Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

June 2018, Volume 31, Issue 1, Page 155-162

Managing Soil Acidity for Crop Production in Sikkim: A Policy Options

Shaon Kumar Das . R. K. Avasthe

ICAR-National Organic Farming Research Institute, Tadong, Gangtok- 737102, Sikkim

ARTICLE INFO

Article history:
Received 2016
Revision Received 2016
Accepted 2016

Key words:
Acidic soil, plant nutrients, agricultural limestone, biochar, agronomical approach

ABSTRACT

Acidic soils create production problems by limiting the availability of some essential plant nutrients and increasing that of the soil solution's toxic elements, such as aluminium, iron and manganese, the major cause of poor crop performance and failure in acidic soils. In East Sikkim, 14.9 percent area is extremely acidic, 29.4 percent area is very strongly acidic, 28.7 percent area is strongly acidic, 18.3 percent area is moderately acidic and 6.5 percent area is slightly acidic in reaction. In North Sikkim, 9.3 percent area is extremely acidic, 18.5 percent very strongly acidic, 34.6 percent strongly acidic, 24.4 percent moderately acidic and 6.5 percent slightly acidic in reaction. In South Sikkim, 30.8 percent area is moderately acidic, 23.4 percent strongly acidic, 18.2 percent slightly acidic, 9.2 percent very strongly acidic and 4.4 percent extremely acidic in reaction. In West Sikkim, 38.9 percent area is moderately acidic, 32.3 percent strongly acidic, 14.2 percent slightly acidic, 9.0 percent very strongly acidic and 2.6 percent extremely acidic in reaction. Strongly to extremely acidic soils (pH<5.5) predominate in 73% of the cultivated area of East district, 62% of cultivated area of North, 44% of the cultivated area of West and 37% of the cultivated area of South district of the state Sikkim. Much technology to make acid infertile soils productive and profitable on a long-term sustainable basis is available, but it needs to be adapted and applied locally. The most commonly used liming material is agricultural limestone, the most economical and relatively easy to manage source. Using locally available weed biomass for making biochar provides unique opportunity to landholders in organic agriculture to manage soil acidity. Now a day's agronomical approach draw more attention for soil acidity management due to economically viable and environmental friendly approach.

1. Introduction

There are four major reasons for soils to become acidic: rainfall and leaching, acidic parent material, organic matter decay, and harvest of high-yielding crops. Wet climates have a greater potential for acidic soils. In time, excessive rainfall leaches the basic elements (calcium, magnesium, sodium, and potassium) from soil profile that prevent soil acidity. Harvest of high-yielding crops plays the most significant role in increasing soil acidity. During growth, crops absorb basic elements such as calcium, magnesium, and potassium to satisfy their nutritional requirements. As crop yields increase, more of these lime-like nutrients are removed from the field.

Compared to the leaf and stem portions of the plant, grain contains minute amounts of these basic nutrients. Therefore, harvesting high-yielding forages such as napier grass and berseem affects soil acidity more than harvesting grain does. It is observed that inceptisols are dominant (42.84%) followed by entisols and mollisols occupying 42.52% and 14.64% respectively. The area under acid soil having pH <5.5 of the state is 683.49 sq. km which is 53.0% of the geographic area. Similarly, percentage area under Zn deficiency (<0.6 mg kg^{-1}) in Sikkim is 15.69% (202.35 sq. km) of the geographic area having highest Zn deficiency in South Sikkim district (82.07 sq. km, 19.1% of TGAD) followed by East (56.84 sq. km, 13.3% of TGAD), West (48.91 sq. km, 15.7 of TGAD), and North (14.53 sq km, 11.8% of TGAD). Percentage area under Mn deficiency(<3.5 mg kg^{-1}) in Sikkim is 10.16%

*Corresponding author: shaon.iari@gmail.com

(131.02 sq. km) of the geographic area having highest Mn deficiency in South Sikkim (48.72 sq. km, 11.3 of TGAD) followed by East (34.52 sq. km, 8.1% of TGAD), North (28.82 sq. km, 23.13% of TGAD) and West (18.96 sq. km, 6.1% of TGAD). Strong soil acidity needs reclamation measure in organically rich soils of the state having very good prospects for sustainable agricultural development with steady maintenance of soil health.

2. Soil Reaction of different District

Soil reaction of East Sikkim

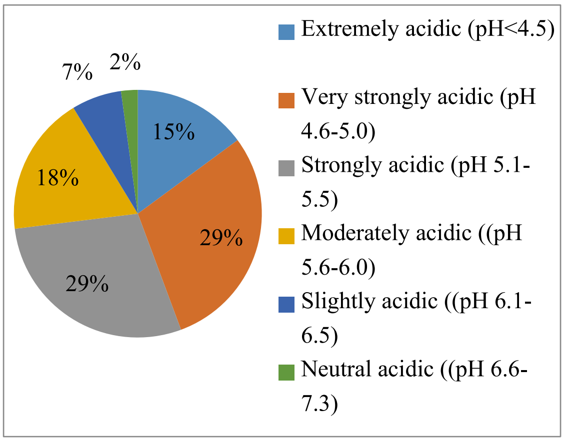
The soils of East Sikkim district have been grouped under six soil reaction classes according to Soil survey manual (IARI 1970). The soil pH ranges from 3.0 to 7.3. Majority area is acidic in nature (97.8% of TSA), in which 14.9 percent area is extremely acidic, 29.4 percent area is very strongly acidic, 28.7 percent area is strongly acidic, 18.3 percent area is moderately acidic and 6.5 percent area is slightly acidic in reaction. Only 2.2 percent of the study areas in the district have neutral soils.

Table 1. Different soil reaction classes in East Sikkim district

Soil reaction	Area (ha)	% of TSA
Extremely acidic (pH<4.5)	6335	14.9
Very strongly acidic (pH 4.6-5.0)	12534	29.4
Strongly acidic (pH 5.1-5.5)	12223	28.7
Moderately acidic ((pH 5.6-6.0)	7769	18.3
Slightly acidic ((pH 6.1-6.5)	2776	6.5
Neutral acidic ((pH 6.6-7.3)	925	2.2
Total study area (TSA)*	**42562**	**100.0**

**Study area includes cultivated land and its fringe areas only*

Figure 1. Soils under different reaction classes in East Sikkim district



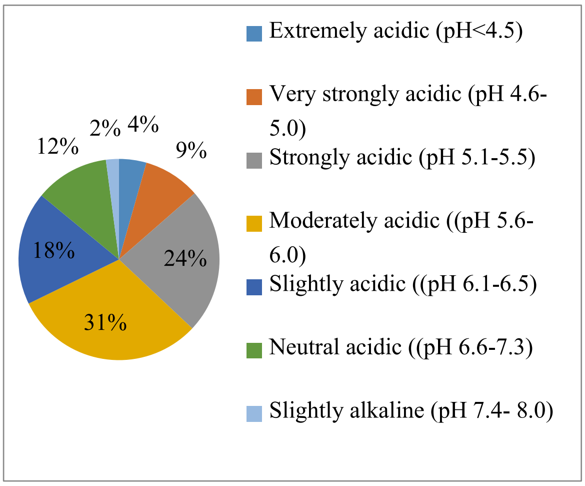
Soil reaction of North Sikkim

The soil reaction (pH) ranges from 3.8 to 8.0. Majority area is acidic (93.3% of TSA), in which 9.3 percent area is extremely acidic, 18.5 percent very strongly acidic , 34.6 percent strongly acidic, 24.4 percent moderately acidic and 6.5 percent slightly acidic in reaction. Soils of 4.5 and 2.2 percent area of the cultivated land and neutral and slightly alkaline in reaction respectively.

Table 2. Soils under different soil reaction classes in North Sikkim district

Soil reaction	Area(ha)	% of TSA
Extremely acidic (pH<4.5)	1152	9.3
Very strongly acidic (pH 4.6-5.0)	2295	18.5
Strongly acidic (pH 5.1-5.5)	4286	34.6
Moderately acidic ((pH 5.6-6.0)	3014	24.4
Slightly acidic ((pH 6.1-6.5)	802	6.5
Neutral acidic ((pH 6.6-7.3)	553	4.5
Slightly alkaline (pH 7.4-8.0)	270	2.2
Total study area (TSA)	**12372**	**100.0**

Figure 2. Soils under different reaction classes of North Sikkim District



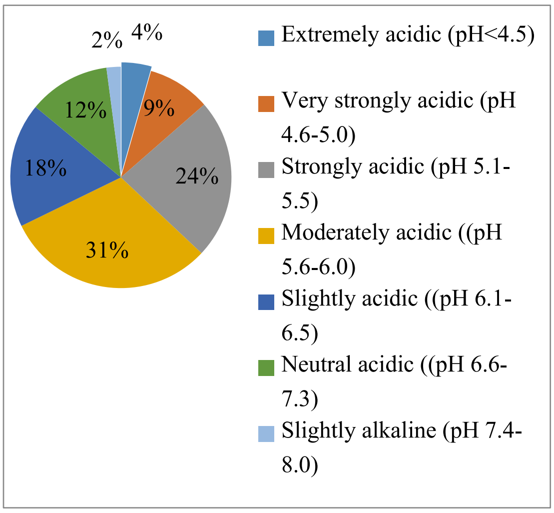
Soil reaction of South Sikkim

The soil reaction (pH) ranges from 4.0 to 8.40. Soils of 97.9 percent area of the cultivated land and its fringe area are acidic in which 30.8 percent area is moderately acidic, 23.4 percent strongly acidic, 18.2 percent slightly acidic, 9.2 percent very strongly acidic and 4.4 percent extremely acidic in reaction. Soils of 11.9 percent area of the cultivated land and its fringe area are neutral and 2.1 percent area is slightly alkaline in reaction.

Table 3. Soils under different soil reaction classes in South Sikkim district

Soil reaction	Area (ha)	% of TSA
Extremely acidic (pH<4.5)	1896	4.4
Very strongly acidic (pH 4.6-5.0)	3942	9.2
Strongly acidic (pH 5.1-5.5)	10078	23.4
Moderately acidic ((pH 5.6-6.0)	13241	30.8
Slightly acidic ((pH 6.1-6.5)	7828	18.2
Neutral acidic ((pH 6.6-7.3)	5131	11.9
Slightly alkaline (pH 7.4- 8.0)	900	2.1
Total study area (TSA)	**43016**	**100.0**

Figure 3. Soils under different reaction classes of South Sikkim



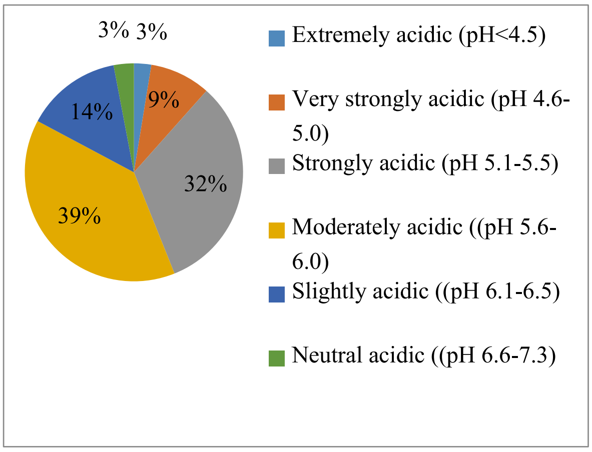
Soil reaction of West Sikkim

The soil pH ranges from 4.02 to 7.76. Soils of 97.0 percent area of the cultivated land and its fringe area are acidic in which 38.9 percent area is moderately acidic, 32.3 percent strongly acidic, 14.2 percent slightly acidic, 9.0 percent very strongly acidic and 2.6 percent extremely acidic in reaction. Soils of 3.0 percent area of the cultivated land and its fringe area are neutral and 2.1 percent area of the district are neutral.

Table 4. Soils under different soil reaction classes in West Sikkim district

Soil reaction	Area (ha)	% of TSA
Extremely acidic (pH<4.5)	797	2.6
Very strongly acidic (pH 4.6-5.0)	2794	9.0
Strongly acidic (pH 5.1-5.5)	10044	32.3
Moderately acidic ((pH 5.6-6.0)	12060	38.9
Slightly acidic ((pH 6.1-6.5)	4413	14.2
Neutral acidic ((pH 6.6-7.3)	928	3.0
Total study area (TSA)	**31036**	**100.0**

Figure 4. Soils under different reaction classes of West Sikkim



3. Soil reaction of Sikkim

Only 7.9% of total survey area (TSA) of the state was occupied by extremely acidic soils (pH < 4.5), whereas , very strongly acidic (pH 4.6-5.0), strongly acidic (pH 5.1-5.5) and moderately acidic soils (pH 5.6-6.0) occupied an area of 16.7%, 28.4% and 28.0% of TSA, respectively. Soils with strongly to extremely acidic reaction (pH< 5.5) together constitute 53.0% of TSA of the state, being predominant in East (73% of TSA) and North (62.4% of TSA) district of Sikkim. Only 12.3% and 5.8% of TSA of the state comprise slightly acidic (pH 5.6-6.5) and neutral soil reaction (pH 6.6-7.3), whereas, 0.9% of TSA of the state consists of slightly alkaline soils (pH 7.4-8.0). Neutral to slightly alkaline soils (pH 6.6-8.0) occupied 14.0% of TSA of South Sikkim district.

Table 5. Soils under different soil reaction classes Sikkim

Soil reaction	Area (ha)	% of TSA
Extremely acidic (pH<4.5)	10191	7.9
Very strongly acidic (pH 4.6-5.0)	21542	16.7
Strongly acidic (pH 5.1-5.5)	36635	28.4
Moderately acidic ((pH 5.6-6.0)	36119	28.0
Slightly acidic ((pH 6.1-6.5)	15866	12.3
Neutral acidic ((pH 6.6-7.3)	7482	5.8
Slightly alkaline (pH 7.4-8.0)	1161	0.9
Total study area (TSA)	**128996**	**100.0**

4. Management options

Soil acidity can be corrected easily by liming the soil, or adding basic materials such as biochar *etc.* to neutralize the acid present. The most commonly used liming material is agricultural limestone, the most economical and relatively easy to manage source.

Using locally available weed biomass for making biochar provides unique opportunity to landholders in organic agriculture to manage soil acidity. Biochar play a major role in organic agriculture for soil acidity management by improving existing best management practices, not only by decreasing nutrient loss through leaching but also improving soil productivity. Besides now a days agronomical approaches draw more attention for soil acidity management due to economically viable and environmental friendly approach. Liming is the most desirable practice of amelioration of acidic soils having pH of less than 5.5. Lime requirement of soils of North Eastern Regions of the country is generally calculated using the data on pH, organic carbon, clay content, and CEC of soils (Fox and Kamprath 1970; Patiram 1996). Continuous liming of soils would be effective to bring soil reaction to an optimum level being favorable for wide spectrum of crops including cereals like rice, wheat, maize, pulses like black gram, green gram, soybean, oil seeds like linseed, mustard, rabi vegetables and large number of sub tropical fruits. Cost effective liming materials are available in north eastern states of the country as paper mill by products like lime sludge, basic slag, paper mill sludge, *etc.* with cheap prices (Sharma *et al.,* 2006).

Agricultural limestone

The liming of soils is commonly done by adding oxides, hydroxides or carbonates of calcium or magnesium. These compounds are referred to as agricultural limes. They are relatively inexpensive, comparatively mild to handle and leave no objectionable residue in the soil. Agricultural lime dissolves in the soil, calcium (Ca) moves to the surface of soil particles, replacing the acidity. When you apply lime, consider the size of the reservoir or buffering capacity. Typically, clay soils have a larger reservoir than sandy ones, which means that they require more lime to achieve a favourable pH. Pay attention to the buffer index or pH on the soil test because it is an indirect estimate of the soil reservoir's size. Lime rates based on exchangeable aluminium have been found adequate for maize production and considerably less than those required to bring the soil pH to 6.5. The amount of liming materials required is crop specific and is calculated by estimation of lime potential and lime requirement of soils and neutralizing values ($CaCO_3$ equivalent) (Avasthe *et al.,* 2014). Application of lime stone @ 4t/ ha resulted optimum yield for wheat and maize in a sequence in the state. It is therefore, recommended that half the amount of limestone (2t/ ha) is needed for sustained production of wheat-maize cropping system in Sikkim state. Application of liming materials in furrows is always preferred than broadcast in terms of unnecessary wastage of liming materials. Considerable increase in maize yield has been observed by furrow application of limestone by applying only 250kg/ ha per year (Avasthe *et al.,* 2014), whereas broadcast application of limestone requires higher doses. The general recommendation for liming materials at different pH for the Sikkim state as per the standard lime requirement guidelines (Patiram 1996) may be depicted in Table 6. The preferred pH of different crops grown in the state may be depicted in Table 7 and Fig 5.

Table 6. Lime requirement at variable pH

Range of pH	Limestone (t/ha)	Burnt lime (t/ha)	Hydrated lime (t/ha)
4.5-4.9	17-15	9.4-8.3	12.8-11.3
5.0-5.4	14-12	7.7-6.6	10.5-9.0
5.5-5.9	11-8	6.1-4.4	8.3-6.0
6.0-6.4	7-5	3.9-2.8	5.3-3.8
6.5-6.9	4-2	2.2-1.1	3.0-1.5

Table 7. Preference of crops to different soil reaction

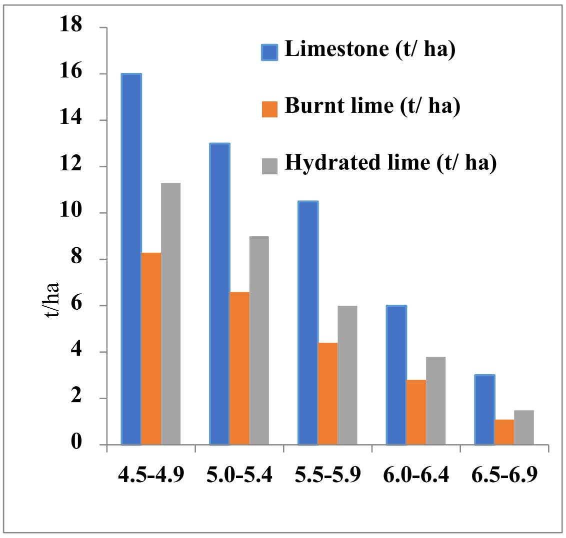
Field crops	**Preferred pH range**	**Field crops**	**Preferred pH range**
Maize (*Zea mays*)	5.0-6.5	Pea (*Pisum sativum* L.)	5.5-7.0
Millets	4.0-6.0	Lentil, gram *etc.*	5.5-7.0
Rice (*Oryza sativa* L.)	4.0-6.5	Sugarcane (*Saccharum officinarum* L.)	6.0-7.5
Sorghum (*Sorghum vulgare* L.)	6.0-7.5	Cotton (*Gossypium hirsutum*)	5.0-5.5
Wheat (*Triticum aestivum*)	6.0-7.5	Potato (*Solanum tuberosum* L.)	5.0-5.5
Barley (*Hordeum vulgare* L.)	6.0-7.5	Sugar beet (*Beta vulgaris*)	6.5-8.0
Oats (*Avena sativa* L.)	5.0-7.5	Tobacco (*Nicotiana tabacum*)	5.5-7.5
Rye (*Secale cereale*)	5.0-7.0	Cowpea (*Vigna sinensis*)	5.0-6.5
French bean (*Phaseolus vulgaris* L.)	5.5-7.0	Sunflower (*Helianthus annus*)	6.0-7.5
Barseem (*Trifolium alexandrinum*)	6.0-7.5	Tea (*Camellia sinensis* L.)	4.0-6.0
Groundnut (*Arachis hypogaea* L.)	5.0-6.5	Soybean (*Glycine max* Merr.)	5.5-7.0

The desirable soil pH range for most of the field crops is 6.0 to 7.0. Shoemaker *et al.* (1961) buffer method is used for determination of lime requirement of an acid soil. The amount of lime in terms of pure calcium carbonate required to bring the soil pH to the desired level (6.0, 6.4 and 6.8) can be observed from the following table 8.

Table 8. Lime requirement of an acid soil

pH of soil buffer suspension (field soil sample)	Lime required to bring pH down to indicated pH (tons of $CaCO_3$/acre)		
	pH 6.0	pH 6.4	pH 6.8
6.7	1.0	1.2	1.4
6.6	1.4	1.7	1.9
6.5	1.8	2.2	2.5
6.4	2.3	2.7	3.1
6.3	2.7	3.2	3.7
6.2	3.1	3.7	4.2
6.1	3.5	4.2	4.8
6.0	3.9	4.7	5.4
5.9	4.4	5.2	6.0
5.8	4.8	5.7	6.5
5.7	5.2	6.2	7.0
5.6	5.6	6.7	7.7
5.5	6.0	7.2	8.3
5.4	6.5	7.7	8.9
5.3	6.9	8.2	9.4
5.2	7.4	8.6	10.0
5.1	7.8	9.1	10.6
5.0	8.2	9.6	11.2
4.9	8.6	10.1	11.8
4.8	9.1	10.6	12.4

Figure 5. Lime requirement at various pH for soils of Sikkim



Biochar as soil ameliorant

Biochar is carbon rich charcoal-like substance created by heating biomass in limited oxygen condition through a process known as pyrolysis. The current availability of biomass in India (2010-2011) is estimated at about 500 million tons/year. In India, about 435.98 million tons of agro-residues are produced every year, out of which 313.62 million tons are surplus. These residues are either partially utilized or un-utilized due to various constraints. Locally available weed biomass which are not economically important and cause considerable crop loss can be used as an important source of biomass for preparation of biochar. ICAR-National Organic Farming Research Institute, Tadong, Gangtok has identified six weeds species around their research farm *viz. Ageratum* spp., *Lantana* spp., *Artemisia vulgaris*, *Chromolaena odorata*, *Bidens* spp., *Neyraridia* spp. and utilized their biomass to prepare biochar. The effect of weed biochar addition on soil pH (clay loam) was observed to determine the liming potential of biochar. Biochar is basic in nature (pH > 7.0). It can react similarly as agricultural lime does *i.e.* by increasing soil pH (upto 1 point increase in pH). Biochar should be applied along with other inputs like compost or manure at the same rate every year to realize the actual benefits. Application rates of these organic inputs can be reduced as biochar also contains some nutrients (Das et al. 2014). It was found that rates between 5-10 t/ha (0.5-1 kg sqm) have beneficial effect on soil properties and crop yield. Our studies showed that biochar increases/improves soil moisture retention upto 20%, nutrient use efficiency upto 15%, CEC upto 35% and crop productivity upto 30%. Biochar increases grain yields (≥15%) by decreasing leaf SPAD value at sites with low P availability in upland rice (Das and Avasthe 2016). Thus, biochar can be explored as an example of using a lesser important waste material that is produced as a by product of burning of fuel to the benefit the agricultural system through scientific technology.

Conservation agriculture practices

Conservation tillage systems often increase soil pH. In conservation agriculture soil is minimum disturbed, ground cover and residue recycling, somewhat follow the principles of closed ecosystems and reduces the chances of soil acidity. In contrast conventional agriculture practices follow the clean cultivation concept and plant material is removed from the eco-system as in the harvest of grain or the making of hay then the eco-system is left more acid.

Table 9. Generation and surplus of crop residues in Sikkim

State	Residue generation (MNRE, 2009)	Residue surplus (MNRE, 2009)	Residue burned (IPCC coeff.)	Residue burned (Pathak *et al.*, 2010)
	Million t/yr			
Sikkim	0.15	0.02	0.01	0.01

**Source: IARI (2012)

Organic manures application

Most people recognize the value of animal waste as a plant nutrient source or soil amendment, but the potential of manure, especially poultry litter, to neutralize soil acidity and raise soil pH is less known. When manure is applied to soil, nitrification and decomposition produce various acids. It releases H^+ into soil solution (Das et al. 2014). The organic matter added with manure acts as pH buffer, releasing H^+ in response to the addition of alkaline materials and accepting H^+ in response to the addition of acidic materials. Some solid manure also contains significant concentrations of Ca, Mg and lime. The organic matter and lime-like materials in solid manure tend to offset the acidity produced when the NH_4 in the manure is converted to NO_3. Application of solid cattle manure moves soil pH towards neutrality in acidic (Benke *et al.,* 2009), thus improving nutrient availability especially for P and micronutrients (Das 2014). Researchers found that poultry manure is as effective as lime in raising soil pH and in reducing aluminium toxicity.

Flooded land

Maintaining the reduced condition of flooded (anaerobic) soil inhibits acid development, which requires oxidation. This solution almost limits the use of the area to rice growing. Unfortunately droughts occur and can in short period cause acidification of these soils.

Method of raising plant

Older seedlings raised in nursery on good soil should be used. Planting of old seedling of rice showed higher degree of resistance to survive under acidic soil over the new seedlings of rice.

Crop Selection

Selection of crops tolerant to acidity is an effective tool to counter this soil problem and breeding of such varieties is of specific importance for attaining higher productivity particularly in the areas where liming is not economical.

Crop intensification with rotation

Using crop rotations can lead to dramatic increases in soil fertility in general and maintaining the soil pH towards the neutrality in particular, help to optimize nutrient and water use by crops, and improve our soil resources.

Crop diversification

Inclusion of legume in cropping system not only economizes nitrogen requirement of cropping system but also helps in efficient utilization of native phosphorus due to secretion of certain acids that helps in solubilization of various forms of phosphorus (Fenton and Helyar, 2002). This capacity of legumes makes them efficient in native utilization of phosphorus present in different forms. Increased available P is a result of P acquisition from insoluble phosphates through root exudates.

Leaching of NO_3-N reduction

When NO_3-N is leached away it leaves that part of the soil more acidic. If the NO_3-N is taken up further down the profile there can be an increase in pH_{Ca} at the point of uptake. However, when the NO_3-N is leached below the root zone it leaves the soil profile more acidic. It qualifies the effect of each factor and indicates how the effect can be influenced.

Sub-soil mixing

Delving drags clay from the sub-soil and mixes it through the upper soil profile. This has been shown to help to raise the sub-surface soil pH and improve conditions for plant growth, but is only effective when the underlying clay is less acid than the soil being treated.

Topsoil erosion prevention

If the topsoil is removed by erosion the increase in the acidity of the soil is permanent. Similarly if the biomass is burned and the ash is washed or blown away then soil is left a little more acidic. Higher organic matter levels often mean higher levels of available nitrate nitrogen and the potential for further acidification due to leaching.

Subsurface pH monitor

On heavy soils, monitor the 10-20 cm soil layer. On lighter textured soils include the 20-30 cm layer. This is because the most acidic layer and consequently the most aluminium toxic layer for lighter textured soils are often between 15-25 cm. The surface pH_{Ca} needs to be above 5.5 to achieve adequate downward alkalinity into subsurface.

5. Policy needs

The benefits of soil acidity management in agriculture relate to soil health improvement, higher crop production and productivity and improved use-efficiency of inputs. There is a need to undertake policy-related research to quantify the benefits under a range of situations to aid policy level decisions. Some of the policy needs to manage soil acidity in agriculture are:

- ❖ Developing a soil acidity management policy for the state defining clearly various competing uses.
- ❖ Using all the available resources for management of soil health.
- ❖ Proper orientation and trainings should be conducted to bring awareness among the farming community with regard to the benefits of soil acidity management.
- ❖ Promote on farm production of inputs for soil acidity management.
- ❖ Regular soil testing to know the pH value.

Table 10. Dolomite requirement for soil acidity management in Sikkim

Net sown area under arable crops (ha)	Dolomite required (tonnes)		
	Broadcast application @ 2 t/ha	Furrow applied @ 250 kg/ha	Broadcast application @ 1 t/ha with FYM application @ 10 t/ha
60,000	1,20,000 tonnes (1st year) 60,000 tonnes (3rd year and every alternate year thereafter)	15,000 tonnes (annually)	60,000 tonnes (annually)

Conclusion

Soil acidity decreases the availability of most of the plant nutrients. It also affects adversely the important microbiological processes, such as nitrogen fixation. Several factors are responsible for the origin of acid soils. Several technologies are available to make acid infertile soils productive and profitable on a long-term sustainable basis, but it needs to be adapted and applied locally. However, among the soil acidity correction technology locally available farmer's friendly approaches pay more attention because these are the copious, economically viable and environmental friendly.

Reference

Avasthe RK, Das SK, Reza SK. (2014) Integrated Nutrient Management through Organic Sources. In:Handbook on organic crop production in Sikkim. (Eds. R. K. Avasthe, Yashoda Pradhan and Khorlo Bhutia). Published by Sikkim Organic Mission, Govt. of Sikkim and ICAR Research Complex, Sikkim Centre, Tadong, Gangtok, Sikkim. Pp. 317-328.

Benke M B, Hao X O, Donovan J T, Clayton GW, Lupwayi N Z, Caffyn P, M. Hall (2009). Livestock manure improves acid soil productivity under a cold northern Alberta climate. *Canadian J Soil Sci* 90: 685-697.

Crawford TW, Singh U, H. Breman (2008). Solving agricultural problems related to soil acidity in central Africa great lake region. CATALIST project report. Pp 64.

Das SK, Avasthe, R.K, S. K. Reza, (2014). Management of Soil Acidity. *In:* Handbook on organic crop production in Sikkim. (*Eds.* R. K. Avasthe, Yashoda Pradhan and Khorlo Bhutia). Sikkim Organic Mission, Govt. of Sikkim and ICAR Research Complex, Sikkim Centre, Tadong, Gangtok, Sikkim. Pp. 307-310.

Das SK, R.K. Avasthe, (2016) Soil Acidity Management for Higher Yields in Organic Farming. *In:* Transforming Rural Sikkim: Year Round Organic Crop Production. (*Eds.* R. K. Avasthe, Yashoda Pradhan and Khorlo Bhutia). Sikkim Organic Mission, Govt. of Sikkim and ICAR Research Complex, Sikkim Centre, Tadong, Gangtok, Sikkim. Pp. 219-222.

Das SK. (2014) Role of micronutrient in rice cultivation and management strategy in organic agriculture-A reappraisal. *Agricultural Sciences* 5(09), 765

Das SK, RK Avasthe, R Gopi. (2014) Vermiwash: use in organic agriculture for improved crop production. Popular Kheti 2, 45-46.

Fenton G, K. Helyar (2002) The role of the nitrogen and carbon cycles in soil acidification. In: Acid Soil Action Research Report. Pp 183-199.

Fox RL and Kamprath EJ. (1970) Phosphate Sorption Isotherms for Evaluating the Phosphorus Requirement of Soils. Soil Science Society of America Journal, 34, 902-907.

Helyar K R, WM. Porter (1989) Soil acidification, its measurement and the processes involved. In: Robson, A.D. (ed.). Soil Acidity and Plant Growth. Australia, Academic Press. Pp.61-101.

IARI (1970). Soil Survey Manual. All India Soil and Land Use Survey," Indian Agricultural Research Institute, New Delhi.

IARI (1912). Crop residues management with conservation agriculture: Potential, constraints and policy needs. Indian Agricultural Research Institute, New Delhi, 32 p.

Pathak H, Bhatia A, Jain N, PK Aggarwal (2010). Greenhouse gas emission and mitigation in Indian agriculture – A review. In: *ING Bulletins on Regional Assessment of Reactive Nitrogen*, Bulletin No. 19 (Ed. Bijay-Singh), SCON-ING, New Delhi, 34 p.

Patiram R (1996). Effect of limestone and farmyard manure on crop yields and soil acidity on an acid Inceptisol in Sikkim, India. *Trop Agric* 73: 238–241.

Schoenau J J, JG. Davis (2006). Optimizing soil and plant responses to land applied manure nutrients in the Great Plains of North America. *Canadian J Soil Sci* 86: 587-595.

Sharma PD, Baruah TC, Maji AK, Patiram (2006). Management of acid soils in NEH Region, Natural Resource Management Division (ICAR), Krishi Anusandhan Bhawan-II, Pusa Campus, New Delhi. Technical Bulletin, pp 14.

Shoemaker HE, McLean EO, Pratt PF. (1961). Buffer methods of determining lime requirements of soils with appre.

Slattery WS, Ridley AM, SM. Windsor (1991). Ash alkalinity of animal and plant products. *Australian J Exp Agric* 31: 321-4.

Soils of Sikkim for Optimising Land Use, NBSS Publ. 60b, 1996, ISBN: 81-85460-39-6.NBSS&LUP (2016).

Soil Series of Sikkim. NBSS Publ.105, (2004) ISBN: 81-85460-83-3

Soil Nutrient Mapping of Sikkim, (2016). NBSS Report 1086

Wong MTF, Hairiah K, J. Alegre (2004). Managing soil acidity and aluminum toxicity in tree- based agroecosystems. *In :* Below ground interaction in tropical agroecosystems concept and model with multiple plants components, M van Noordwijk, G. Cadisch and C.K. Ong (Eds), Wallingford, UK. CABI. P. 143-156.