Chapter 4

Management of Acidic Soils

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Introduction

Soil acidity is a serious constraint to crop production in many regions of the world including India. Acidic soils in India are mainly prevalent in the humid Southwestern, Northeastern and Himalayan regions (Maji et al. 2008). They are particularly acute in the humid tropical regions that have been subjected to severe weathering. In India, about 48 m ha out of 142 m ha of arable land are affected by acidity, of which 25 m ha have pH below 5.5 and 23 m ha have pH between 5.6 and 6.5 (Mandal 1997). Strongly acidic and moderately acidic soils cover 6.24 m ha (1.9%) and 24.41 m ha (7.4%), respectively of the country's total geographic area (Maji et al. 2012). In the Northeastern region, approximately 95% of the soils are acidic and nearly 65% have strong acidity with pH below 5.5 (Sharma and Singh 2002). Acidic soils of Odisha account for 70% of its total geographical area (Jena 2008). A similar finding was reported in Odisha by Nanda et al. (2008) based on the analyses of 1,219,000 soil samples. A recent study conducted by ICRISAT found that of the 40,265 soil samples analysed, more than 80% were acidic in nature (see Chapter 3).

Effects of soil acidity

The major limiting factors associated with acidic soils (Table 4.1.) are toxic effects, nutrient imbalance and reduced microbial activity. Soil acidity causes toxicity of aluminium (Al) and manganese (Mn) and reduces the availability of nutrients such as calcium, magnesium, phosphorus, nitrogen, boron and molybdenum. It also retards biological activities in the rhizosphere, especially the symbiotic/or mutualistic association of plants with beneficial fauna and flora (Thakuria et al. 2016). These factors directly and indirectly affect plant growth. Other major constraints associated with acidic soils include severe water stress due to restricted root growth in the subsurface horizon (Adams 1984). Together, these severely limit the scope of increasing crop productivity. Aluminium toxicity and the associated deficiency of phosphorus are major constraints to crop production on 67% of the total acidic soils in the country (Eswaran et al. 1997).

Table 4.1. Classification of soils based on pH (Sarkar 2015).

Category	pH range
Extremely acidic	<4.5
Very strongly acidic	4.5-5.0
Strongly acidic	5.1-5.5
Moderately acidic	5.6-6.0
Slightly acidic	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	> 9.0

Soil classification based on pH

The causes of soil acidity include acidic parent materials such as granite, gneiss, sandstone; leaching of basic cations (Ca, Na, K and Mg), sesquioxides and humus, accumulation of organic matter, carbonic and other organic acids; soil forming processes like lateralisation and podzolisation; oxidation of sulfur and the application of acid forming inorganic fertilizers.

Acidic soil management

Liming

Amelioration of soil and sub-soil acidity constitutes an important aspect of acidic soil management. Application of lime and/or alternative liming material along with other management practices are needed to address soil acidity (Tables 4.2 and 4.3). Apart from increasing yield, application of lime enhances the efficiency of applied fertilizers, improves the effectiveness of some herbicides, protects the environment and increases the net profit of farmers (Prochnow 2014).

Benefits of liming

- Reduces soil acidity and improves soil pH, base saturation and CEC
- Increases nutrient availability
- Changes insoluble soil complexes of P and S to more plant available forms
- Improves biological activity
- Improves nitrogen fixing by legumes
- Improves soil physical structure
- Reduces Fe, Al and Mn toxicities
- Improves the effectiveness of certain herbicides
- Reduces fungal diseases
- Increases crop yields.

Table 4.2. Calcium carbonate equivalent (CCE) values of some important liming materials.

Liming materials	Calcium carbonate equivalent (%)*
Calcium oxide	179
Magnesium oxide	250
Calcium hydroxide	136
Magnesium carbonate	119
Dolomite	109
Calcium carbonate	100
Basic slag	86
Paper mill sludge	80

* Calcium carbonate equivalent is the acid-neutralizing capacity of the material compared to pure calcium carbonate expressed as a weight percentage of $CaCO_3$ (Das 2014).

Table 4.3. Characterization of locally available liming materials in Odisha.

Liming material with source	Effective neutralizing value*/ Calcium carbonate equivalent (%)	Ca (%)
Ballarpur Paper Mill Sludge (PMS)	60.8-84.2 (64.9)**	20.2-29.0 (21.7)
Rayagada PMS	55.4-92.0 (73.9)	20.8-46.56 (30.5)
Brajarajnagar PMS	66.6-84.1 (78.9)	27.0-50.25 (34.6)
Jeypore PMS	51.8-86.6 (71.0)	20.6-33.0 (27.0)
Emami PMS, Balasore	37.4	12.2
Press mud, Aska Sugar Factory	2.8	4.5
Dolomitic limestone	192.05	55.0
Chilika liming material (shell)	190.15	47.5

Source: Jena (2008)

* Effective neutralizing value (ENV) is a quality index used to express the effectiveness of liming material in neutralizing soil acidity. The quality index is based on both purity and fineness.

** Figures in parenthesis are mean values.

Harmful effects of over-liming

One of the most detrimental effects of over-liming is the alteration of the physical properties, rather than the chemical properties in tropical soils. Soil permeability is also known to be affected by over-liming. High infiltration rates and consequent rapid leaching of bases from tropical soils are attributed to highly unstable soil structure and increased binding tendency of ferrous and aluminum oxides in soil particles. Over-liming destabilizes the soil structure, which in turn causes soil aggregates to break apart resulting in reduced permeability and inadequate drainage. The addition of lime of either calcium or magnesium to soil increases the number of small aggregates at the expense of larger ones.

Pulp and paper mill effluents

Huge quantities of effluents are generated from pulp and paper, tannery and textile industries that could be used in managing acid soils. Paper Mill Sludge (PMS) has been tested for its suitability and found to be a good and cheap source compared to calcite and dolomite. Table 4.4. gives an estimate of available PMS in Odisha.

Lime sludge is a solid waste produced while converting wood/bamboo chips into pulp in the paper industry. Its major component is $CaCO_3$; it contains low levels of potentially toxic heavy metals and can be a cheap source of amelioration of soil acidity.

Integrated Nutrient Management (INM)

Integrated Nutrient Management constitutes the use of lime, organic manure and inorganic fertilizers, and is often recommended to increase crop productivity in acidic soils. Besides better soil aggregation, narrow

Table 4.4. Annual availability of PMS in Odisha.

Paper mill	Annual production (m t)
Emami Paper Mill, Balasore	25,000
JK Paper Mill, Rayagada	30,000
Sewa Paper Mill, Koraput	2,500

Source: Jena (2008).

fungal:bacterial biomass ratio, greater number of earthworm casts and greater diversity in bacterial community are some significant positive aspects of INM in acidic soils.

Phospho-gypsum (PG) or gypsum

Chemically, gypsum ($CaSO_4.2H_2O$) is a neutral salt with no direct effect on soil pH. However, many researchers have shown that phospho-gypsum, a by-product in the production of phosphoric acid from phosphate ore and sulfuric acid, can ameliorate sub-soil acidity and hasten root development. This is very relevant in rainfed ecosystems where the absorption of water and nutrients is limited due to poor development of the root system.

Growing acid-tolerant crops

Aluminium toxicity limits crop production in acidic soils, to which soil liming is the answer. However, considering the huge quantities of lime and associated costs involved in amelioration of these soils, growing acid-tolerant crops and cultivars might be a viable alternative. Blueberries, potatoes and watermelons tend to be more acid tolerant than crops like corn, soybean, wheat, alfalfa and clover. There is considerable variability in Al tolerance among plant species, which has enabled breeders to develop Al-tolerant cultivars and study the physiology and biochemistry of Al tolerance in germplasm. Wheat has proven to be a useful candidate in this respect, with up to 10-fold difference in Al tolerance among its genotypes compared to other cereals (Prochnow, 2014). Paddy is a good choice because flooding neutralizes the acidity and associated negative effects where water is abundantly available.

Agroforestry systems such as multi-storey cropping systems can also reduce erosivity of raindrops and leachability of nutrients. The system's ability to reduce soil acidity depends on the tree species and the structure of the agroforestry system. Baggie et al. (2000) investigated the potential of organic residues from nitrogen fixing trees such as *Albizia zygia* and *Gliricidia sepium* to ameliorate acid infertile rice soils. It was revealed that after four weeks of incubation, *A. zygia* and *G. sepium* increased the pH of the soil from 4.4 to 5.1 and 5.3, respectively as these species exude basic cations into the rhizosphere.

Organic manure as an amendment

Both logistic and economic reasons make it impractical for resource poor farmers to apply high quantities of lime in acidic soils. This has led to exploring alternatives. Organic materials of plant and animal origin have been known to improve the fertility, structure and biological properties of soil, in addition to reducing soil acidity or associated Al saturation. The magnitude of soil pH increase depends on the type of organic manure, its rate of application and buffering capacity of the soil. It was found that the application of 20 t/ha and 40–50 t/ha of organic residue increased soil pH by 0.2–0.6 and 0.8–1.5 units, respectively (Noble et al. 1996). Application of organic manure to acidic soils has a direct effect on soil organic matter content, amelioration of Al toxicity and reduction in soil acidity. This is mainly attributed to the complexation process in the soil (Wong and Swift 2003).

It was also demonstrated that pig stay manure was more effective than $CaCO_3$ in ameliorating Al toxicity in red acidic soils. Addition of green manure and animal waste to acidic soils reduced Al toxicity and increased crop yields (Hue 1992). Other effects may include the enrichment of soil fertility, improving soil physical characteristics and augmenting microbial activities.

Similarly, using biogas slurry, crop residues and organic materials like biochar could be the right choices to manage acidic soils. Pyrolytic biochar can be used as a soil amendment to improve soil fertility and reduce soil acidity (Steiner et al. 2007; Chan et al. 2008). The ameliorative effects of direct incorporation of plant materials into soils cannot last long, as they are rapidly decomposed by microorganisms (Xu et al. 2006). It was indicated that biochar is recalcitrant and might persist for hundreds of years in soils (Rebecca 2007). Natural coal and coal extracts have also been shown to ameliorate acidic soils and improve root growth (Yazawa et al. 2000).

Rhizosphere management and other approaches

Depending on the pH, clay, organic matter, sesquioxides and phosphorous fixing ability of acidic soils, P applied as water soluble Single Super Phosphate (SSP) is often transformed into aluminium and iron-bound complexes within 24 hours of application and may become unavailable for uptake by plants. Such fixation has been observed to be less in the case of Rock Phosphate (RP) (Bhattacharya and Singh. 1990). Under such circumstances, rhizosphere-based P management might be useful in enhancing phosphorous use efficiency in acidic soils (Kalidas-Singh et al. 2013). This involves synchronization of P mineralization rate in the rhizosphere with P uptake by the plant during various growth phases, minimizing phosphorous fixation in the rhizosphere and increasing tissue phosphorous concentration for better root development during the initial stages of crop growth.

These may be achieved by building up the population of Phosphate Solubilizing Microorganisms (PSM) in the rhizosphere, slow release of P over a long duration through combined application of PSM and RP and root dipping of seedlings in a orthophosphate solution. Phosphate Solubilizing Bacteria (PSB) can dissolve the bound forms of phosphates into available monocalcium phosphate in the soils. This occurs due to exudation of organic acids (e.g., gluconic acid), release of pathogen-suppressing metabolites like siderophores, phytohormones and lytic enzymes, and increase in phosphatases activity in the roots to hydrolyse organic P compounds to improve P acquisition by the plant (Richardson et al. 2009).

Liming the wetted zone or using calcium nitrate as nitrogen source through fertigation could be another best option to manage acidic soils. Fallow time is required for the climax vegetation to accumulate the required nutrients and for associated soil chemical and physical conditions to be established. Seed priming with water and nutrient solutions such as P and Zn is an important strategy to reduce fertiliser requirement, strengthening crop establishment and increasing crop yields (Sekiya and Yano 2010). Since nutrients or nutrient sources are directly applied to seeds, many undesirable interactions between the applied nutrient and the soil matrix (such as fixation of applied P) could be avoided.

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