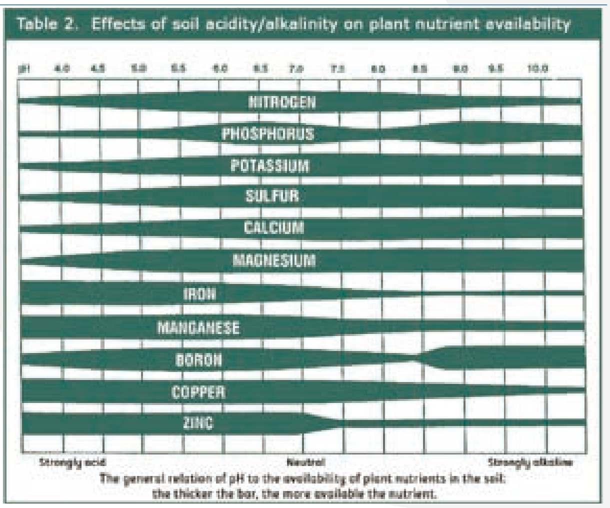

Figure 1. Left: Soil pH scale from 5.5 to 8.5. Notice that the scale is logarithmic (Log); - there is a 10 fold increase in acidity from pH 5 to pH 6. Right: The effect of pH on nutrient availability; narrow bar means that the nutrient is relatively inaccessible, a broad bar that it is relatively accessible. Very high or very low pH may cause nutrient deficiency or toxicity, dependent on nutrient, actual amount and plant species.

2. Physiological adaptations to growth in areas with low pH

H^+ is, as all other nutrients, toxic at high level. Toxicity means that it enters sites in the biochemical processes, where it replaces essential compounds. Chemical compound or ions have particular roles in structures and physiological / life processes, and if essential ions are replaced with H^+, it causes structural or physiological breakdown. The same can happen if, for example, the aluminium or iron concentration rises drastically. These minerals are absorbed and necessary in the physiological processes, but too high concentration is fatal.

Biological nitrogen fixation by root-based and free-living *Rhizobium* bacteria declines in acid soil and practically ceases below pH 5.5. A derived effect of acidity may thus be nitrogen deficiency.

Figure 3. Methods to check soil acidity. Top, electronic pH meter; centre, indicator strips; bottom, indicator plant, here example of an Oxalis species

Measuring soil acidity

Soil acidity varies in a field and a reliable measurement must thus be based on representative soil sampling. Depending on size of plantation site and anticipated variation, about 10 samples per hectare could be taken as representative. Samples may be about 'a handful', this is not crucial, and similar amounts from each place. In agriculture, soil samples are taken from the surface, where soil is mixed as a part of cultivation practice. Where soil is not mixed, for example degraded forest land, pH may change with depth. It can here be relevant to check pH at different levels of the soil stratum. Before pH measurement, the samples are mixed and dried. There are two different ways to determine soil pH.

- Direct measurement by the aid of an electric pH-meter. Here the pH is measured directly in a buffered solution of soil in distilled water or $CaCl_2$. The soil contains a certain concentration of H^+ ions. The ions must be detached from the soil colloids by dissolving the soil in water / $CaCl_2$; the sample must be carefully shaken. An exact quantity of water or $CaCl_2$ is used for an exact quantity (weight) of dry soil sample, - this is important because we are measuring a concentration. Most guidelines suggest 5 gram dry soil dissolved in 5 ml. distilled water. Using $CaCl_2$ the quantity should be 5g soil to 10 ml 0.01M $CaCl_2$ (guidelines on exact quantities vary, but which one is followed does not affect the result, because the pH meter is calibrated accordingly). The pH meter consists of a monitor and an electrode. Before the measurement, the pH meter is calibrated with a solution with known pH. This is part of the pH-meter package. The electrode is now put directly into the supernatant of the soil solution and the pH is read directly on the display. pH measurement in $CaCl_2$ is more exact than pH in water solution. Because the role of Ca^{++} ions is to detach the H^+ ions, the latter concentration will be higher, and the pH measured in $CaCl_2$ is thus normally lower, - often by 0.5-0.9. Indication of the method of measurement is therefore important. Usually it is indicated as pH (w) and pH ($CaCl_2$) respectively.
- pH can be measured via a pH indicator. A number of chemicals change colour with different pH. A combination of some of these indicator chemicals is used in pH indicator strips. Comparing the indicator colour with the colour of the reference scale will show the pH. The sample is prepared the same way as for electronic measurement. The indicator method is not as exact as direct electronic soil measurement, but will often suffice for practical purposes.

A quick method to get an impression on soil acidity is to look at the plants growing. Herb species tend to disperse widely, and species composition indicates to a large extent soil conditions on the site. The particular acid-indicator species vary with geographical locality. However, some genera tend to indicate low pH anywhere. Acid tolerance and thus indicator plants occur sporadically in many plant families, but tend to be prevalent in for example Oxalidaceae (*Oxalis*), Polygonaceae (e.g. *Rumex*) and Ericaceae (e.g. *Erica*). Several ferns and grasses also indicate acid soil. Fungi tend to be more prevalent in acid soil in general, but particular fungal species can be very good acid indicators.

Tree species adapted to high soil acidity

A number of species have been documented to be able to grow under acidic soil conditions. Unfortunately literature often fails to document more specific details. For example 'how' acid and whether acid soil is a tolerance or a necessity. A species like *Acacia aleucocarpa* will grow on almost any soil, from acid to alkaline. Other species are always found on acid soil. As the effect of acidity is closely linked to nutrient availability and possible toxicity under acid condition, species growth performance and tolerance to acid soil is thus also dependent on mineral composition of the soil. With these restrictions, following list contains species, which have been reported growing on acid soil.

Acacia aulacocarpa	*Hevea brasiliensis*
Acacia angutissima	*Hyeronima alchorneoides*
Acacia aneura	*Illicium verum*
Acacia auriculiformis	*Larix spp*
Acacia cincinnata	*Leucaena trichandra*
Acacia crassicarpa	*Lithocarpus*
Acacia karoo	*Magnolia spp*
Acacia koa	*Manglietia conifera*
Acacia mearnsii	*Melaleuca cajuputi*
Acacia pennatula	*Mimosa scabrella*
Acacia sieberiana	*Olea africana*
Albizea lebbeck	*Pentaclethra macrophylla*
Alnus nepalensis	*Picea spp*
Anacardium excelsum	*Pinus kesiya*
Anisoptera costata	*Pinus merkusii*
Bactris gasipaes	*Pinus roxburgii*
Betula spp.	*Podocarpus*
Calliandra calothyrsus	*Populus spp*
Callophyllum brasiliense	*Prosopis chilensis*
Casuarina oligodon	*Quercus spp.*
Cunninghamia lanceolata	*Robinia pseudoacacia*
Dactyladenia barteri	*Samanea saman*
Erythrina fusca	*Salix spp*
Eucalyptus camaldulensis	*Tephrosia candida*
Eugenia stipata	*Tephrosia volgii*
Fagus	*Terminalia catappa*
Gmelina arborea	*Terminalia amazonia*
Guazuma ulmifolia	*Vochysia ferruginea*

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