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MANAGEMENT OF PROBLEMATIC SOILS

SOSC 5132

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Chapter 1

Introduction

1.1.Problems of soils for agricultural use

Soil is a dynamic natural body occurring in the upper few meters of the Earth's surface at the interface between the atmosphere, biosphere, hydrosphere and geosphere. A soil is both an ecosystem in itself, and a critical part of the larger terrestrial ecosystem. The soil is the largest and most chemically active reactor at the earth's surface. The physical and chemical nature of the soil at the surface of the profile greatly influences plant emergence and early growth, especially of the root system. Therefore, it has an enormous effect in controlling plant growth and the quality of the environment in which we live.

The constraints of food security and widespread poverty, as they affect development and livelihoods, are well known and are implied in Sub-Saharan region in Africa (SSA), whereby population growth at 3% supersedes agricultural production rate of 2% per annum. Although causes of food insecurity and poverty are numerous, the decline in soil fertility with resultant decreasing crop yields is generally highlighted and stressed. The global demand for food and raw materials produced by agriculture makes the further study and optimal utilization of soil resources of the earth imperative and urgent. The dilemma is feeding a fertile population from infertile soils in a fragile world (Borlaug, 1993). In science and politics the opinion prevails that the soils of different continents can supply not only the recent demands of mankind, but may fulfill all future food and agricultural product requirements of the ever growing population. In order to meet the requirements, the further study of soil resources must be given paramount importance, with particular regard to soils and soil forming processes that are associated with unfavorable fertility. Acidic and Salt affected soils are belong to those types of soils that have low fertility. They occur in various agro-ecological areas and an extent in many countries that they hinder or prevent agricultural production.

1.2. Global and national extent of the problems

World agriculture faces a wide set of soil fertility issues. Soil fertility depletion on smallholder farms is one of the fundamental biophysical root causes responsible for declining food production in Africa. Acid soils occupy a considerable area of the planet earth. For decades, soil acidity has been a major constraint to crop production throughout the world. However, in

developed nations, the use of lime to counteract acidity in high-input agriculture over the past 50 to 100 years has led to a marked decrease in the area of acid soils under cultivation and to spectacular increases in yields. There is a positive correlation between high temperature and rainfall and the occurrence of acid soils. Thus, although parent materials have distinctive influence on the development of soil acidity, rainfall & temperature appear to have been more dominant factors favoring the development of soil acidity on a global basis. Acid soils' infertility has also been reported to be one of the major chemical constraints to crop productivity in considerable areas on Ethiopian soils. The problem is especially, significant in the north-western, south-western, southern and central regions of the country which covers about 40% of Ethiopia. It occurred in areas that receive precipitation high enough to leach down soluble salts and/or basic cations appreciably from the surface layers (root zone) of the soils.

Salt affected soils occupy extensive areas and occur globally, and are extremely wide spread throughout the various continents of the world. They are found in cold (permafrost), temperate, subtropical, and tropical belts, that is, all the way from the subarctic to the equator and for south of it which have continental or arid climate and where, therefore, evapotranspiration exceeds precipitation either permanently or at least some time of the year. Salt affected soils are soils that have been adversely modified for the growth and production of most crop plants due to the presence of excessive concentrations of either soluble salts, or exchangeable sodium, or both. For agricultural purposes, salt-affected soils are regarded as a class of problem soils that requires special remedial measures and management practices.

Based on the FAO/UNESCO Soil Map of the World, the extent of salt affected soils in the world (excluding Europe) has been estimated by Massoud at 901.4 million ha. Including the estimates of the extent of salt affected soils in Europe (50.8 million ha) prepared by Szabolcs (1974), the area facing salinity and sodicity can be put at a total of 952.2 million ha. Currently, over one-third (1/3) of the developed agricultural lands in the arid and semi arid regions of the world reflect some degree of salt accumulation and have prevented the farming of additional areas of these regions.

In general, Ethiopia possessing a total land area of 11, 033,000 ha of salt affected soils [Saline + Saline phase (10,608,000 ha) and Sodic + Sodic phase (425,000 ha; 3.85%)] and it is thereof known to be the first in Africa. Following Ethiopia are Chad, Egypt and Nigeria having a total area of 8,267,000, 7,360,000 and 6,502,000 ha of salt affected lands, respectively. Moreover,

Ethiopia stands ninth in the total land area of salt affected soil among the various countries in the world, surpassed by Australia, USSR, Argentina, China, Iran, India, Paraguay, and Indonesia in this order and followed by Pakistan. In terms of a percentage of the total land, Ethiopia stands 7th in the world.

Chapter 2

Soil acidity

A soil is referred as acidic if its reaction throughout the root zone is an acid soil, precisely with pH < 7 but for the purpose of characterization and classification, acid soils may be defined as those having pH less than 5.5. Soil pH is probably the most important chemical soil parameter. It reflects the overall chemical status of the soil and influences a whole range of chemical and biological processes occurring in the soil. Because of its implications in most chemical reactions in the soil, knowing the actual value of soil pH and monitoring its changes is critical for understanding the physicochemical functioning of the soil.

Soil acidity, the prevalence of H^+ and Al^{3+} cations in the soil solution, as reflected in soil pH levels generally below 5, is widespread in the highly weathered and leached soils in the tropics (mainly *Acrisols*, *Feralsols* and *Nitisols*).

2.1. The Extent of soil acidity problem in the world and in Ethiopia

Acid soils' infertility has also been reported to be one of the most chemical constraints to crop productivity in considerable areas of the world in general and in Ethiopian highlands in particular. Soil acidity is the most prevalent problems in production of food and fiber because at least 40%, and by some estimates as much as 70%, of the world's arable land is affected, acid soils occupy a considerable area of the planet earth. With increased pressure to produce more food for the expanding population of this planet and with urbanization claiming large chunks of arable land, agriculture is pushed more and more into marginal land plagued with edaphic and other stresses, including acidity.

For decades, soil acidity has been a major constraint to crop production throughout the world. However, in developed nations, the use of lime to counteract acidity in high-input agriculture over the past 50 to 100 years has led to a marked decrease in the area of acid soils under cultivation and to spectacular increases in yields. Estimates of the total area of top soils affected by acidity throughout the world vary from 3,777, 109 to 3,950,109 ha, representing approximately 30% of the total ice-free land area of the world.

Acid soils are rampant and occupy about 41 percent of the area coverage of the country. Out of this about 28 percent are moderate to weakly acidic (pH of 5.5 - 6.7); 13.2 percent are strong to moderately acidic (pH < 5.5) and nearly one-third have aluminum toxicity problem (Schlede, 1989) (Figure 1). The problem is significant especially in the north-western, south-western, southern and central regions of the country which receive precipitation high enough to leach down soluble salts and/or basic cations appreciably from the surface layers (root zone) of the soils. These include:

➤ Gojam and Gonder (North-Western), ➤ Ilubabor, Wollega and Keffa (South-Western),

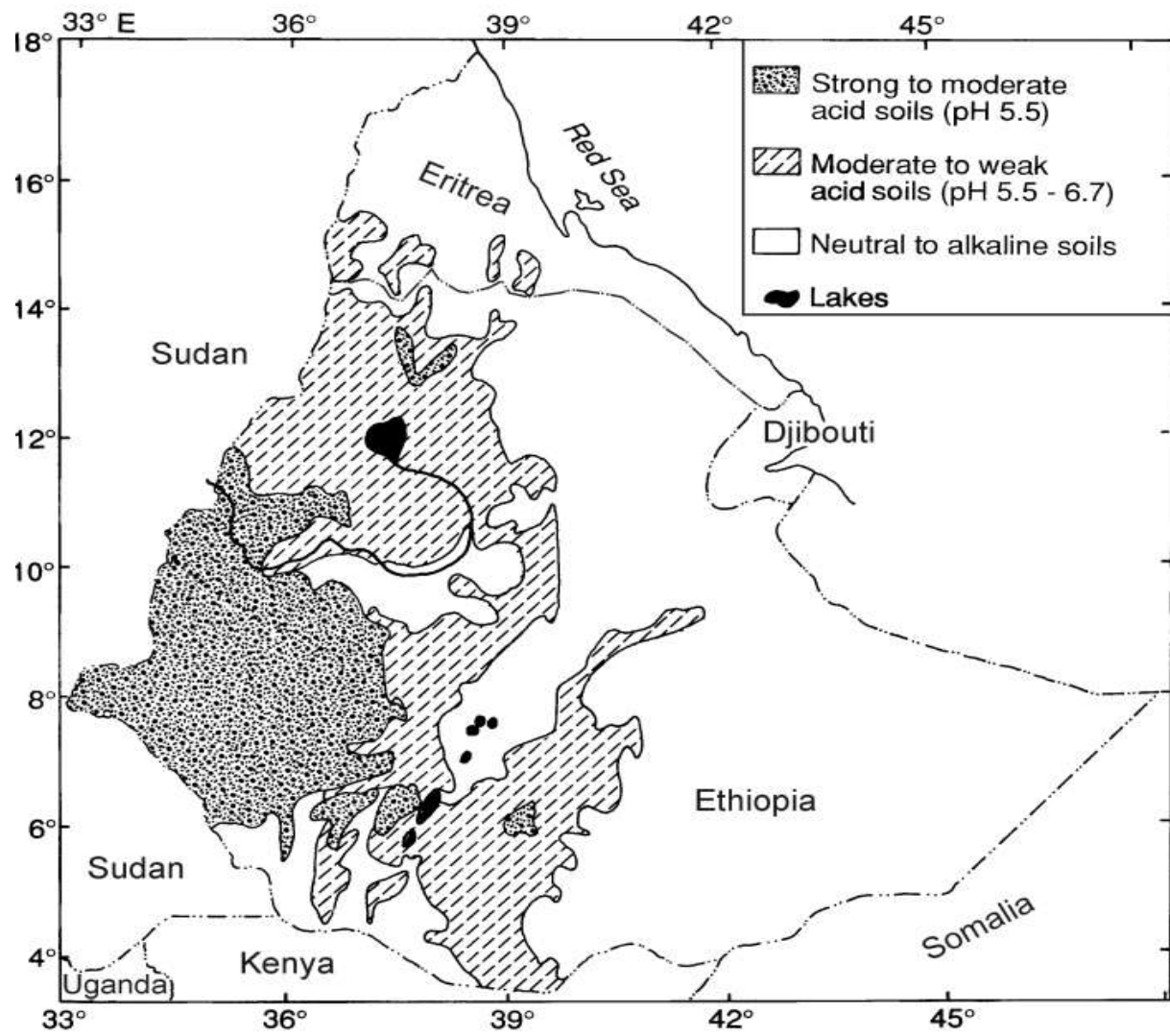➤ North Bale and North Sidamo (South) and ➤ Arsi and Shoa (Central) (Figure 1)

Figure 1. Distribution of acid soils in Ethiopia and Eritrea (Schlede 1989).

2.2. The factors responsible for soil acidity

Soil acidification is a complex set of processes, which in the broadest sense, can be considered as the sum of natural and anthropogenic processes that lowers the pH of soil solution. The natural and anthropogenic acidifying processes include:

- ➢ Acidic parent materials
- ➢ Climate, natural leaching of bases by carbonic, organic or nitric acid
- ➢ Weathering of non-acidic minerals
- ➢ Use of fertilizers
- ➢ Oxidation of pyrites
- ➢ Organic matter, humus formation (natural);
- ➢ Alumino silicate clay minerals
- ➢ Basic cations' uptake by plants, biomass harvest (which stimulate increased uptake), and
- ➢ Atmospheric inputs of lime from anthropogenic sources, or marine influences.

Usually, there exist positive correlations between high temperature and rainfall and the occurrence of acid soils. Thus, although parent materials have distinctive influence on the development of soil acidity, rainfall & temperature appear to have been more dominant factors favoring the development of soil acidity on a global basis. Vegetation, which is known to change its complex, has also contributed well in bringing about variations in acid soil characteristics. Thus, the natural causes of soil acidity are:

- ➢ Climate (high temperature and rainfall)
- ➢ Soil parent materials, and
- ➢ Vegetation
- ➢ Anthropogenic factors

Climate- climate has been well recognized that in soils of dry region, a large supply of bases is usually present, since little water passes through the soil. With an increase in rainfall, the content of soluble salts is reduced to a low level, and any calcium carbonate and gypsum present are removed. With further increase in rainfall, a point is reached at which the rate of removal of bases exceeds the rate of their liberation from non-exchangeable forms. It has been reported that in regions having an annual rainfall of up to 500 mm, most of the soils contained carbonates within the upper 50 cm depth. The depth of carbonate distribution increases as the rainfall of the region increase. With a rainfall of about 1000 mm, the soils become free of carbonates to a depth

of more than 100 cm. The soil pH ranges from 8 in areas receiving a rainfall < 400 mm to 5 in areas with rainfall of 1000 mm with concomitant increase in titrable acidity of soils.

On the other hand, in areas of high temperatures and rainfall that promote lush vegetation as in the western and southern Ethiopia, weathering intensity becomes great and this brings elements into solution. In area with strong *intensity of leaching* under high soil permeability, there would be increased removal of such elements as Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, $SO_4^=$ and HCO_3^-.

Parent materials- rocks which contain an excess of quartz or of silica as compared to their content of basic minerals or of basic elements are classed as acid rocks. Granite and rhyolite are the major examples. When rocks which are deficient in bases are disintegrated or decomposed in the process of the accumulation of soil material, it appears acidic although no loss of base has occurred during the process of soil formation. There are considerable areas of siliceous sandy soils, produced from acid parent rocks that are always been in need of lime. Most acid soils, however, have been developed as a result of leaching and crop removal of bases. Soils developed on non-calcareous bearing parent materials in humid environments will be acidic.

Aside from the oxides and carbonates, most minerals are compounds of basic elements with some of silicic or aluminosilicic acids. As these compounds are broken down by chemical weathering, at least a part of the bases pass into the carbonates or bicarbonate forms, which have an appreciable solubility and are leached away when rainfall is sufficient. On the other hand, the negative or acidic radicals of the compounds pass over in to hydrated Al silicate and acid salts of silicic acid usually with the elimination of some free SiO_2. The hydrated Al silicates are relatively insoluble and so accumulate in the soil, contributing to the soil acidity

The principal hydrous oxides of soils are Al and Fe which occurs in amorphous, crystalline, or colloidal form as coating on other mineral particles or as interlayer in clay mineral structures. When the pH of the soil decreases, these oxides get into solution and through stepwise hydrolysis reactions release H_+ ions resulting in to further acidification.

Vegetation or crop cover: Grass vegetation is less effective than forests in the weathering of parent material for the formation and development of acid soils. Thus, growing forests are themselves a cause of soil acidity. Trees and shrubs may play a role in minimizing soil acidification through the development of deep root systems capable of taking up bases such as Ca and Mg in deep layers of the soil profile and returning them to the topsoil as leaf litter

containing excess cations or ask alkalinity. Furthermore, trees and shrubs, with their deeper rooting patterns and perennial nature, have a potential to capture more soil nitrate than crops and annual pastures, thereby reducing nitrate leaching and decreasing net acid input. Plant species and genotypes differ substantially in concentrations of excess cations or ash alkalinity and their ability to produce acid and to utilize soil nitrate. It should be noted, however, that the decrease of acidity in the topsoil due to leaf litter decomposition is at the expense of increased acidification in the deep soil layer. Excess cations or ash alkalinity in leaf litter of trees ranged from 36 to 247 cmol kg^{-1}. Most eucalypt and acacia species and radiata pine had relatively low concentrations of ash alkalinity, whereas a number of northern hemisphere deciduous species had higher ash alkalinity.

Soil acidification under legumes is greater than under non-legume crops because of large excess uptake of cations over anions due to N_2 fixation and the low capacity to take up nitrate once organic N is decomposed. Plants take up cations and anions from soil solutions to satisfy their requirement for growth. The relative amounts of various ions absorbed from soil solutions by plant roots are determined by the specific plant requirements for these ions and the composition of the soil solution. In most cases, plants take up more cations than anions, with a net extrusion of H to maintain the charge balance. Many legumes, however, commonly export H ions into their rhizosphere when actively fixing N_2. The acidity generated by fixation of N_2 in legumes has been found to be equivalent to the excess uptake of cations over anions by the plant and to vary from 0.2 to 0.7 mole H per mole of fixed N. Thus, continuous legume cultivation and inappropriate nitrogenous fertilizer use have generated sufficient soil acidity that cereal cultivation has had to be abandoned due to aluminum and manganese toxicity. However, some tropical legumes do not apparently acidify their rhizospheres as much as do temperate legumes when actively fixing.

On the other hand, vegetation growth increased organic matter content of the soils. Soil organic matter or humus contains reactive carboxylic, enolic and phenolic groups that behave as weak acids. They dissociate releasing H+ ions. Furthermore, the formation of CO_2 and organic acids during decomposition also result in replacement of bases on the soil exchange complex with H+ ions. The accumulation of soil organic matter results in the breaking of nutrient cycles and thus contributes to the acidification of soils in a similar manner to the removal of alkaline produce (Figure 2).

Anthropogenic factors

Soil acidification is a slow natural process that occurs during pedogenesis and can be either accelerated or slowed down by farming practices. Application of fertilizer: some fertilizers leave an acidic residue in the soil, others a basic residue and still others seemingly have no influence on the soil pH. Soil acidification as a result of application of acid forming fertilizers is of concern in areas of heavy and sustained fertilizer use. The acid forming ability of different fertilizers is measured in terms of equivalent acidity which is the number of parts by weight of $CaCO_3$ required to neutralize the acidity resulting from the use of 100 parts of the fertilizer material, usually expressed as kg of $CaCO_3$ per 100 kg of fertilizer. The equivalent acidity of ammonium sulfate, calcium nitrate and urea is 110, 20 (excess base) and 84, respectively, while that of super-phosphate is zero. Agricultural production systems undergo accelerated soil acidification as a consequence of anthropogenic inputs and outputs. Ammonium nutrition increases and nitrate decreases soil acidification under other crops. Application of N fertilizers, such as urea and ammonium sulfate, to soils can produce H ions through oxidation of NH_4^+ ions to NO_3^- ions (nitrification). Because the NO_3^- ions are not strongly adsorbed by the soil, it is common that some of the NO_3^- ions not taken up by the crop are liable to leach or move down through the soil. The negatively charged NO_3^- ions are accompanied by positively charged basic cations, such as Ca^{+2}, Mg^{+2}, K^+, and Na^+, in order to maintain the electric charge on the soil particles. However, addition of basic nitrate fertilizers such as $Ca(NO_3)2$ and $NaNO_3$, however, causes little change or sometimes increases the soil pH, the extent of soil acidification was generally higher with ammoniac than with urea fertilizers (Figure 2).

Fertilizers vary in their rates of soil acidification. The acidifying effect of fertilizer materials is expressed as acidity equivalent. The *acidity equivalent* is defined as the number of parts of pure lime (calcium carbonate) required to neutralize the acidity caused by 100 parts of a fertilizer material.
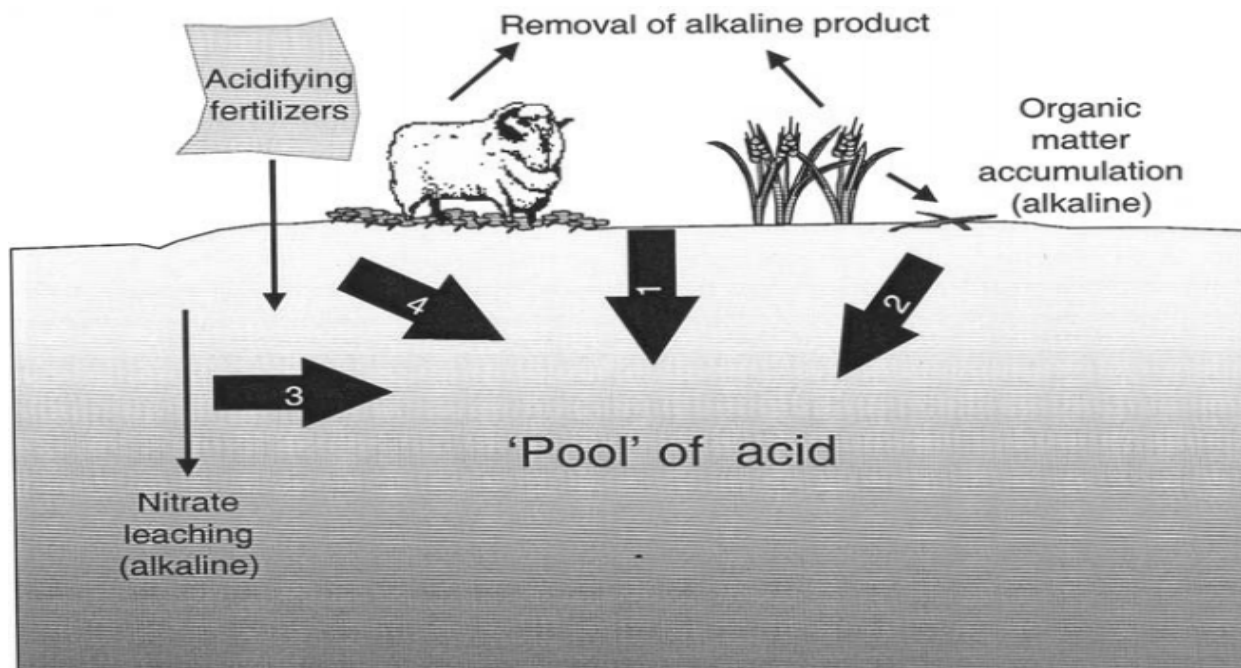
Figure 2. Schematic representation of the main sources of acidification of agricultural soils.

2.3. The effects acidity on soil properties

Major effect is poor plant growth in acid soils, thus an improvement of acidic soils leading to better crop growth through addition of limestone is known to agriculturist much earlier. There is currently much emphasis on Al and Mn toxicity as factors limiting plant growth on acid soils. Although Al and Mn toxicity may be problems on many acid soils, nutrient deficiencies such as Ca, P, N, and Mo are also widespread. As increasing the soil pH by liming can increase the availability of these nutrients, a plant response to liming cannot be assumed to be due solely to the alleviation of toxicity. Most acidic soils are Mo deficient, thus liming the legume yield. Most acid soils are also extremely P deficient, a problem usually exacerbated by the presence of active Fe and Al oxides. Large amounts of P fertilizer are required in addition to liming to make them productive.

While comparing physical constants of acid and non-acid soils of West Bengal have reported that acid soils have relatively lower bulk density but have higher water holding capacity, particle density, pore space, capillary pores and volume of expansion than adjoining non-acid soils. Lime application is known to increase the amount of total water stable aggregates and non-capillary pore space in long-term experimental plots. The lime derived Ca coagulates soil colloids, improves soil structure, and increase the stability of aggregates. The improvement of crop yields on acid soils after liming may be due to the indirect effect of better physical condition of the soil.

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Acid soils are usually deficient in Ca and sometimes in Mg as well. The P content of acid soil is usually very low. A yellowish-white incrustation is formed on the surface of acid paddy soils of when they get dried. The crust has a high concentration of sulfates with sufficient amount of Fe and Al to cause toxicity to plants.

Soil acidity not only affects physical and chemical properties of soil but also the biological dynamics of the soil as a whole. Certain groups of microorganisms are preferentially stimulated and others are retarded. Development of microbial population of the soil is limited by the food supply, which leads to competition among various organisms. In general, the competitive ability of fungi as compared to that of bacteria and actinomycetes increase with an increase in soil acidity. Soil OM decomposition and N mineralization occur less rapidly in acid soils, which are enhanced by liming. Soil acidity has long been recognized as harmful to N fixation by Rhizobia as rhizobia are sensitive to Al^{3+}, Mn_{2+} and H^+ ions' toxicity. Liming not only improves the activity of rhizobia but also that of nitrifiers.

Soil acidity can markedly decrease root growth and nutrient uptake and alter the cation/anion uptake ratio. Low pH generally decreases cation uptake but does not affect or stimulate anion uptake. Hence, low pH decreases excess cation uptake and consequently H excretion.

Some common indications of an acid soil are:

a. A prevalence of red sorrel,

b. The repeated failure of alfalfa and clover,

c. Thin or patchy stand of clover and alfalfa on soils produce good yields of other crops

d. Clover and alfalfa turning yellow in early spring

2.3. Amendment (amelioration) of acidic soils

Lime was used even before the birth of Christ to improve the productivity of acid soils. Topsoil acidity can be effectively ameliorated by liming. Liming is most commonly practiced to overcome the impact of soil acidification. The practice of liming acid soils to reduce phytotoxic levels of Al and Mn has long been recognized as necessary for optimal crop production in such soils. The practice of liming acid soils to reduce phytotoxic levels of Al and Mn has long been recognized as necessary for optimal crop production in such soils.

However, an integrated approach involving liming, management practices, and plant tolerance will probably be necessary, particularly where the acidification potential is high and acidification is likely to extend into the subsoil.

2.3.1. Liming materials

Lime is an imprecise word, for it includes calcium oxide, calcium hydroxide, and calcium carbonate. The quality of agricultural limestone in neutralizing soil acidity is to a large extent governed by its Ca and Mg content, particle size. Liming materials having an alkaline effect: the anion is either OH^-, CO_3^{2-} or SiO_4^{4-}. These are anions that forms non-dissociated or hardly dissociated combinations with H+. Some important liming materials are calcite ($CaCO_3$), dolomite ($CaMg(CO_3)2$), calcium hydroxide ($CaOH_2$), magnesium hydroxide ($MgOH_2$), calcium oxide (CaO), magnesium oxide (MgO).

Requirements of a Satisfactory Liming Material

When the chemist speaks of lime, he usually refers to calcium oxide (CaO), but from the agricultural point of view, a more general meaning is implied by the term. Agriculturally, lime may be used to indicate any compound of calcium or of magnesium capable of counteracting the harmful effects of an acid soil. It may mean the oxide, the hydroxide, or the carbonate of calcium and/or magnesium. There is no accepted word for a material that neutralizes soil acidity which must include not only the said compounds but also some slags and other calcium silicate. It may be more appropriate to use the term **liming material**. A satisfactory liming material for neutralizing acidity should meet the following requirements:

a. It should have a mild alkalizing effect to enable raise the pH of acid soil to near neutral. It should be mild in action so as to avoid harmful effects if by chance an overdose is applied,

b. It should provide a desirable proportion of cations on soil exchange complex. The added material should therefore be mostly Ca^{2+}, although some Mg^{2+} is also desirable. The material should have little or no Na^+,

c. The liming material should have a favorable effect on soil structure. The most favorable base developing crumb soil structure is Ca^{2+},

d. The material should be least expensive,

e. The accompanying anion of the material must be able to reduce the activity of H+ ion.

Thus, although Na_2CO_3 is highly effective material, it could not be recommended for neutralizing soil acidity because it has too strong an alkalizing effect, supply the wrong cation,

and is too expensive to be used as a liming material. Similarly, although gypsum ($CaSO4.2H_2O$) and $CaCl_2$ also contain Ca^{2+}, they can not be used as liming materials because they are neutral salts and have no alkalizing effect. Large amounts of neutral salt may actually lower measured soil pH. The materials commonly used for liming acid soils are oxides, hydroxides, carbonates, and silicates of calcium and magnesium.

Effectiveness of different forms of lime

The chemical effectiveness of an agricultural limestone is evaluated on the basis of its $CaCO_3$ equivalence. This is defined as the acid neutralizing capacity of the liming material expressed as weight percent of $CaCO_3$. A calcitic limestone has a lower neutralizing capacity than a dolomitic limestone because of higher atomic weight of Ca than that of Mg. Pure dolomite has a $CaCO_3$ equivalence of 108. The rate of dissolution and, hence, the effectiveness of lime is affected by the Mg content of limestone. Calcitic limestone generally reacts faster with acid soils than does dolomitic limestone (Table 1). The acid neutralizing capacity of liming materials is expressed as weight percentage of $CaCO3$. Calcitic limestone has lower neutralizing power than dolomitic limestone.

In considering the effectiveness of a liming material, it is to be remembered that the total neutralizing power is not the only factor of importance. Burned lime (CaO) is changed to hydrated lime under ordinary moist soil conditions before it has time to act chemically with the soil; consequently, it would not be expected to be more effective than hydrated lime applied directly. Theoretically, the hydrate (and oxide) form of lime can be expected to react in the soil somewhat more rapidly than finely ground limestone, because the former is a very fine powder and can therefore be more thoroughly distributed in the soil. Moreover, freshly slaked lime consists mostly of calcium hydroxide, which is more soluble in water than $CaCO_3$ of ground limestone. This difference in solubility may result in its being more thoroughly and uniformly distributed through the soil if rain follows soon after the application of lime.

Consequently, because of greater solubility and more thorough distribution in the soil, calcium hydroxide should be more active than the carbonate in producing chemical changes in the soil. It is to be emphasized, however, that calcium hydroxide will sooner or later change into the carbonate form in the soil. Under certain conditions, this change may require several weeks, and during that time the hydroxide form can be considered more chemically active than the carbonate.

However, over a period of years, or even a rotation, there seems to be little difference in the effectiveness of the various forms of lime when applied in equivalent quantities. Dolomitic stones are harder and dissolve more slowly than calcium stones, and for this reason, it is not customary to consider the higher neutralizing value of magnesium stones in determining the amount of lime to apply.

Table 1. Relative neutralizing power of different forms of lime

Form of lime	Molecular weight	Neutralizing value (%)	Pound equivalent to 1 ton of pure CaCO3
Calcium carbonate	100	100	2000
Magnesium carbonate	84	119	1680
Calcium hydroxide	74	135	1480
Magnesium hydroxide	58	172	1160
Calcium oxide	56	178	1120
Magnesium oxide	40	250	800

When to apply lime?

It is usually best to apply lime considerably in advance of seeding and mixed thoroughly with the soil. Generally speaking lime may be applied any time during the year when it is most convenient. Often however the crop rotation, farming system and the form of lime used will be the deciding factors. The legume in the rotation is often the crop most sensitive to soil acidity. It is usually best to apply lime considerably in advance of seeding legumes to permit lime to correct the acidity. When quick- reacting hydrated lime is used, it should be added at low rate and may be applied near the time of planting. When potato is taken in rotation, liming should follow it to keep the scab organism under control. In a cereal-legume rotation apply lime before cereal. On grasslands, lime could be spread at any time. If a farmer fails to get limestone applied before planting a crop, a top dressing of limestone may pay, however, it should be considered as an emergency measure, and not a practice. The dissolution rate of limestone is reduced by low temperature, hence a faster dissolution is expected in summer than in winter. The residual effect of lime usually lasts for 5-7 years.

How to apply lime?

Careful determination of lime requirements of different soils will be little good unless the lime is properly applied. The principal requirement of any method of applying lime is that it should be distributed evenly and, except when applied to pastures, it should be thorough-ly mixed with the soil. Lime, even as it dissolves, moves to no appreciable extent laterally and only to a limited

extent vertically. The only way of mixing the lime thoroughly with the soil is by tillage operations. Uneven distribution may result in patchy growth showing local shortage where liming will be necessary again. The placement of lime is important because it affects how quickly, to what depth, and over what period of time the effects of lime are required.

When large applications are used, split applications are recommended, half before plowing and rest after plowing, usually to 10-15 cm depth. Where land is deep plowed, more lime than the standard dressing will be required, because the recommendations are based on the depth of furrow slice (15 cm). Where sub-soil is also very acid, deep placement using sub-soiler, a very expensive process, is required because lime does not move in the soil appreciably.

Frequency of liming

The residual effects of liming are usually expected to last for 5-7 years. There is an increase in exchangeable aluminum with time at all but the high lime rates, possibly because of leaching of bases, uptake of calcium by crop plants, release of $H+$ ions from organic matter, and residual acidity of nitrogenous fertilizers. An annual application of 200-500 kg lime/ha/year has been reported to be adequate to maintain the level of calcium and magnesium in the soil under continuous cropping while keeping a check on the release of exchangeable aluminum. Ground limestone when used may have liming action for several years while hydrated lime and quick lime which are usually composed of fine particles and react quickly in the soil may have to be applied more frequently and at lighter rates.

The best guide for the application of lime is a periodic testing of the soil reaction within the root zone. Inspections at intervals not greater than two to three years is advisable to economize the process of amelioration and to avoid over-liming injury to plants.

Over-liming injury

Over-liming can be defined as liming at rates higher than to neutralize the exchangeable aluminum or eliminate manganese toxicity. Negative yield response to over-liming has been reported in several locations. Over-liming promotes the formation of smaller aggregates and thus, reduces infiltration, noncapillary porosity and makes the soil more susceptible to erosion. Over-liming also induces phosphorus deficiency by forming insoluble calcium phosphate. Over-liming soils high in oxide coatings greatly increase the adsorption of boron by clays and reduces the availability of boron. Lime induced Mn and Zn deficiency has also been reported.

Soils prone to over-liming

Very sandy soils with low CEC are likely to be over-limed if treated like neighboring heavy soils. Highly leached and weakly buffered soils are more prone to over-liming. If liming is necessary for these soils, it needs to be done judiciously to overcome the toxic levels of Al and Mn but not to induce nutrient deficiencies.

Escaping over-liming injury

Application of large amounts of manures, green manure crops, compost. phosphatic fertilizers and Zn, Mn & B can overcome over-liming hazards. Use of dolomitic limestone or a coarser lime may also help overcome the hazard of over-liming injury because of less solubility or slow reactivity. Hydrated lime $Ca(OH)_2$ is very reactive and has short-lived residual effect. A smaller and frequent application could be an attractive alternative to effective utilization of $Ca(OH)_2$. Light and frequent dressings of lime is especially recommended in sandy soils prone to micronutrient deficiencies. Light and frequent dressings and/or coarser lime is helpful in overcoming over-liming hazards.

2.3.2. Lime requirement

Lime requirement is determining the quantity of lime added to neutralize soil acidity. The lime requirement (LR) of an acid soil is the amount of lime or other base required to neutralize the dissociated and un-dissociated acidity in the range from initial acid conditions to a selected neutral or less acid condition. Normally, the basis of selection of the point to which the soil is to be neutralized is pH for most favorable plant growth. However, it may be based on another criterion such as inactivation of exchangeable Al, percent base saturation etc. & it is sometimes altered on the basis of economic consideration.

The LR of a soil is defined as the amount of liming material required to raise the pH to a prescribed value usually ranging from 6.0 to 7.0. It is expressed as $CaCO_3$ equivalent in meq/100 g of soil or tons of $CaCO_3$ per ha. $CaCO_3$ is chosen because the economy and growth enhancing qualities of lime make it the most common base used for neutralizing acidity. The field buffer capacity is essential for prescribing the amount of lime required to achieve the optimal pH.

Lime requirement of an acid soils is affected by its degree of weathering, clay content, organic matter content, form of acidity and buffering and CEC of soils. Burnt lime (CaO) soon changes to hydrate form of $Ca(OH)_2$. It is possible to define a process for making decisions about lime use so that all components, the soil, plant, and the agricultural system involved, are considered.

The higher the clay content of the soils, the more acidic cations can be adsorbed to the cation exchange sites. Also, as cation exchange sites increase, the more polymerized hydroxy Al ions accumulate between the layers of the clay crystal. Yet less water may percolate through a fine textured than coarse textured soil. Hence, a fine textured soil usually has a higher base saturation than a similarly exposed coarser textured soil. However, at the same level of pH, a fine textured soil requires greater amount of lime than a coarse textured soil for bringing them to same desired level pH improvement.

Methods of lime requirement methods

There are numerous methods of estimating the lime requirement of soils in the world.

Laboratory methods are commonly employed for estimating lime requirement. These methods vary from simple qualitative and indirect tests to more quantitative and direct lime requirement methods involving determination of exchangeable hydrogen, exchange acidity, soil reaction and methods that determine readily available calcium supply.
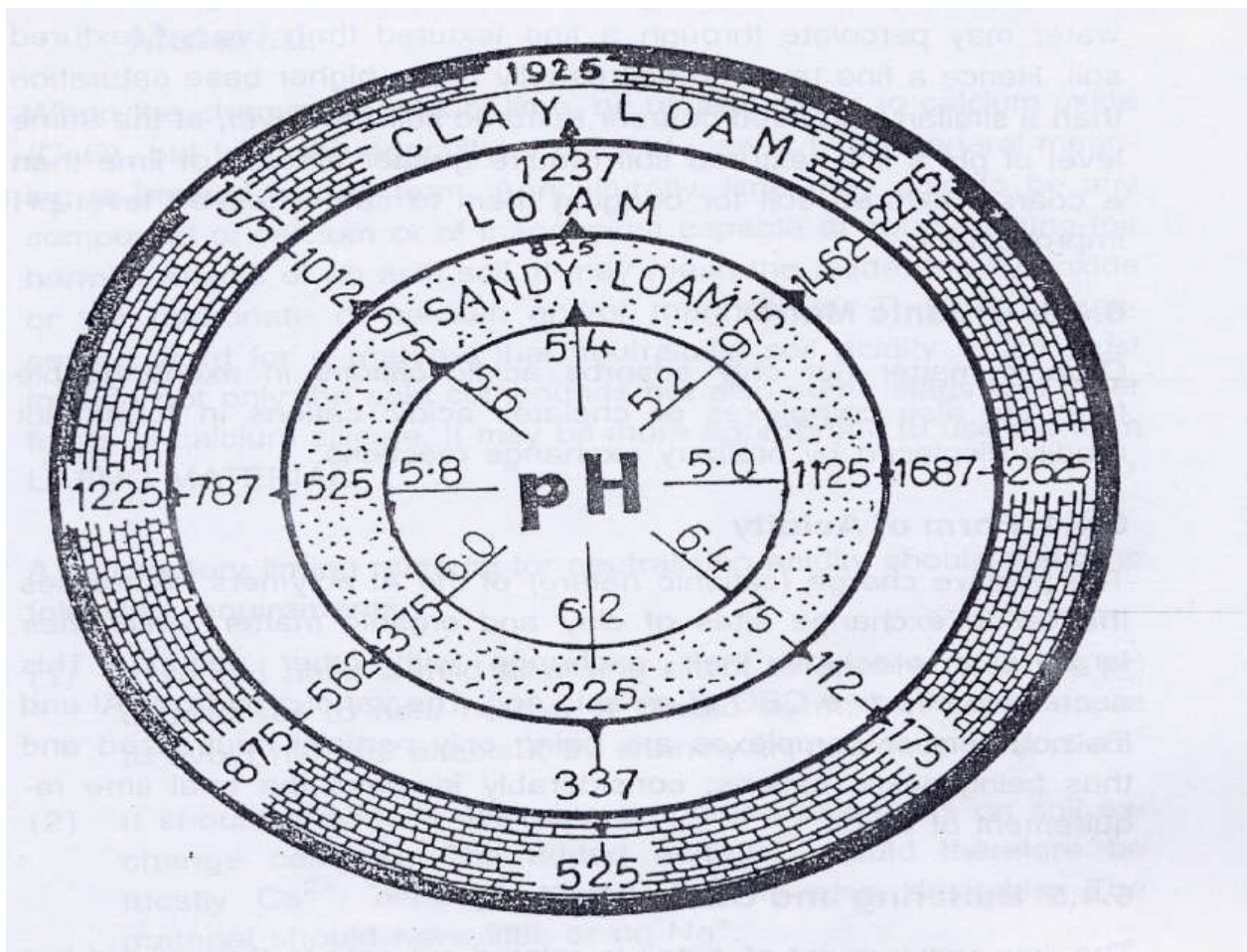

Figure 2. Ready-reckoner determining lime needs of different soils (kg/ha)

❖ Shoemaker *et al.* (1961) found that lime requirement through Buffer method of to be relatively more accurate one and especially well adopted for soils requiring more than 400 lbs lime per acre, having pH value from 5 to 8 and containing less than 10 per cent organic matter. But, it over estimated for the acid soils containing less amount of exchangeable acidity.

❖ As per Kamprath (1970) reference LR is estimated based on the exchange aluminium content of the soils Lime requirement = 1.54 (EAI)

Where as EAI is the 'Extractable Aluminium Index' obtained by extracting 5 g soil with 50 ml of 0.2 N NH_4Cl.

❖ For Ethiopian soils lime requirement determined based on the following equation

LR = LRF (EA-PAS% x*ECEC)*

Whereas LR= Lime requirement (t/ha)

EA= Exchangeable Acidity =Al + H ions

PAS= Permissible Acid Saturation

ECEC= Effective Cation Exchange Capacity

Acid saturation percentage= $\underline{\text{Exchangeable acidity}}$ x100

ECEC

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases (Ca_{2+}, Mg_{2+}, Na_+ and K_+) extracted by the NH_4OAc method and exchangeable acidity determined by 1N KCl extraction method.

ECEC (cmol$_c$kg^{-1}soil)=Ca^{2+}+Mg^{2+}+Na$^+$+K$^+$+ Exchangable acidity

Permissible acid saturation (PAS) for different crops

Some cultural practices used for amelioration of acidic soils

There are considerable literature evidences suggesting that application of wood ash and manure can be used for the control of acidity related problems. An alternative liming materials such as manure and wood ash application can increase plant growth in acid soils by ameliorating Al toxicity. Wood ash contain Ca and/or Mg compounds that displace H, Fe and Al ions from soil colloids, thus wood ash has liming effect. Wood ash had neutralizing value of 72 %,. Optimum application of wood ash can amend acid soil. Manure has liming effect besides organic manures act as a nutrient source. Several studies revealed that applications of manures on acid

soils increases soil pH and a decrease in Al solubility. Moreover, incorporating organic residues has substantial liming effect to acidic soils also.

Effective methods used to control and protect the problem

An integrated used limestone with organic sources fertilizers has the synergetic effect on ameliorating acid soils problem. Thus, combined use of soil ameliorants and organic and inorganic fertilizers has great effects on minimizing the problem and increasing crop yield.

2.4. Subsoil acidity problem

In many highly weathered acid soils, subsoil acidity has been observed to limit plant growth in spite of the fact that the plow layer is adequately limed. Root growth is curtailed in subsoil horizons of such soils as a result of Al toxicity and calcium deficiency. Restricted root growth makes the water stored in subsoil unavailable to plants. Water stress during temporary drought is easy to foresee under such conditions.

Many soils in natural ecosystems and under permanent pastures have a higher surface than subsurface pH. This trend is the outcome of an amelioration of the acidifying processes in the surface soil by the deposition and oxidation of organic anions at or near the surface ($RCOO + H_+$ $H_2O + CO_2$). Moreover, if nitrate uptake by plant occurs largely from the surface soil, acid excretion by roots will be minimized in the topsoil and maximized in deeper soil layers. Nitrate absorption is usually most of the total anion absorption which controls the balance of cation to anion absorption by roots besides excretion of $H_+/(OH_-, HCO_{3-})$.

Subsoil acidity is common in highly weathered soils where the acidity is largely derived from the parent material rather than advanced weathering process. These soils are usually located in areas receiving adequate annual rainfall, but with a growing season during which drought conditions frequently occur. High intensity rains that are characteristics of such areas, results in high runoff, which further accentuates the problem.

Acid soils have developed under humid conditions resulting in Al_{3+} occupying a large proportion of exchange sites below the normal plow depth. Subsoil acidity is mostly confined to colder climates and is certainly not limited to the warmer climates. The processes resulting in the formation of acid subsoils are very important in determining the specific nature of the problems and for recommending appropriate reclamation measures.

High temperature and rainfall are two factors that promote rapid weathering of primary as well as secondary Al-Fe-silicate minerals releasing, in the process, basic cations as well as Al and Fe

into the soil solution. The basic cations react with anions to form highly soluble salts, carbonates, and hydroxide. Aluminum and Fe ions, in the presence of salts, hydrolyze into hydrated Al and Fe with the release of H ions, acidifying the surrounding solution. In times, the hydrated Al and Fe, by themselves or by reacting with the various soil constituents, re-synthesize into amorphous or crystalline oxides and hydroxides to support high concentration of active Al in soil solution.

In areas where rainfall exceeds evapotranspiration, the highly soluble bases are leached to greater depth than are Al and Fe, leaving behind soil horizons enriched in active Al and Fe and compacted by their oxides and hydrous oxides. As the horizon becomes more acidic, more Al and Fe are solubilized from primary minerals and from their secondary oxides and. hydroxides. This leads to increased Al and Fe saturation of the exchange complex of the colloidal soil constituents and to subsoil infertility. When Al saturation of the exchange capacity exceeds 60%, appreciable amounts of Al_{3+} start to get into the soil solution. At this point, Al toxicity caused by subsoil acidity could set in.

Amelioration Technology

Liming to increase Ca_{2+} and decrease Al_{3+} would have been the answer, had the acidity been nearer the surface. Thorough mixing of lime into the target soil is necessary because downward movement is slow due to its low solubility. Moreover, its neutralization by surface acidity (H^+ and Al_{3+}) and adsorption of Ca_{2+} by pH dependent sites as a consequence of pH increase leaves less of it available for subsoil acidity. Often these soils have compacted subsoil which further complicates the problem. Loosening of subsoil under such circumstance may have to be considered as an additional requirement over and above chemical treatments.

When lime is applied to the surface of a soil having high clay con-tent with high pH-dependent charge, much of the calcium may be retained close to the site of application because a large percentage of it is used for the creation of negative charge. While the resulting increase in topsoil CEC is often highly beneficial for sustained and stable improvement in soil productivity, it is also necessary to raise the subsoil pH in order to encourage deeper root system for efficient utilization of moisture and nutrients from subsoil.

Reducing aluminum toxicity in the subsoil is a major but difficult management objective in many areas. When deeper lime incorporation is not feasible, other ways must be sought. The use of aluminum tolerant varieties is one alternative. The possibility of downward movement of Ca and Mg is another

A, Deep Mixing of Lime

For soils with serious subsoil acidity, surface application of lime may not be the practical answer to the problem. Several years were required for surface applied lime to increase soil pH to a depth of 15 cm, primarily due to low solubility and mobility of lime in soils. The reaction of lime with the soil moisture supplies the soil with both OH and HCO_3. These, however, are immediately neutralized by H at the surface. Any increase in pH in the surface soil may also increase Ca adsorption due to the extra negative charges generated in the amphoteric soil constituents.

Neutralization of the basic constituents of lime and the adsorption of Ca at the surface work to keep the ameliorative effect of lime to the surface. Thus, not only is subsoil acidity not checked by surface application of lime, but it fails to supply Ca to the deeper horizons to alleviate subsoil infertility.

The rate at which the liming material reacts with subsoil acid is governed largely by degree of mixing with the subsoil. None of the common tillage operation except rototilling was found to produce good mixing. Attempts to improve yield by deep placement of lime have not been convincing. In spite of this, the practice of deep mixing is some times recommended. Deep mixing of lime could be achieved by plowing down the surface applied lime; by plough sole application of lime or by injecting it behind a subsoiling tool. None of these methods have given satisfactory neutralization of subsoil acids. Efforts to uniformly incorporate lime by excavating the soil to a specified depth using tile sections or metal rims failed to provide satisfactory answer.

Application of limestone to exposed sub-soil, which may possess a net positive charge, can move the soil to zero charge and deflocculation, thereby increasing its erodibility. Use of a mixture of limestone and gypsum improves the structure of subsoils. Deep placement of lime to raise subsoil pH even in advanced countries has not found widespread use because of the cost involved. In developing countries, where the problem primarily exists, it is an unacceptable solution because of the prohibitive cost and the heavy equipments required.

B, Leaching of Surface Applied Lime

Deep mixing and placement of lime below plough layer involves high operational cost and require heavy machinery and power. Moreover, it exposes infertile subsoil. Efforts have

therefore, been made to ameliorate subsoil acidity by making heavy surface application of lime and allowing it to leach downward.

These results show that downward movement of Ca and Mg occurs in well aggregated soils when they are limed at the rates needed to neutralize exchangeable Al or at higher rates. One possible explanation of this phenomenon is that, once the permanent charge sites are saturated, exchangeable Ca and Mg held on the pH-dependent charge sites is likely to move down fairly easily. The porous nature of well aggregated soils with oxidic mineralogy and the high annual rainfall of the sites favor such a movement. This situation is certainly different from that prevailing in soils with 'layer silicate systems where downward movement of un-reacted lime particles may be limited.

The high leaching losses of calcium suggest that calcium applied as lime to the soil surface may move downward and increase the base status of the subsoil. This led Morelli et al. (1971) to observe increased calcium content of subsoil 3 and half years after surface application of lime. Relatively low rates of 2.8 tons/ha of lime increased the pH from 4 to over 5.5 in the 20 to 60 cm layer with a corresponding increase in exchangeable calcium.

Chapter 3

Soil salinity and alkalinity

All soils and natural waters contain soluble salts. The amount of salts in the root zone (or the salt concentration in the soil solution) determines whether the soil is "normal" or "salt-affected" when an "excessive" amount or concentration of soluble salts occurs in the soil and it adversely affects crop growth. In irrigated areas, the formation of salt-affected soils is the most important process of land degradation. Salt-affected soils exist mostly under arid and semi-arid climates, in more than 100 countries.

Salt affected soils are soils that have been adversely modified for the growth and production of most crop plants due to the presence of excessive concentrations of either soluble salts, or exchangeable sodium, or both. For agricultural purposes, salt-affected soils are regarded as a class of problem soils that requires special remedial measures and management practices. This is because salt constituents of such soils produce harmful effects to plants by increasing the salt contents of the soil solution and the degree of saturation of the soil exchange complex by sodium. Excessive accumulation of soluble salts or exchangeable sodium impose a stress on growing crops that can lead to decreased yields and, in severe cases, complete crop failure and

total loss of land value. Salinity problems are caused from the accumulation of soluble salts in the root zone. These excess salts reduce plant growth and vigor by altering water uptake and causing ion-specific toxicities or imbalances.

3.1. The Extent of soil salinity problem in the world and in Ethiopia

Salt affected soils occupy extensive areas and occur globally, and are extremely wide spread throughout the various continents of the world. They are found in cold (permafrost), temperate, subtropical, and tropical belts, that is, all the way from the subarctic to the equator and for south of it which have continental or arid climate and where, therefore, evapotranspiration exceeds precipitation either permanently or at least some time of the year.

The extent of salt affected soils in the world (excluding Europe) has been estimated 901.4 million ha. Including the estimates of the extent of salt affected soils in Europe (50.8 million ha), the area facing salinity and sodicity can be put at a total of 952.2 million ha. Currently, over one-third (1/3) of the developed agricultural lands in the arid and semi arid regions of the world reflect some degree of salt accumulation and have prevented the farming of additional areas of these regions.

In general, Ethiopia possessing a total land area of 11, 033,000 ha of salt affected soils [Saline + Saline phase (10,608,000 ha) and Sodic + Sodic phase (425,000 ha; 3.85%)] and it is known to be the first in Africa. Following Ethiopia are Chad, Egypt and Nigeria having a total area of 8,267,000, 7,360,000 and 6,502,000 ha of salt affected lands, respectively. Moreover, Ethiopia stands ninth in the total land area of salt affected soil among the various countries in the world, surpassed by Australia, USSR, Argentina, China, Iran, India, Paraguay, and Indonesia in this order and followed by Pakistan. In terms of a percentage of the total land, Ethiopia stands 7th in the world.

Despite the wide spread occurrence of salt affected soils in the country, we still do not have an accurate cadastre on their extent as well as on their distribution and their exact geographical location. Most of these soils are, however, concentrated in the plain lands of the arid and semi-arid regions of the nation mainly in the Ethiopian Rift Valley System, the Ogaden lowlands, the Denkil Plains and the Red Sea Coast, and various valley bottoms. Most of the irrigated large state farms producing export crops such as cotton, sugarcane, fruits and vegetables are situated in these zones. Yet sizeable areas of these zones are being converted into saline and sodic soil conditions annually at an alarming rate (Figure 4B).

Figure 4A. White salt crusts on the surface soils (furrows and ridges) of irrigated lands in the Awash River basin (Melka Sedi Farm) indicating the presence of severe soil salinity

Figure 4B. White salt crusts (efflorescence) and shiny black film of dry colloidal particles (black alkali) on the surfaces of irrigated lands in the Wabi Shebele River basin indicating the presence of soil salinity and sodicity

3.2. Factors responsible for soil salinity problems

Soluble salts are salts in the soil which readily dissolve and become concentrated in the soil surrounding the root zone. The soluble salts occurring in soils consist mostly of various proportions of Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and occasionally K^+, CO_3^{2-} and NO_3^- ions with minor quantities of B, F and Li that are seldom of major importance because of their toxicity to plants (Figure 4A). These ions are released and made soluble from rocks and minerals during the processes of geochemical and pedo-chemical weathering. Hence, original source of soluble salts in soils of arid regions is weathering of rocks and primary minerals contained in them. In line with this, the original source of soluble salts in the salt affected soils of Ethiopia is *in situ* weathering of Na, Ca, Mg and K rich igneous rocks and their primary minerals occurring in the volcanic regions of the country. These include granites, feldspars & alumino-silicates of Na and

23

K, hyper alkaline silicic lavas, olivine-& dolerite-andesite basaltic magmas, carbonates, volcanic ash, tuff, pumice & rhyolite parent materials. These parent materials undergo intensive disintegration and decomposition when exposed to the action of natural waters and carbonic acid forming large quantities of mobile silica, alumina and free HCO_3^- & CO_3^{2-} ions of alkali & alkaline earth bases.

If a soil has too much sodium (> 15% exchangeable Na percentage) resulted soil Alkalinity (Sodacity) problem it may disturbed the structure of soil. $ESP = \dfrac{E_{Na}X}{CEC} \times 100$ As sodium percentage increases, so does the risk of dispersion of soil aggregates (see Figures 5). Any salt that accumulates in excessive amounts in soil can cause toxicity and plant growth problems.
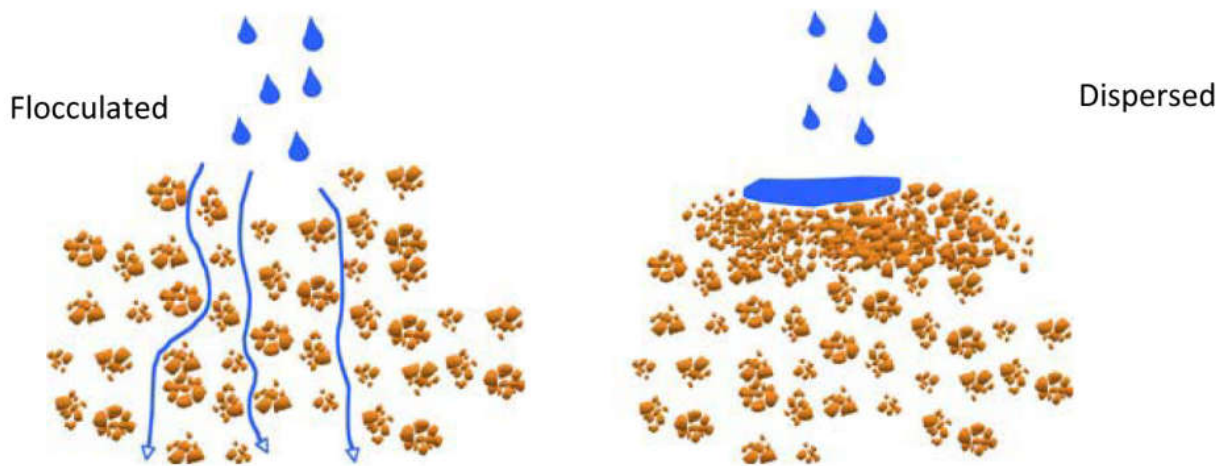

Figure 5. The difference between flocculated (aggregated) and dispersed soil structure. Flocculation (left) is important because water moves through large pores and plant roots grow mainly in pore space. Dispersed clays (right) plug soil pores and impede water movement and soil drainage.

Addition of sodium-containing salts particularly its carbonates to the soil may result in saturating the soils exchange complex with Na. As the salt concentration increases, calcium and magnesium may precipitate as their respective carbonates. It causes calcium carbonate to accumulate in the soils and results in a gradual increase in proportion of sodium in solution and thereby the proportion of the sodium adsorbed on soil colloids also increases (Figure 6).

The process of progressively increasing the Na saturation on the soils exchange complex is called sodication. Sodication induces deterioration in physical properties and the soils so formed are called *sodic soil, solods, solonetz or black alkali soils* (Figure 7). If these soils occur only in small areas (in small localized spots), are often called *slick spots*.
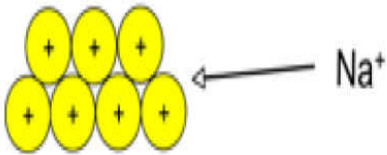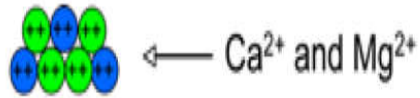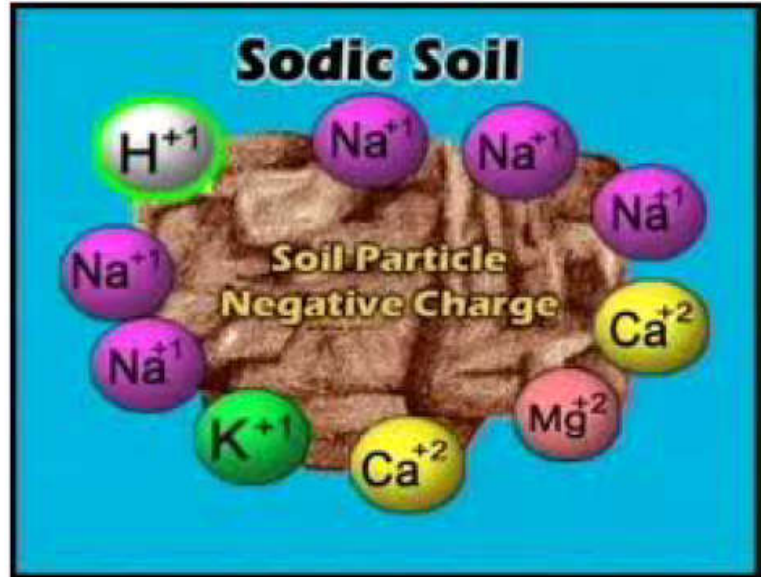
Figure 6. Cations as flocculators. Cations bring together negatively charged clay particles to flocculate soil clays (making clumps or "aggregates"). Sodium (Na+) is a much poorer flocculator than Ca^{2+} and Mg^{2+} because it has less charge and because its ionic size in water is much larger

Figure 7. Views of barren sodic soils

The rate of release of soluble salts from the *in situ* weathering of rocks and their primary minerals is so low compared with the rate of their removal by water that direct accumulation of excessive salts and development of soil salinity and/or sodicity from this source alone is probably of little or no practical significance. Thus, the adverse processes of salinization and alkalization of soils of arid and semi arid regions are the consequences of quite diverse and

interacting factors of surface and ground waters, physical properties, climate, relief and geomorphology and other biological activities. These include one or more of the following:

1. Aridity of climate (ET exceeding precipitation at least some time of the year). Salts build up on the surface where a shallow water table exists and where evaporation exceeds infiltration. Annual rainfall in arid and semi-arid regions is not sufficient to leach down salts to the deeper layers of soil. Coupled with it, high evaporation in these areas results in the accumulation of large amount of salts in the root zone (Figure 5).
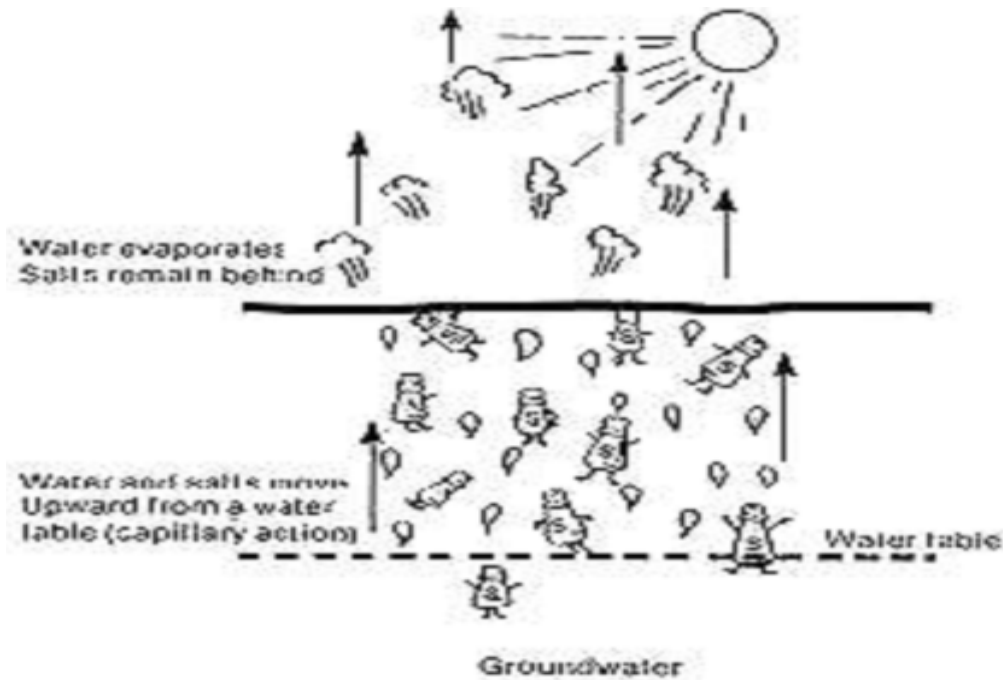

Figure 5. Excess evaporation but low infiltration of water result soil salinity problem

2. Low lying topography

3. Lack of adequate drainage

4. High salt and alkali (mineralized) groundwater

5. Rising and/or near surface water-table

6. Intense and often inefficient irrigation practice, including method of irrigation, amount of irrigation water applied at a time and frequency of irrigating.

7. Use of poor quality (salty or alkali) irrigation water

8. Residual (fossil) salts of former alluvial, lacustrine or marime environments.

9. Exposure of salty or alkali subsoil layers to the surface by land leveling or earth moving during land clearing and development.

10. Decay of salt and/or sodium containing plants

11. The atmosphere assisted by biological activities and rainfall

In accordance with the above, the processes accounting for the salinization and alkalization of the salt affected soils in Ethiopia are rather more diverse and complicated, and include:

➢ Residual (fossil) salts of former alluvial, colluvial, lacustrine/marine deposits of weathered products of the salt and Na rich primary minerals of igneous rocks originating from the volcanic regions of the Central Highlands and the Rift Valley System of the country.

➢ Mineralized near surface or rising ground waters

➢ Intense and often inefficient irrigation practices along with poor or inadequate drainage and drainage systems

➢ Low lying topography and the resultant arid climate or insufficient annual rainfall to leach accumulated salts from the plant root zone.

➢ A combination of two or more of the above factors and in some areas the use of low or poor quality irrigation waters and exposure of salty and alkali subsoils through land leveling.

Classification of the Salt-affected Soils

The US Salinity Laboratory Staff in 1954 grouped salt-affected soils into three general categories for management purposes (Table 2)

Table 2. Classification of salt-affected soils

Salt-affected soil	Soil pH (pHs)	Electrical conductivity (ECe) (dS m⁻¹)	Sodium adsorption ratio (SAR)	Exchangeable sodium percentage (ESP)	Typical soil physical condition (soil structure)
None	< 8.5	< 4	<13	< 15	flocculated
Saline	< 8.5	>4	<13	<15	flocculated
Sodic	< 8.5	<4	>13	>15	dispersed
Saline-sodic	< 8.5	>4	>13	>15	flocculated

Irrigation Water Quality

All the irrigation waters contain some salts, but the amount and nature of salts vary. The concentration and composition of dissolved constituents in water determines its quality. The quality of irrigation water depends mainly on its salt content, proportion of Na+ to divalent cations and nature of anions (alkalinity or sodicity) and toxicity of some ions.

Over an extended period of irrigation, salts will accumulate in the soil and a salinity problem may develop. If the water or river system being used in major irrigation projects is of high quality, there is little risk of salt build-up. However, farmers considering the development of

small irrigation systems utilizing sources of water such as ponds, sloughs or ground water may face salinity problems. Any water source for irrigation should be analyzed to make certain that it will not result in a build-up of salts. Salinity is more of a water problem than soil problem. Weathering of rocks and minerals, alone, seldom produces a soil salinity problem. Because the salts are soluble, water moves and accumulates them in some parts of the landscape. To understand how these salt accumulations occur, we must understand the movement of underground water. Salts can invade any type of soil, productive or unproductive, and when this invasion occurs, otherwise highly productive soils can be converted to unproductive soils (Figure 8).

Nonsaline Soil   Moderately Saline   Highly Saline

No color shows unavailable water; Color shows available water

Figure 8. Salinity and available soil water

The most important irrigation water quality characteristics that are related to salinity and alkalinity or sodicity and toxicity are

(a) Total dissolved salts (TDS) or electrical conductivity (EC)

(b) Sodium adsorption ratio (SAR),

(c) Residual sodium carbonate content (RSC) and

(d) Concentration of boron

3.3. Managements (amelioration) of saline soils

The primary objective of reclamation and management of salt-affected soils is to reduce soluble salts and exchangeable sodium to levels that permit ideal or near ideal plant growth so that the productivity of these soils is restored.

Without adequate drainage, proper reclamation of any salt-affected soil cannot be achieved on a long-term basis. Salt affected soil problems do not develop overnight, it takes years for salts to accumulate enough to reduce crop growth and/or water infiltration. Reclamation can take long. Management of water is the key to controlling salinity. The degree to which water movement can be managed determines the feasibility of controlling the salinity problem. Therefore it is at least as important to mange recharge as it is to cope with discharge of ground water. Control of ground water recharge can be obtained through removal of the excess water by improving drainage or cropping practices that use up more of the moisture. Continuous cropping or growing perennial forages uses up more recharge water than summer fallow cropping. Regardless of crop rotation length, adequate fertilization will encourage better use of soil moisture. Where recropping is attempted, snow trapping may be used to increase soil moisture and to distribute snowmelt water uniformly.

Crop selection is the main management practice that a farmer can use to combat a soil salinity problem in the discharge area. Leaving the soil bare promotes evaporation & salt accumulation at the surface. Therefore fallowing or growing non-tolerant crops aggravates salinity problems. The tolerance of various annual, forage and vegetable crops is shown in Table 3A. Barley, sunflower and safflower are the most tolerant of the annual crops grown in Saskatchewan. In most saline management cropping situations, barley becomes the mainstay of the cropping program. While continuous cropping to one annual plant species is not a general agronomic recommendation, it may have a role in management of moderately saline soils. Close attention to disease problems will be required and if disease problems will be required and if disease becomes significant, changes in the cropping pattern will be required.

Table 3 A. The relative tolerance of crops to salinity

Tolerated Salinity (EC)^{*2}	Annual field crops	Forage crops	Vegetable crops
None to Slightly Saline (0-4)	Soybeans	Red Clover	Peas
	Field Beans	Alsike	Beans
	Faba Beans	Timothy	Onions
	Peas		Celery
	Maize		Radishes
			Cucumber
			Carrots
			Corn (sweet)
Moderately Saline (4-8)	Canola Flax Mustard Wheat Oats 2-Row Barley Safflower Sunflower 6-Row Barley Sugar Beets	Reed Canary Grass Fescue Intermediate Wheat Crested Wheatgrass Bromegrass Alfalfa Sweet Clover	Tomatoes Lettuce Cabbage Potatoes Peppers Spinach Asparagus Garden Beets
Severely to Very Severely Saline (8-16)	Barley may produce some crop but this land is best suited to tolerant forages.	Altai Wild Ryegrass Russian Wild Ryegrass Slender Wheatgrass Tall Wheatgrass Beardless Wild Ryegrass Levonns alkaligrass Salt Meadow Grass	
Crops within each group are listed in order of increasing salt tolerance.			

Table 3 B. The tolerance of crops to salinity

Sensitive (0-4 mmhos/cm)	Moderately Tolerant (4-6 mmhos/cm)	Tolerant (6-8 mmhos/cm)	Highly Tolerant (8-12 mmhos/cm)
Field Beans (Dry)	Corn	Wheat	Barley
Red Clover	Grain Sorghum	Oats	Rye
Ladino Clover	Soybean	Triticale	Bermudagrass
Alsike Clover	Bromegrass	Sunflower	Crested Wheatgrass
	Sudangrass	Alfalfa	
	Sorghum-Sudans	Tall Fescue	
		Sweet Clovers	

Physical Reclamation

This type of reclamation involves physical and mechanical means to remove the salts and/or to improve permeability and thereby internal drainage within the soil profile. These methods include deep-ploughing, sub-soiling, profile inversion, sanding, flushing and scrapping.

Deep ploughing and sub-soiling methods mechanically break the impermeable layer, cemented sub-soil layer or hardpan in the soil profile at some depth to enhance the infiltration and transportation of salts dissolved in water to deeper soil layers. Deep ploughing has been shown to

benefit water penetration, aeration and plant growth in the poorly-structured soils. However, the benefits of deep ploughing are short-lived, especially on sodic soils. Profile inversion can be employed in situations where surface soil is relatively free of salts and Na but soil below is sodic, saline or saline-sodic. In this method, good surface soil is retained while the salty sub-soil is inverted down the profile. It is, however a cumbersome procedure.

Sometimes sand is mixed in the salt-affected soil to improve permeability and air water relations in the root zone. However, in clayey sodic soils, inadequate quantities of sand will rather create problems due to sand's cementing effect. In such cases, large quantities of sand have to be applied to check the cementing effect that at times seems impractical for a large area.

Flushing involves washing away the surface accumulated salts by flushing water over the surface. It is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from the soil is rather small, this method does not have much practical significance. Scrapping the salts that have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. It might temporarily improve crop growth, but the ultimate disposal of salts still poses a major problem. Also this method fails to give a permanent solution under shallow water table conditions where salts can again rise and accumulate at the surface due to evapotranspiration.

Chemical Reclamation

Reclamation of sodic soil requires removal of part or most of the exchangeable sodium, improvement of the soil physical structure and lowering of the soil pH. Mined gypsum is the most commonly used chemical amendment for sodic soil reclamation because of its abundant availability and low cost. Chemically gypsum is $CaSO_4.2H_2O$ and occurs extensively as the natural deposits. Gypsum has been used successfully to reclaim the sodic soils and enhance crop productivity of these once barren lands. The exchangeable sodium is replaced by the more favorable calcium ions according to the exchange reaction given in equation and the sodium thus exchanged is leached out of the root zone.

$$2 \text{ Na- X} + Ca^{2+} \text{ (solution)} = \text{Ca-X} + 2Na^+ \text{ (solution)}$$
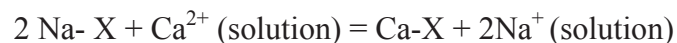
Where, 'X' is the exchange complex of the soil.

Calcium needed for this reaction can be furnished by either calcium-based amendment or calcium carbonate present in the soil whose solubility may be enhanced by application of organic amendments or acid formers. Amendments are the materials which provide Ca^{2+} or mobilize

Ca^{2+} in the soil for replacing exchangeable sodium to reduce alkalinity (pH) and sodicity (ESP) of the soil. For reasonably quick results cropping must precede the application of soil amendments followed by leaching for removal of soluble salts from the soil profile The amount and type of chemical amendments required to reclaim a sodic soil depend upon physico-chemical properties of soil mainly pH, EC and ESP. Crop tolerance to sodicity and economic condition of the farmers determine the desired level of replacement of exchangeable sodium. Generally, there are two types of chemical amendments:

a) *Soluble sources of calcium:* Gypsum ($CaSO_4.2H_2O$), calcium chloride ($CaCl_2$) and phospho-gypsum (an industrial bye-product)

b) *Acids or acid-formers:* Elemental sulphur, sulphuric acid, sulphates of iron and aluminium, pyrites and lime sulphur

The choice and effectiveness of these two types of amendments mainly depend upon presence or absence of $CaCO_3$ in the soil. In absence of $CaCO_3$ as is the case in noncalcareous soils, only soluble sources of calcium should be used and application of acids or acid-formers is not recommended. But, when soil contains calcium, both the sources may be used. Although sparingly soluble $CaCO_3$ is a potential source of calcium and is recommended for acid soil reclamation, it is not recommended for the reclamation of sodic soils because of its low solubility which decreases further with rise in soil pH.

Effect of gypsum on plant growth

Application Method

Gypsum is normally applied-broadcast and then incorporated into the soil by disking or ploughing as it is more effective in the removal of exchangeable sodium than when applied on the soil surface. Also mixing limited quantities of gypsum in shallower depths is more beneficial than mixing it with deeper depths. Deeper-mixing exposes gypsum to react with Na_2CO_3 of the soil resulting in lesser reduction in ESP throughout the depth. This can decrease the seed germination rate and consequently the crop yield. In shallow mixing, soluble carbonates move down with the wetting front without reacting with applied gypsum.

For improving sodic soils with hardpans or dense clay subsoil layers, deep ploughing (up to 100 cm) has been found to be a useful practice. Improvement in crop yields as a result of deep ploughing occurs because of enhanced water intake rates and depth of penetration. Gypsum is excavated as lumps from deposit sites, it requires grinding before it can be used for sodic soil reclamation. The fineness to which gypsum must be ground is a matter of economic consideration. It is often said that the finer the gypsum particles, the more effective it would be for the reclamation of sodic soils. But very fine grinding involves higher cost.

Biological Reclamation

Sodic soils are generally low in organic matter. Addition of organic materials and crop residues in the soil helps in improving and maintaining soil structure, preventing erosion, and supplying essential plant nutrients besides reclaiming the sodic soils. Organic materials and the plant roots help in enhancing the biological activity in soil. Organic amendments on decomposition increase the partial pressure of CO_2 and produce organic acids. These processes help in increasing electrolyte concentration, mobilizing calcium through enhancing the solubility of soil calcite, lowering pH and ESP of the soil. Most commonly used organic amendments are crop residues, FYM, green manure, poultry manure etc.

The effectiveness of any organic amendment depends upon the amount of CO_2 produced and extent of reduction. To achieve maximum benefits from application of organic amendments, submerged conditions should be maintained to help maintain lower redox potential (*i.e.* the reduced conditions) during the course of their decomposition. Due to their coarse texture and slow decomposition, these organic materials do not allow the pores to be clogged and make the soil porous by maintaining channels and voids which improve water penetration and facilitate leaching of the salts out of the root zone.

Generally application of organic materials together with inorganic amendments is cost-effective, hastens the reclamation process and increases the crop yields; thus, their combined use should be encouraged. Application of 20 t FYM ha^{-1} combined with gypsum gives higher crop yields than the gypsum applied alone. Also application of FYM is economical only when it is locally available with the farmer. But when it is to be purchased then it is not economical compared to gypsum alone. For biological amelioration to be effective, relatively large quantities of organic amendment *i.e.* FYM (30-40 t ha^{-1}) have to be applied. Further, if the C:N ratio of organic materials is very wide as is the case with saw dust, rice husk and rice straw, these materials decompose slowly and may be less effective than *Sesbania* which has a narrow C:N ratio. Under such circumstances, deficiency of N may be encountered and should be taken care of. Nevertheless, beneficial effects of straw incorporated in a sodic soil under submerged conditions can be attributed to: (i) the decomposition of organic matter, evolution of CO2 and certain organic acids, (ii) lowering of pH and the release of cations by solubilization of CaCO3 and other soil minerals thereby increasing the EC, and (iii) replacement of exchangeable Na by Ca and Mg, causing lowering of the ESP.

Organic materials when applied in conjunction with inorganic amendments or when applied alone in soils of mild sodicity, have proved beneficial. Thus their use in the reclamation of sodic soils occupies an important place. Green manures and crop residues are the potential organic amendments in addition to gypsum for bringing on gradual soil improvement in physical and biological properties of the calcareous black sodic soils.

On the other hand, planting of sodicity-tolerant crops which listed in Table 4 such as Karnal grass and para grass also have family high degree of tolerance to sodic environment.

Table 4. Relative tolerance of crops to soil sodicity

ESP (range*)	Crop
2 – 10	Deciduous fruits, nuts, citrus, avocado
10 – 15	Safflower, black gram, peas, lentil, pigeon pea
16 – 20	Chickpea, soybean
20 – 25	Clover, groundnut, cowpea, onion, pearlmillet
25 – 30	Linseed, garlic, cluster beans
30 – 50	Oats, mustard, cotton, wheat, tomatoes
50 – 60	Beets, barley, *Sesbania*
60 – 70	Rice

*Relative yields are 50% of the potential of the given crops in the respective sodicity ranges

Gypsum Requirement – Concept and Methods for Determination

The quantity of gypsum or any amendment necessary to reclaim sodic soil depends on the total quantity of sodium that must be replaced. This, in turn, depends on the soil texture and mineralogical make-up of the clay, extent of soil deterioration as measured by exchangeable sodium percentage (ESP) and the crops to be grown. The relative tolerance of a crop to exchangeable sodium and its normal rooting depth will largely determine the soil depth up to which excess adsorbed sodium must be replaced for achieving satisfactory crop growth. Replacement of each mole of adsorbed sodium per 100 g soil will require half a mole of soluble calcium. The quantity of pure gypsum required to supply half a centimol of calcium per kg soil for the upper 15 cm soil depth can be compared as

$$\frac{\text{molecular weight of gypsum}}{200} = \frac{172}{200} = 0.86 \text{ g kg}^{-1} \text{ soil}$$

= 86 x 10-5 kg kg^{-1} soil = 86 x 10-5 x 2.24 x 106 kg ha^{-1} = 1926 kg or 1.93 t ha^{-1}
If it is desired to replace larger quantities of adsorbed sodium, the quantity of gypsum can be accordingly increased.

The first step for ensuring crop production in salt-affected soils is to leach the salts to below the root zone. For sodic soils, application of appropriate chemical/organic amendments is required to displace sodium ions from the exchange complex before initiating any leaching and drainage programme. Thus, it is important to ensure adequate drainage in the soil for allowing sufficient leaching for the success of any reclamation process. It requires that sufficient water should pass through the soil to lower the salt concentration to permissible limits and help maintain salt and water balance in the root zone soil. When salts come from a shallow water table, the water table must be lowered by providing drainage before reclamation can be accomplished.

The success of any leaching programme in the long run requires that the output of salts leaving the root zone should be more than, or equal to the inputs *i.e.* quantity of salts entering the root zone. Reclamation of salt-affected soils basically needs drainage for evacuating excess water and salts from the crop root zone. Provision of drainage, as already stated, is of utmost importance for saline soils. Drainage system should be designed to regulate the salt and water balance for both the surface and sub-surface soil.

Assignment

1. Why do saline and sodic soils occur in dry regions while acidic soils in highland regions?
2. How can we ameliorate acidic soils mention different options?

3. Why the plants grown in saline soils appear water-stressed?

4. Why do high sodium relative to calcium causes dispersion of soil colloids?

5. Why gypsum applied to sodic soils in priory of leaching as to other saline soils for reclamation?

6. Discuss the factors responsible for the development of acidic and saline soils?

Chapter 4

Deteriorations of soil structure and its management practices

Soil in good physical condition should have a soft porous, crumbly structure, where small soil particles have formed into aggregates. These aggregates are numbers of soil particles glued together by clay and organic compounds such as humus. Some deteriorations of the physical property of soils (structure) are soil compaction, surface crusting and hard pan developments. Soil structure determine root growth, water and air movement, etc. There are big differences in rates of water movement into different soils and subsoils, so normal rates will vary from one soil type to another.

How does soil structure decline?

Soil structure can be damaged over time in a number of ways.

A, By water

Rain falling on bare soil will impact hard enough to break soil aggregates into smaller particles, which are then easily removed by erosion, or compacted to form a dense soil that inhibits plant growth and water penetration.

B, By machinery

Wheels of all types of machinery can compress soil into compacted layers, which then resist water penetration and inhibit plant growth. This is more so when wet soil is trafficked.

Cultivating soil can also rapidly destroy soil structure especially if it is performed when the soil is too wet or too dry, or done too often. Some machines are more damaging to soil structure than others, with rotary hoes and disc ploughs being among the most severe.

C, By stock

The pressure of stock feet on wet soil can severely damage soil structure by causing compaction and pugging. This is especially so if plant growth is poor and not many roots are present to hold soil together.

D, By salt

The sodium in salt will bind to clay particles and replace the calcium that helps hold the soil together. This causes the clay to disperse, and the detached clay particles then clog the pore spaces. This reduces the aeration and the permeability of the soil that restricts water movement and plant root growth. Salt in

the soil reduces the ability of plants to take up water, and the sodium in the salt can be toxic to plants, depending on how concentrated it is in the soil. *Note*. Irrigating sodic soils with slightly salty water can retain good soil structure, but crop production will be limited by sodium toxicity.

4.1. Soil compaction and its management practices

Soil compaction can occur when the crumbly structured nature of a virgin soil in good condition is collapsed by stock or machinery traffic, or by too harsh or too many cultivations. Prolonged rainfall can also lead to compaction of dispersive soils. Compaction can occur in surface or sub surface layers, or both.

Figure Compact sandy loam before (left) and after (right) breaking into coarse clods..

Compacted soil is less permeable to water, leading to reduced absorption of rain and irrigation water. Because pore spaces between the soil particles are smaller and fewer in number, this causes more rainfall to run off and be lost from the farm, thus reducing potential yields. Plant roots may find it difficult or impossible to penetrate compacted layers, leading to poorer crops and pastures with less drought tolerance. The soil has fewer and smaller spaces between soil particles, reducing plant root respiration and desirable microbiological activity. This leads to poorer plant growth and an increase in plant diseases.

Water penetration into the soil is reduced, leading to less soil water stored and increased runoff, with increased erosion and loss of plant nutrients. Pores between soil crumbs that contain air are

smaller or collapsed. This leads to unfavorable conditions for plant roots and soil organisms. Reduced penetration to depth by plant roots, thus limiting nutrient uptake.

Increased moisture stress on plants and soil organisms in dry or drought conditions. Increased waterlogging of topsoil during wet seasons, leading to poor plant growth. Waterlogged soils inhibit beneficial soil microbes and favor disease organisms, increasing the risk of crop diseases. Less crop or pasture growth leads to lower net farm income. Poorer stock health, also leading to poorer net farm income.

How to ameliorate compacted soils

Deep rip under favorable soil moisture conditions with an implement such as a paraplough or a winged ripper. The soil should be evenly moist, neither too wet, nor too dry for this treatment. Deep ripping may not be effective on dispersive soils.

Follow up deep ripping by planting deep-rooted plants, then minimise traffic by stock and machinery. The use of controlled traffic methods of sowing crops (tramlining) using GPS guidance systems will limit compaction by machinery.

Use deep-rooted perennials in pasture mixes. Applications of gypsum may help if the soil has high clay content only if the clay is sodic or contains high levels of magnesium.

4.2. Surface crusting and its management practices

Cultivated soil with reasonably high clay content can form surface crusts after rain, which may inhibit seedling emergence. This crusting is easily observed. Crusting is usually caused by too much cultivation and/or too low an organic matter content of the soil. The remedy is to return the soil to a pasture phase, or increase organic matter content by stubble retention, minimum till cropping or green manuring. Sodic soils are also prone to crusting.

Soil crusting will often inhibit seedling emergence

4.3. Hardpans and its management practices

Hardpans are hard layers, usually at the depth of maximum cultivation, but can occur almost at the surface, or even deeper in the soil profile. They reduce water, air and plant roots penetrating through them, and can cause serious loss of yield and waterlogging of the surface soil by inhibiting drainage.

The occurrence of hardpans can be determined by pushing a 6 mm diameter steel rod up to one meter in length into the soil when it is moist, and noting increases in effort needed to push the rod to depth. If a hardpan is present, it will be difficult to push the rod through this layer. This rod can be attached to a device that measures force to make an instrument known as a penetrometer.

Loss of subsoil structure

If the subsoil has become compacted, water penetration down the profile will be poor, and will usually show up as surface waterlogging, or excessive water runoff after rain. Plant roots will have great difficulty penetrating to depth, and will have less drought resistance and poorer growth. To check subsoil structure, it will be necessary to dig a hole, preferably a metre or more deep, and carefully inspect the face of the soil profile. Dispersion can be seen as very dense sticky clay, often due to too much sodium compared to calcium. Clays high in magnesium are very hard and dense, with a large columnar structure.

The extent to which water and plant roots are able to penetrate soil profiles can also be determined by looking for roots at depth. Roots may be seen to reach a point where they turn and go sideways instead of continuing down the soil profile if they hit a hardpan. This effect may also be due to acidity, sodicity or salinity

How to ameliorate hardpan soils

Deep ripping to break up hardpans. Changing to minimum till or direct drilling methods of sowing. Deep ripping and sowing down to deep-rooted perennial pasture.

Avoiding trafficking soil with machinery as much as possible, especially when soil is very wet.

Wide tyres with low inflation pressures significantly reduce soil compaction if machinery must be used on wet paddocks. Aerating the soil using a narrow tyned ripper to loosen the soil and break up hardpans as they develop may be warranted.

Sow deep-rooted perennial pastures if the climate and soil allows.

Use a management system that encourages high levels of organic matter and biological activity in the soil.

Chapter 5

Poor drained (marshy soil) and other soil problems

Water ponding on the soil surface after relatively light rain, or remaining ponded for several hours after rain, indicate soil structural decline. Water logging cause loss of nutrients such as N (through denitrification) due to favoring anaerobic condition.. Soils developed gleying in waterlogged conditions due to lacking of oxygen. Almost all plants of economic importance, except rice, grow best when soil pores are no more than **75** % full of water.

Waterlogging in compacted soil

Waterlogging can affect yields adversely by bringing about changes in the (a) soil strength, (b) soil pH, (c) oxygen availability, (d) water and thermal regimes, (e) accumulation of carbon dioxide, bicarbonate, carbonate and sulphides *(S-), (f)* oxidation-reduction status of soil, (g) nature of microbes (aerobic, facultative-anaerobic and anaerobic), and (h) nutrient availability by altering the uptake, solubility, translocation and interactions

Ameliorating waterlogged soils

Tile drainage has been adopted on waterlogged lands to convert them into agricultural lands.

Artificial drainage aims at increasing aeration to the growing plant roots by removing at least **25%** of the water by volume in Saturated soils.

Growing tolerant crop to waterlogging conditions such as rice,