REVIEW ARTICLE

The effects of alkalinity on physical and chemical properties of soil

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Although it is difficult to clearly separate soil functions into chemical, physical, and biological processes because of its dynamic, interactive nature, soil has certain chemical, physical and biological properties. Soils that are significantly acidic or alkaline cover most of the land in the world. Soil salinity affects plants directly through reduced osmotic potential of the soil solution and the toxicity of specific ions such as boron, chloride, and sodium. Soil alkalinity affects the physical and chemical properties of the soil. Some adverse effects of alkalinity on soil physical properties are texture, soil structure, soil color, Infiltration and Soil porosity, surface crusting, and swelling factor. Effects of soil alkalinity on soil chemical properties include soil pH and nutrient availability, Nutrient availability and alkalinity of soil. Alkalinity of soil can be maintained by various methods to for successful crops in alkali soils.

Key Words: *Salinization; Soil alkalinity; Soil porosity; Nutrient availability*

INTRODUCTION

Soil is an important component of the terrestrial ecosystems of the Earth. It supports plant growth and provides a habitat for large numbers of animals and microorganisms that decompose leaf litter and plant residues, thereby helping to cycle the nutrients on which plant growth depends. It has had these functions since plants first colonized the land. According to Shukla, Soil is the upper most layer of earth crust, and it supports all terrestrial life. Most living things on earth are directly or indirectly derived from soil. Soil is prone to degradation or decline in its quality due to misuse and mismanagement with agricultural uses, contamination with industrial uses, and pollution with disposal of urban wastes. Sustainable use of soil resources, therefore, requires a thorough understanding of properties and processes that govern soil quality to satisfactorily perform its functions of value to humans [1].

Soil has chemical, physical and biological properties even though it is difficult to clearly separate soil functions into chemical, physical, and biological processes because of the dynamic, interactive nature of these processes. These factors will be influenced by different factors. Soils that are significantly acidic or alkaline cover much of the world's land area. Generally, there are geographic, geological, biological and climatological reasons why soils tend to be either acidic or alkaline, and their natural state can be greatly modified by human actions. Soils profiles vary in their properties and may be either acidic or alkaline throughout, or may be either acidic or alkaline within different layers, though very generally the near surface layers tend to be more acidic than sub-surface layers [2].

In areas where rainfall is low, soil leaching is usually insufficient to completely remove salts from soil profiles and it is common in these regions for soils to contain carbonate or bicarbonate ions that are concentrated by evapotranspiration processes. With increasing aridity, these alkaline materials and associated salts of sodium and gypsum accumulate closer to the soil surface. Large areas in the semi-arid and arid climatic zones have accumulated calcium carbonates as rubble layers or hardened sheets that may act as a chemical or physical barrier to penetration by plant roots. The world's arid regions amount to about 50 million square kilometers, or about 30 percent of its land area, and their soils are usually alkaline, though some will be acidic as a result of past climates that were more humid. There are additional areas that have soils that are alkaline, such as the regions where Lossiah materials (wind-blown soil dust sourced from more arid regions) containing calcium carbonate have been deposited, or where soils have developed on calcareous parent materials. The latter are usually emerged calcareous marine or lacustrine sediments, but they may also contain significant sodium bicarbonate and carbonate in regions of low rainfall local scale, alkaline soils frequently develop in valley floors where carbonates and other salts accumulate due to the concentration of alkaline through flow or ground waters [3].

An excessive accumulation of salts in the soil profile causes a decline in agricultural productivity. Soil salinity affects plants directly through the reduced osmotic potential of the soil solution and the toxicity of specific ions such as boron, chloride, and sodium. If the salts are primarily sodic salts, as is frequently the case, their accumulation increases the concentration of sodium ions in the soil's exchange complex, which in turn affects soil properties and behavior. Thus, salinity can also have indirect effects on plant growth through, deleterious modification of such soil properties as swelling, porosity, water retention, and permeability [4].

Objectives

1. To understand or review the adverse condition of alkaline soil on physical properties of soil.
2. To understand or review the adverse condition of alkalinity on soil chemical properties.

SOIL ALKALINITY AND SOURCES OF ALKALINITY

Soil alkalinity

Alkalinity occurs when there is a comparatively high degree of base saturation. The presence of soluble salts and calcium magnesium sodium carbonates, also give a preponderance of hydroxyl ions over hydrogen ions in the solution. Under such condition the soil is alkaline, sometime very strong so, especially if sodium carbonate is presented, a PH 9 or 10 being common. Alkaline soil is; of course, characteristics of most arid and semiarid regions. Salinization refers to the accumulation of salts such as sulphates and chlorides, and alkalization to the accumulation of sodium on cation exchange sites. Salts, blown inland from oceans, introduced in irrigation water, or produced by weathering, accumulate in depressions and may render the soil infertile. The traditional and recently proposed classifications of categories for salt affected soils are saline (white alkali), sodic soils, and saline-sodic soils. Sodic (black alkali) soils are a particularly difficult to management problem. The water permeability of these soils to

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water is very slow. The ph. of sodic soil is commonly greater than 9 or 9.5 and the clay and organic fractions are dispersed. Dispersed organic matter accumulates at the surfaces of poorly drained areas as water evaporates and imparts a black color to the surfaces, hence the name (black alkali) [5-10].

Alkali or alkaline soils have been defined as soils with high pH-value, which is caused by excessive (usually more than 15% of the exchange sites) amount of exchangeable sodium ions and soluble salts capable of alkaline hydrolysis. The most injurious alkaline sodium compounds in the soils and irrigation waters are Na_2CO_3 (sodium carbonate) or $NaHCO_3$ (sodium bicarbonate). The very soluble sodium carbonate is generally very quickly eliminated but in arid climates it can accumulate and result in sodic alkaline soils.

The progressive saturation of the soil complex with ‘alkali’ ions (mainly Na), the term alkalization is used here to indicate a rise of the pH to ‘alkaline’ values. The strongly alkaline reactions of most solonetzes and many other sodic and saline sodic soils are due to the presence of appreciable concentrations of carbonate and bicarbonate ions in the soil solution. Hence the sum of ($HC0_3$-) and ($C0_3$.) plus the (usually negligible) excess of (OH-) over (H+) is referred to as the alkalinity concentration.

Sources/causes of soil alkalinity

Sources of Alkalinity Parent materials have a wide ranging mineralogical composition and pH, and young soils inherit these properties from the parent material. Throughout the world there are parent materials and soils that contain several percent or more of calcium carbonate; they are calcareous. When calcareous soil is treated with dilute HCI, carbon dioxide gas is produced, and the soil is said to effervesce. Carbonate Hydrolysis The hydrolysis of calcium carbonate produces OH- which contributes to alkalinity in soils: Calcium carbonate is only slightly soluble, and this reaction can produce a soil pH as high as 8.3 assuming equilibrium with atmospheric carbon dioxide. In calcareous soil, carbonate hydrolysis controls soil ph. When a soil contains Na_2CO_3, the pH may be as high as 10 or more, which is caused by the greater solubility of Na_2CO_3 and greater production of OH by hydrolysis in a similar manner. Sodium affected soils with 15 percent or more of the CEC saturated with Na' are called sodic and are also highly alkaline. The causes of soil alkalinity are natural or can be man-made. The natural development is the existent of soil minerals producing sodium carbonate upon weathering. The man made development is due to the application of irrigation water (surface or ground water have a relatively high proportion of sodium bicarbonates. The reason for alkalinity are: i) in arid and semiarid areas salt formed during weathering are not fully leached, ii) in coastal areas if the soil contains carbonate the ingression of sea water leads to the formation of alkali soil due to the formation of sodium carbonate, iii) irrigated soil with poor drainage [11-15].

EFFECT OF ALKALINITY ON PHYSICAL AND CHEMICAL PROPERTIES OF SOIL

Excess exchangeable Na is harmful because it induces undesirable physical and chemical changes in soils. An excessive accumulation of salts in the soil profile causes a decline in agricultural productivity. Soil salinity affects plants directly through the reduced osmotic potential of the soil solution and the toxicity of specific ions such as boron, chloride, and sodium. If the salts are primarily sodic salts, as is frequently the case, their accumulation increases the concentration of sodium ions in the soil's exchange complex, which in turn affects soil properties and behavior. Thus, salinity can also have indirect effects on plant growth through, deleterious modification of such soil properties as swelling, porosity, water retention, and permeability [16].

Alkaline soil has different effects on physical and chemical properties of soil. As mentioned in the effects of alkalinity are listed below. Due to the occurrences of the high content of salt, it causes an osmotic pressure in plants, leading to plasmolysis (the contraction of the protoplast of a plant cell as an effect of loss of water from the cell.

The quality of water produced in the plants is reduced due to the existence of salt.

The inability of the plant to absorb nutrients required from the soil.

The alkalinity of the soil causes a corrosive action on the bark of roots and stems.

The sodium ion has adverse effects on plant metabolism.

The alkaline soil has a low infiltration rate.

Rain water stagnates in the soil very easily.

The adverse condition effect of alkalinity on soil physical properties

Soil physical properties, including texture, structure and porosity, the fraction of pore space in a soil. The physical properties of soil depend largely on the sizes of the soil particles (soil texture) and on their arrangement (soil structure), as in aggregates. To a large extent texture and structure determine the distribution and movement of water and air in soil, and the availability of water to plants. They also affect the growth of plant roots. Sodium has the opposite effect of salinity on soils. The primary physical processes associated with high sodium concentrations are soil dispersion and clay platelet and aggregate swelling. The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion. Soil dispersion causes clay particles to plug soil pores, resulting in reduced soil permeability. When soil is repeatedly wetted and dried and clay dispersion occurs, it then reforms and solidifies into almost cement-like soil with little or no structure. The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting [17].

Texture: Soil texture plays an important role in all aspects of irrigated agriculture, and the role of soil texture with respect to effects of salinity and sodicity is no exception. Soil texture helps determine how much water will be able to pass through the soil, how much water the soil can store, and the ability of sodium to bind to the soil. Another important aspect of soil texture has to do with surface area. Because of their tiny size, a given volume of clay particles has far more surface area than the same volume of a larger sized particle. This simply means that clay soils are at a greater risk than course textured soils for excess sodium to bind to them and cause dispersion. Sands have larger particle sizes, resulting in less surface area; correspondingly, they cannot accept as much sodium as clay particles.

Soil structure: The arrangement or organization of the particles in the soil (i.e., the internal configuration of the soil matrix) is called soil structure. A stable structure at the soil surface promotes more rapid infiltration of water during storms and results in reduced water runoff and soil erosion and greater water storage within the soil. Beyond the potentially toxic accumulation of Na+ in plant tissue, sodicity presents a physical limitation to plant growth due to the dispersing effects of exchangeable Na+ on clays and organic colloids. Although dispersion is suppressed in saline sodic soils by high salt concentrations, if the excess salt is removed by leaching, clay swelling and dispersion result. The consequences of dispersion are colloid migration, the clogging of soil pores, and dramatic reduction in the rate at which water can percolate through the soil. Dispersed soils have very poor structure, with the result that surface crusting, cementation, and soil erosion become problems. Sodic soils have poor structure compared to saline and saline-sodic soil as mentioned in Table 1 below.

Table 1

Classification of saline and sodic soils and their structure

	EC (Ms/em)	ESP (%)	Typical pH	Structure
saline	>4	<15	<8.5	Good
sodic	<4	>15	>9.0	Poor

Saline-sodic	>4	>15	<8.5	Fair-good

Soil color: Color is about the most obvious and easily determined soil property. Soil color is important because it is an indirect measure of other important characteristics such as water drainage, aeration, and the organic matter content. Since humus becomes dispersed in sodic soils, it can deposit at the surface during the evaporative loss of water from the soil. This process gives some sodic soils a characteristically appearance; the name "black alkali" has been used historically to describe these soils.

Infiltration and soil porosity: Porosity refers to the relative volume of voids or pores, and is therefore expressed as a fraction or percent of the total volume or of the volume of solids. The supply of water and air to plant roots and soil organisms therefore depends on the total pore space, on the sizes of the pores and on the drainage conditions of the site. Soil dispersion hardens soil and blocks water infiltration, making it difficult for plants to establish and grow. The major implications associated with decreased infiltration due to sodium-induced dispersion include reduced plant available water and increased runoff and soil erosion.

Soil dispersion not only reduces the amount of water entering the soil, but also affects hydraulic conductivity of soil. Hydraulic conductivity refers to the rate at which water flows through soil. When sodium-induced soil dispersion causes loss of soil structure, the hydraulic conductivity is also reduced.

Surface crusting: Surface crusting is a characteristic of sodium affected soils. The primary causes of surface crusting are 1) physical dispersion caused by impact of raindrops or irrigation water, and 2) chemical dispersion, which depends on the ratio of salinity and sodicity of the applied water. Surface crusting due to rainfall is greatly enhanced by sodium induced clay dispersion. When clay particles disperse within soil water, they plug macro pores in surface soil by two means. First, they block avenues for water and roots to move through the soil. Second, they form cement like surface layer when the soil dries. The hardened upper layer, or surface crust, restricts water infiltration and plant emergence.

The swelling factor: The ratio of salinity (EC) to sodicity (SAR) determines the effects of salts and sodium on soils. Salinity promotes soil flocculation and sodicity promotes soil dispersion. The combination of salinity and sodicity of soils is measured by the swelling factor, which is the amount a soil is likely to swell with different combinations of salinity and sodicity. Essentially, the swelling factor predicts whether sodium-induced dispersion or salinity-induced flocculation will more greatly affect soil physical properties.

The effect of soil alkalinity on soil chemical properties

Most chemical interactions in the soil occur on colloid surfaces because of their charged surfaces. Due to their chemical make-up and large surface area, colloids have charged surfaces that are able to sorb, or attract, 'ions' (charged particles) within the soil solution. In alkaline soils, the ionic forms++ - - Na, K, Cl and NO predominate with increasing presence of bicarbonate and other complex forms of sulfate and bicarbonate. The increasing presence of bicarbonate and borate, and possibly the aluminate ion, often due to evaporative concentration and limited leaching can result in very high soil pH and plant toxicities. Trace metal elements are present in such low concentrations that Fe, Mn and Zn become deficient (Merry, n, d). The predominance of Na+ on the exchanger phase may occur due to Ca^{2+} and Mg^{2+} precipitating as $CaSO_4$, $CaCO_3$, and CA $Mg(CO_3)_2$. Sodium then replaces exchangeable Ca^{2+} and Mg^{2+} on the exchanger phase [18].

Soil pH and nutrient availability: The pH is the negative logarithm of the hydrogen ion activity (fundamental soil). Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H+) in the soil.

A high amount of H+ corresponds to a low pH value and vice versa. Soil pH can affect CEC and AEC by altering the surface charge of colloids. A higher concentration of H+ (lower pH) will neutralize the negative charge on colloids, thereby decreasing CEC and increasing AEC. A higher pH (towards 10) can indicate the presence of sodium carbonate. The neutral point is pH 7.0. A solution is acidic if the pH is below 7and alkaline if it is above 7. Clay particles stick to one another in most soils, the exception being 'alkali' soils in which sodium ions cause the clays to disperse.

The greatest general influence of pH on plant growth is its effect on the availability of nutrients for plants, Nitrogen availability is maximum between pH 6 and 8, because this is the most favorable range for the soil microbes that mineralize the nitrogen in organic matter and those organisms that fix nitrogen symbiotically. High phosphorus availability at high pH-above 8.5-is due to sodium phosphates that have high solubility. In calcareous soil, pH 7.5 to 8.3, phosphorus availability is reduced by the presence of calcium carbonate that represses the dissolution of calcium phosphates. Maximum phosphorus availablity is in the range 7.5 to 6.5. Below pH 6.5, increasing acidity is associated with increasing iron and aluminum in solution and the formation of relatively insoluble iron and aluminum phosphates. Note that potassium, calcium, and magnesium are widely available in alkaline soils. As soil acidity increases, these nutrients show less availability as a result of the decreasing CEC and decreased amounts of exchangeable nutrient cations: decreased amounts of XCa, XMg, and XK. Iron and manganese availability increase with increasing acidity because of their increased solubility. These two nutrients are frequently deficient in plants growing in alkaline soils because of the insolubility of their compounds. Boron, copper, and zinc are leachable and can be deficient in leached, acid soils. Conversely, they can become insoluble (fixed) and unavailable in alkaline soils. The relationships shown in are for minimally and moderately weathered soils.

Nutrient availability and alkalinity of soil: Alkalinity of soil solutions can create additional toxicity for plants. Typically, the alkalinity is in the form of HCO_3 and CO_3, anions known to reduce the availability of Fe to plants. The high pH is likely to reduce the availability of numerous other micronutrients (e.g., Zn, Mn) as well. At high pH, Al solubility actually increases because of the reaction: AI (OHh (s)+OH-=Al(OH)- and the dissolution of AI-organic complexes. There is some evidence that Al toxicity might contribute to poor plant growth in alkaline soils. Certain micronutrients, notably Cu and Mo, also become more soluble in alkaline soils. Nutrient deficiencies of some nutrient are problem in alkaline soil. Deficiencies of iron and manganese are common in alkaline soils where oxidized forms of iron and manganese exist as insoluble oxides and hydroxides. As a consequence, deficiencies are common in arid regions where many soils are calcareous and alkaline. Cereals and grasses, including sugarcane, tend to have a manganese deficiency when grown on alkaline soils.

Plants increase their ability to absorb iron from calcareous and highly alkaline soils in two ways. First, plant roots decrease the pH in the rhizosphere by the excretion of H+ that solubilizes ferric iron. Second, for monocots (grasses), siderophores are excreted by the roots. Siderophores (iron bodies) are metabolites secreted by organisms that form a highly stable coordination compound (organic chelate) with iron. The siderophores solubilize ferric iron, which is subsequently absorbed by the roots and the iron used by the plant. Microorganisms also excrete siderophores. These mechanisms enable certain plant species to satisfy their iron needs when growing on alkaline soils.

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The chemical properties of sodic/alkaline soil: Sodic soils have an ESP>15, the ECe is <4 dS m-1, and the lower limit of the saturation extract SAR is 13. Consequently, Na+ is the major problem in these soils. The high amount of Na+ in these soils, along with the low ECe, results in dispersion.

MANAGEMENT OF ALKALINE SOIL

For successful crops in alkali soils ESP of the soil must be lowered which can be achieved by application of amendments. Gypsum ($CaSO_4$. $_2$H2O) is the most commonly used amendment for reclamation.

Alkaline soils with solid $CaCO_3$ can be reclaimed with grass culture, organic compost, waste hair, organic garbage, waste paper, rejected lemons/ oranges, etc. ensuring the incorporation of much acidifying material (organic material) into the soil, and enhancing dissolved Ca in the field water by releasing CO_2 gas. Deep ploughing and incorporating the calcareous subsoil into the top soil also helps.

Many times salts' migration to the top soil takes place from the underground water sources rather than surface sources. Where the underground water table is high and the land is subjected to high solar radiation, ground water oozes to the land surface due to capillary action and gets evaporated leaving the dissolved salts in the top layer of the soil. Where the underground water contains high salts, it leads to acute salinity problem. This problem can be reduced by applying mulch to the land. Using poly-houses or shade netting during summer for cultivating vegetables/crops is also advised to mitigate soil salinity and conserve water/ soil moisture. Poly-houses filter the intense summer solar radiation in tropical countries to save the plants from water stress and leaf burns.

Where the ground water quality is not alkaline/ saline and ground water table is high, salts build up in the soil can be averted by using the land throughout the year for growing plantation trees/ permanent crops with the help of lift irrigation. When the ground water is used at required leaching factor, the salts in the soil would not buildup. Plowing the field soon after cutting the crop is also advised to prevent salt migration to the top soil and conserve the soil moisture during the intense summer months. This is done to break the capillary pores in the soil to prevent water reaching the surface of the soil.

Clay soils in high annual rain fall (more than 100 cm) areas do not generally suffer from high alkalinity as the rain water runoff is able to reduce/leach the soil salts to comfortable levels if proper rainwater harvesting methods are followed. In some agricultural areas, the use of subsurface "tile lines" are used to facilitate drainage and leach salts. Continuous drip irrigation would lead to alkali soils formation in the absence of leaching/drainage water from the field.

Gypsum also reacts with sodium carbonate to convert into sodium sulphates which is a neutral salt and does not contribute to high ph. There must be enough natural drainage to the underground, or else an artificial subsurface drainage system must be present, to permit leaching of the excess sodium by percolation of rain and/or irrigation water through the soil profile.

Calcium chloride is also used to reclaim alkali soils. $CaCl_2$ converts Na_2CO_3 into NaCl precipitating $CaCO_3$. NaCl is drained off by leaching water. Calcium nitrate has a similar effect, with $NaNO_3$ in the leachate. Spent acid (HCl, $H2SO_4$, etc.) can also be used to reduce the excess Na_2CO_3 in the soil/water.

To reclaim the soils completely one needs prohibitively high doses of amendments. Most efforts are therefore directed to improving the top layer only (say the first 10 cm of the soils), as the top layer is most sensitive to deterioration of the soil structure. The treatments, however, need to be repeated in a few (say 5) years' time. Trees/plants follow gravitropism. It is difficult to survive in alkali soils for the trees with deeper rooting system which can be more than 60 meters deep in good non-alkali soils.

It will be important to refrain from irrigation (ground water or surface water) with poor quality water. In viticulture, adding naturally occurring chelating agents such as tartaric acid to irrigation water has been suggested, to solubilize calcium and magnesium carbonates in sodic soils.

These plants sequester the sodium carbonate they absorb from alkali soil into their tissues. The ash of these plants contains good quantity of sodium carbonate which can be commercially extracted and used in place of sodium carbonate derived from common salt which is highly energy intensive process. Thus alkali lands deterioration can be checked by cultivating barilla plants which can serve as food source, biomass fuel and raw material for soda ash and potash, etc (from wikipedia, the free encyclopedia).

DISCUSSION AND CONCLUSION

The presence and concentration of salts in soil can have adverse effects on soil function and management. Salt-affected soils are most common in arid and semiarid regions where evaporation exceeds precipitation and dissolved salts are left behind to accumulate, or in areas where vegetation or irrigation changes have caused salts to leach and accumulate in low-lying places. The three main types of salt-affected soils are saline, sodic and saline-sodic. Saline soils contain a high amount of soluble salts, primarily calcium (Ca2+), magnesium (Mg2+), and potassium (K+), whereas sodic soils are dominated by sodium (Na+). Saline-sodic soils have both high salt and Na+ content. Salts in soil can affect structure, porosity and plant/water relations that can ultimately lead to decreased productivity. The pH of a soil is one of the most important properties involved in plant growth. There are many soil pH relationships, including those of ion exchange capacity and nutrient availability. For example, iron compounds decrease in solubility with increasing pH, resulting in many instances where a high soil pH (soil alkalinity) causes iron deficiency for plant growth.

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