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Review

Nutrient Depletion, Organic Matter Loss, Soil Acidification, Sodicity, and Salinization Resulted Due To Nature Interactions. Causes and Way Forward, A Review

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Abstract

Nutrient depletion, organic matter loss, salinity, sodicity, and acidity are as a result of natural interactions that have tremendously resulted to decline in food and nutrient security and environmental quality. They are highly dynamic among different agro ecological regions. Most of the problems that cause these natural interactions are removal of crop residue, burning of crop residue, soil erosion and runoff, gaseous losses of nitrogen and leaching results to nutrient depletion; temperature, soil moisture and water saturation, soil texture, topography, vegetation and biomass production results to organic matter loss; low rainfall, high temperature, high evapotranspiration, inadequate drainage, deforestation, intensive cropping and over grazing result to salinity; sodic water, poor drainage, and deforestation result to sodicity; weathering and leaching, OM decomposition, acid rain, crop production and removal, application of acid forming fertilizer result to acidity. Nutrient depletion, organic matter loss, salinity, sodicity, and acidity could be managed through the combination of these practices; optimized timing and rate of fertility application, optimized use of agrochemical, use of organic fertilizer, use of cover crop, use of crop rotation and conservation tillage practice, mulching, efficient irrigation, use of tolerant crops, and liming. These practices, if effectively implemented will ameliorate the effects of nutrient depletion, organic matter loss, salinity, sodicity, and acidity thereby enhancing soil fertility for optimum crop production.

Keywords: Nutrient depletion, organic matter loss, salinity, sodicity, and acidity

INTRODUCTION

Nutrient depletion, organic matter loss, salinity, sodicity, and acidity occur mostly as resultant effects of nature interactions such as parent material, climate, and activities of organisms. Soil degradation is one of the most significant threats facing mankind which not only weakens the productive capability of an ecosystem but also affects overall climate globally (Barrow, 1991). The consist increase in nutrient depletion, organic matter loss, salinity, sodicity, and acidity are the foremost restraint on our capacity for sustainable agriculture to ensure food and nutrient security, and conducive quality environment. To avoid the soils from getting degraded in terms of nutrient depletion, organic matter loss, salinity, and acidity, it is necessary to correct the harmful condition through the application of proper adaptive management techniques.

Soil management practices have evolved to provide sustainable soil management systems, adapting both to the environment and to existing social and economic circumstances. An understanding of the factors that determine the sustainability of these systems will make it possible to establish sound principles of sustainable soil management. Such management aims not only to maintain or improve soil productivity but to avoid all forms of soil degradation to conserve the environment. A major concern of good soil management is keeping soil in place and maintaining its fertility.

Soil management should, among other factors, maintain or improve crop productivity and mitigate existing soil constraints, such as nutrient depletion, organic matter loss, soil acidity, sodicity, and salinity. In the contemporary context, it should also promote resilience in the soil in the face of natural disasters. The focus of soil management practices in this study is to (i) replenish depleted soil nutrient, (ii) combat soil acidification, sodicity, and salinization (iii) restore OM. These practices enhance soil productivity and environmental quality.

Nutrient Depletion

Nutrient depletion in soils adversely affects soil quality and reduces crop yield and consequently poses a potential threat to global food security and agricultural sustainability. The continued lack of required nutrient replenishment of nutrient depleted soils as well as nutrient losses through wind and water erosion are not only exacerbating soil degradation, but also jeopardizing agricultural sustainability (Ayoub, 1999; Sheldrick *et al.,* 2002). This is evident in the long-term decline in crop yields under conditions of low-input and unbalanced fertilization in many parts of Africa, Asia, and Latin America (FAO/UNDP/UNEP/World Bank, 1997). Dynamically, nutrient depletionis the process by which the soil nutrient stock is shrinking because of continuous nutrient mining without sufficient replenishment of nutrients harvested in agricultural products, and of nutrient losses by soil erosion and leaching. Soil erosion is mainly a natural process and usually treated as an independent issue. And the nutrient loss from leaching is also driven by a natural process although it is exacerbated by application of fertilizers, especially N. Therefore, human-induced nutrient depletion is defined as a soil nutrient mining process driven by biomass removal without adequate replenishment of the required nutrients. It constitutes a majority of generic soil nutrient depletion, and can be evaluated in term of the annual nutrient deficit within a specific cropping system.

However, in cropping systems, such removal can comprise the major component of soil nutrient depletion. Other components include nutrient removal in vegetative parts of crops and their residues, and losses through soil erosion, runoff, leaching, and burning of crop residues, and gaseous losses (eg. denitrification and volatilization). When soil is first brought under cultivation and cropping there may be a substantial reserve of nutrients in the soil. The outputs of nutrients often exceed inputs for several years, but this can only occur by depleting there serve of soil nutrients. For a while, the system may remain productive and non-responsive to nutrient additions (Russell, 1981). However, in the long term, the system is unsustainable.

Factors that promote nutrient depletion

Removal in crop residues

Nutrient removal in economic production is necessary; it need not be so in crop residues because these can be returned to the soil. When returned to the soil, crop residues have a number of beneficial effects: they provide substrate for microbial and mesofauna activity which assists in nutrient cycling, they increase OM and reduce losses of total N, available P, and exchangeable K, especially under zero tillage, and they aid aggregation, infiltration, and soil water retention and influence soil temperature (Prasad and Power, 1991). When crop residues are removed from the soil, substantial amounts of nutrients are also removed. Hence, the rate of soil nutrient depletion increases, especially of the basic cations K, Ca, and Mg.

Burning of crop residues

Significant soil nutrient depletion can occur by the burning of surface and standing biomass. Burning of crop residues causes a loss in the gaseous form of most of the C, N, and S they contain. Furthermore, substantial losses of P, Ca, K, and Mg can occur in particulate form during a hot bum (Walker *et al.,* 1986). About 90 % of such losses originate from the tropics and sub-tropics (Kuhlbusch *et al.,* 1991), where they may be particularly critical for the stability of agro-ecosystems. The loss of N from burning of crop residues may affect the nutrient balance of agricultural systems, as has been shown by Dalal (1992) who found that the practice significantly decreased the total N content. Whilst burning is a useful management option for disease control under some circumstances, it has a cost in terms of nutrient depletion.

Soil erosion and runoff

Soil erosion by water and/ or wind is a geomorphic process, and in a natural ecosystem at steady- state, its degrading effect is negligible because the rate of erosion loss approximates the rate of soil formation. When the ecosystem is disturbed by clearing of vegetation and/or land development, soil erosion may become a most visible process of soil fertility depletion by removal of the most fertile topsoil. In its less visible forms, it has an insidious and detrimental effect on long-term soil productivity, selectively removing organic matter, and fine soil particles, and leaving behind coarse particles. In general, the impact on soil fertility by wind erosion decreases, and that by water erosion increases with increasing rainfall (Marshall, 1973). Water erosion also increases with increasing rainfall intensity. Hence, erosion of soil leaves it with less N, P, and K, and potentially lower productivity (White *et al.,* 1991).

Gaseous losses of N

Nitrogen can be lost by denitrification in the soil through anaerobiosis. Ammonia volatilization can also occur, especially when ammonical fertilizers are surface-applied, and from dung and urine of animals. Generally, the loss of soil nitrate through denitrification increases with an increase in easily decomposable OM, soil temperature and nitrate concentration, and with a decrease in oxygen supply. Volatilization losses of ammonia from ammonium and ammonium-producing fertilizers may be as high as 25 %, depending upon the method of application, soil type, CEC of the soil, moisture content, temperature, and plant growth (Vallis*et al.,* 1985).

Leaching

Leaching is often the most important process of soil nutrient depletion in agro-ecosystems. The most common nutrient that limits crop growth, N as nitrate-N is most readily leached beyond the root zone. Ritter (1989) reported that leaching losses of N as NO_3 can be large (4-350 kg/ha/yr) when soil nitrate-N concentration is high and high rate of movement large amount of water. Hence management of water movement and N supply are required in controlling nitrate leaching. Soil management practices such as zero tillage and crop residue retention may enhance nitrate-N leaching by increasing water infiltration and movement in the soil (Turpin *et al.,* 1992), or reduce leaching losses through lowering soil nitrate-N concentrations. Therefore, there isa need for effective management of available soil water and nitrate supply concerning crop growth and cropping intensity.

Practical methods of managing nutrient-depleted soils

Optimized timing and rate of fertilizer application

Optimizing the timing and rate of fertilizer applications ensures that the nutrients are available in the soil at a time when the plant can take them up, which limits nutrient loss, hence reducing the risk of water pollution and downstream eutrophication (Carpenter *et al.,* 1998). A fertilizer management plan can help in implementing optimized nutrient management, soil testing to establish soil nutrient status before fertilization, and precision farming, to ensure that nutrient additions are targeted where needed. Subsurface application of slurries to reduce ammonia volatilization can increase nitrous oxide emissions, so there can be trade-offs associated with this practice (Sutton *et al.,* 2007).

Optimized use of agrochemicals

Reductions in use of broad-spectrum bioactive agrochemical will benefit soil biota. The under-application of pesticides and herbicides could also plausibly have a net negative environmental impact if it means that more land needs to be brought into production (Carlton *et al.,* 2012). The application of agrochemical appropriately will also reduce water pollution through leaching.

Application of organic fertilizers

Organic fertilizer includes any material added to soil to improve its properties which can be physical, chemical or biological to allow healthy crop growth. They improve soil properties and processes such as structure, water retention, permeability, water infiltration, drainage and aeration, nutrient supply, and biological activities which are important for the proper functioning of soil to support sustainable agricultural production (Ussiri and Lal, 2005). However, different organic fertilizer types and doses affect soil properties and processes differently. Because organic fertilizer increase water infiltration, water storage, reduces surface sealing, erosion, and loss of nutrients in runoffs, they have potential to be used to minimize the effects of drought and floods. The organic fertilizers also provide nutrients for the crop plants which are another important, often limiting the requirement for healthy crop growth.

Use of Cover crops

Cover crops are grown to improve soil fertility and productivity. Some cover crops, such as legumes, can also fix nitrogen from the atmosphere and add it to the soil, thereby increasing nitrogen availability for other crops. Cover crops are generally mowed, sprayed with herbicide, or killed before or during soil preparation for the next primary crop. Reduced nitrate production has environmental benefits as it lowers the potential for leaching and gaseous nitrogen losses. Residue incorporation produced lower mineralization rates and reduced N_2O emissions than the bare ground due to the temporary immobilization of nitrogen in the soil (Baggs *et al.,* 2000).

Use of Crop rotation

Crop rotation plays a major role in enhancing weed control and mitigating the risk of pest and diseases incidence, particularly in the soil (Kirkegaard *et al.,* 2008). Having legumes in the rotation also improve the nutrient cycle. Boulal *et al.* (2012) states that crop rotation would also help to conserve a manageable amount of residues in the system by combining high and low producing crops. Different crop species with different root systems explore different soil horizons and hence increase the efficiency of the use of soil nutrients. Magdoff, (1993) had earlier reported that the types of crops grown, roots amount, rooting system, biomass yield, and efficiency of harvest, and the management of residues affect soil nutrients. The interaction between with cover crops, conservation tillage and a good amount of residue crops in rotation increase amounts of soil nutrients. The principal objective of crop rotation is to contribute to the achievement of a production that is profitable and sustainable, maintaining soil fertility.

Reduced till options

Minimum tillage and no-tillage systems on their own will not significantly increase organic matter levels in soil, but will reduce the rate at which the decline. When combined with other actions or organic fertilizers they will help to maintain or increase the organic matter level. A major advantage of zero- and minimum-tillage techniques is that they can be used to leave a cover of crop residues on the soil to protect it from the impact of direct rainfall. This prevents the dispersion of soil material from aggregates and maintains the infiltration capacity of the soil, so minimizing run-off and the consequent soil erosion problems. In drier areas, the cover is also important in protecting the soil from erosion by the wind. Keeping a cover on the soil is now widely recognized as the most important factor in soil conservation.

Organic Matter Loss

Organic matter is critical for the stabilization of soil structure, retention and release of plant nutrients and maintenance of water-holding capacity, thus making it a key indicator not only for agricultural productivity, but also environmental resilience (FAO, 2005). The decomposition of SOM further releases mineral nutrients, thereby making them available for plant growth (FAO, 2017; Van der Wal and de Boer, 2017), while better plant growth and higher productivity contribute to ensuring food security.

Loss of organic matter can limit the soil's ability to provide nutrients for sustainable plant production. This may lead to poor yields and enhances food insecurity. Less organic matter also means less food for the living organisms present in the soil, thus reducing soil biodiversity. Loss of soil organic matter reduces the water infiltration capacity of a soil, leading to increased run-off and erosion. Erosion also reduces the organic matter content by washing away fertile surface soil. Under semi-arid circumstances this may even lead to desertification.

There is considerable concern that if soils are allowed to decrease in organic matter, the productive capacity of agriculture will be then compromised by deterioration in soil physical properties and by disruption of the soil nutrient cycling process (Bauer and Black, 1994, Loveland and Webb, 2003).

Factors that promote loss of organic matter

Environmental factors such as soil temperature, soil moisture, and aeration enhance the rate of organic matter decomposition. Since soil texture can affect soil aeration, it also influences soil organic matter decomposition.

Temperature

Several field studies have shown that temperature is a key factor controlling the rate of decomposition of organic matter. The rate of decomposition of OM normally occurs more rapidly in the tropics than in temperate areas. Reaction rates doubled for each increase of 8–9 °C in the mean annual air temperature. The relatively faster rate of decomposition of organic matter activated by the continuous warmth in the tropics implies that it is difficult to achieve high equilibrium levels of organic matter in tropical agro-ecosystems. Therefore, large annual rates of organic matter inputs are required to maintain an adequate labile soil organic matter pool in cultivated soils. Soils under temperate climates commonly have more organic matter because of gradual decomposition and mineralization rates.

Soil moisture and water saturation

Soil organic matter levels increase as a result of an increase in mean annual precipitation of an area. The conditions that elevate the level of soil moisture result in greater biomass production, which provides more residues, and thus more potential food for soil organisms. Soil biological activity requires mostly air and moisture. The microbial activities are at optimal when the soil is at field capacity, which is equivalent to 60 % water-filled pore space (Linn and Doran, 1984). Hence, the periods of water saturation lead to poor aeration in the pedosphere. Most soil organisms need oxygen, and thus a reduction of oxygen in the soil brings about a reduction in the rate of mineralization as these organisms become inactive or even die. Some of the transformation processes become anaerobic, and as such can lead to damaged plant roots caused by waste products or favourable conditions for disease-causing organisms

(FAO, 2005). The increased rate of nitrogen mineralization caused by an increase in level of microbial activity is due to the first few drops of rains activating the labile soil organic matter (Mueller-Harvey *et al.,* 1989).

Farmers who practice “slash and burn” for agricultural land preparation often choose early planting to take advantage of this flush of inorganic nitrogen before it is lost through leaching and runoff. The amount of nitrate present in the soil during the early part of the rainy season is associated to the organic matter content of the soil.

Soil texture

Soils organic matter tends to increase with an increase in clay content of the soil. This increase depends on two principles. First, the bonds between the clay particles surface and organic matter retards the decomposition process. Secondly, the soils with higher amount of clay content increase the potential for aggregate formation. According to Rice, (2002) macro-aggregates physically protect organic matter molecules from further mineralization caused by the microbial attack. The soils under similar agro-climate conditions shows that, the organic matter content in fine-textured (clayey) soils is two to four times that of coarse-textured (sandy) soils (Prasad and Power, 1997).

However, high amount of organic matter are difficult to sustain in cultivated kaolinitic soils within the wet-dry tropics, because climate and soil conditions favour rapid decomposition of organic matter. In contrast, organic matter can persist as organo-oxide complexes in soils rich in iron and aluminum oxides. Such properties favour the formation of soil micro-aggregates, typical of many fine-textured, oxide-rich, and high base-status soils in the tropics (Uehara and Gilman, 1981). These soils rich in iron and aluminum oxides are known for their low bulk density, high micro-porosity, and high organic-matter retention under natural vegetation, but also their high phosphate fixation capacity on the oxides when used for crop production. The parent material influences organic matter accumulation not solely through its impact on soil texture. Soils developed from inherently rich material, such as basalt, are more fertile than soils formed from granitic material, which contains fewer mineral nutrients.

Topography

Organic matter accumulation is usually favoured at the foot of the hills. There are two reasons for this accumulation: conditions are wetter than at mid- or upper-slope positions, and organic matter is transported to the lowest point in the landscape through runoff and erosion. Similarly, soil organic matter levels are higher on north facing slopes compared with south-facing slopes because temperatures are lower (Quideau, 2002).

Salinity and Acidity

Salinity, toxicity, and extremes in soil pH contribute to poor biomass production and, thereby reducing addition of organic matter to the soil. For instance, pH affects humus formation in two broad ways; through decomposition and biomass production. In strongly acid or highly alkaline soils, the growing conditions for microorganisms are poor, resulting in low levels of biological oxidation of organic matter (Primavesi, 1984). Soil acidity additionally influences the supply of plant nutrients and therefore regulates indirectly biomass production and the availability of food for soil biota. The bacteria are more sensitive than the fungi in acidic soil conditions.

Vegetation and biomass production

The level of soil organic matter accumulation depends largely on the amount and quality of organic litter input. In the tropical region, the applications of readily degradable materials with low C:N ratios, such as green manure and leguminous cover crops, favour decomposition and a short-term increase in the labile nitrogen pool during the growing season (FAO, 2005). On the opposite, applications of organic materials with both large C:N ratios and lignin contents such as cereal straw and grasses generally favour nutrient immobilization, organic matter accumulation, and humus formation, with increased potential for improved soil structure development. Plant constituents such as lignin and other polyphenols retard decomposition.

Practical methods of managing organic matter loss

The need to effectively maintain or increase organic matter level in soil depends on the rate of input which must exceed the rate of loss from decomposition and leaching processes. In most cases associate with agriculture, this can be achieved through stubble retention, rotating crops with pasture, afforestation, or the addition of organic residues such as animal manure, litter or sewage sludge. The largest source of soil organic matter readily available is the residue contributed by current crops. Consequently, crop yield and type, method of handling residues, and frequency of fallow are all important factors that will aid in the maintenance of soil organic matter.

Crop rotation

Crop rotations involving perennial forages tend to stabilize soil organic matter at a higher level than crop rotations involving fallow. A production system that includes covers crops, legumes for nitrogen fixation, crop rotation with cereals or grain maize and temporary grass contributes substantially to the increase of organic matter in the soil. The conversion of arable land to grassland is still the most successful conversion practice for enhancing soil organic matter levels.

Zero/Minimum tillage

Zero tillage and reduced tillage will result in a higher concentration of organic matter particularly in the top 10 cm of the soil but will not help increase organic matter in the deeper soil layers below the plough zone. Reducing soil disturbance is often done to improve soil moisture retention to enhance soil function, and can also increase organic matter (West and Post, 2002; Ogle *et al.,* 2005). However, considering the tight coupling of soil C and N, increased organic matter also tends to increase nutrient supply, and also enhances water holding capacity (Lal, 2004) which in turn improves the delivery of ecosystem services, and can increase soil biota. Zero tillage also gives rise to a greater earthworm, and arthropod populations (House and Parmelee, 1985).

Ground cover

Maintaining ground cover through improved residue management, and use of cover crops during traditional bare fallow periods helps to improve organic matter returns to the soil, prevent erosion and surface sealing, maintain soil nutrients, soil moisture, and support an active level of soil biota (Lal, 1997). Similar benefits can be achieved through well-designed rotations and the use of perennial crops or agroforestry (Mbow*et al.,* 2014). In drier areas, the cover is also important in protecting the soil from erosion by the wind. Keeping a cover on the soil is now widely recognized as the most important factor in soil conservation.

Saline Soils

Saline soil means soils with excessive soluble salts that retards seed germination and plant growth (Conway, 2001; Denise, 2003). These soluble salts exist in soil as cations and anions. Cations are calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^{+}), while anions are chloride (Cl^{-}), and sulfate ($SO4^{2-}$) ions. Mostly occurring salts in saline soils are sulfates and chlorides of calcium and magnesium. Small quantities of cations potassium (K^{+}) and (NH_4^{+}) and the anions bicarbonate (HCO_3^{-}), nitrate (NO_3^{-}) and carbonates (CO_3^{2-}) are also present (Appleton *et al.,* 2009; Scianna, 2002). In saline soils soluble salts are in excess while exchangeable sodium is present in small concentration thus having good physical properties, flocculated soil structure and high permeability like in normal soils (Appleton *et al.,* 2009; Jim, 2002). Patchy crop growth and tip burn or chlorosis of leaves of plants is observed due to salt injury in salt effected soil. The saline soil retards the plant growth primarily because of excessive salts in the soil solution (Tan *et al.,* 2015). According to Tan *et al.* (2015) plants cannot get enough water due to high osmotic pressure developed in the root zone which, prevent absorption of moisture and nutrients in adequate amounts.

Causes of salinity

There are two main causes of salinity

- Primary salinity (Natural process)
- Secondary salinity (Anthropogenically induced salinity): Secondary salinity is primarily due to improper irrigation system and use of poor quality water.

Primary salinity

Primary salinity is a naturally occurring process mostly occur in arid and semi-arid regions where rainfall is low while evapotranspiration rate is high, thus there is no sufficient water to leach salts down to avoid salinization (McDowell, 2008). Due to low rainfall, high transpiration and evaporation, salinity rise as salt concentration on soil surface increases while the availability of water decreases (Bridgman *et al.,* 2008). It is estimated that 1000 million hectares of the world's total land which is equal to 7 % of the world's area is salt-affected (Rose, 2004). The primary salinityis the main contribution in salinity which is consequential of natural soil development. Huumllsebusch, (2007) stated that salinity occur naturally mostly in arid tropical areas. Primary salinity is also caused by a natural release of some soluble salts in soil by weathering of the parent material during the soil development process, these soluble salts are Cl^{-} of Na^{+} , Ca^{2+}, and Mg^{2+} and sometimes SO_4^{2-} and CO_3^{2-} (Ashraf and Harris, 2005; Thiruchelvam and Pathmarajah, 2003). Inadequate drainage is another factor causing soil salinization; it may involve the low permeability of soil or elevated groundwater. This high groundwater is often due to physiographic unevenness. The water moves from higher lands over the sloping surface towards the lower lands cause either salty lakes or temporary flooding. Under such conditions, the removal of water from the surface develops saline soil (Ashraf and Harris, 2005). Indurate layers in soil profile and poor soil structure results in low permeability. This low permeability leads to poor drainage by restricting the downward movement of water (Thiruchelvam and Pathmarajah, 2003).

Secondary Salinity

Secondary salinity is mainly due to disruption in hydrological cycle either through the replacement of natural vegetation with deeply rooted vegetation or through the excessive utilization or ineffective supply of water for agriculture (Beresford *et al.,* 2004; Rose, 2004). Salt affected land area is increasing day by day due to anthropogenic land-use practices (Bridgman *et al.,* 2008). Secondary salinity due to anthropogenic practices that alter the hydrologic cycle and disrupt the water balance of the soil between water irrigated and water used by crops (transpiration) (Manchanda and Garg, 2008). In many irrigated areas, the water table has raised due to unjustified amounts of applied water together with poor drainage. Natural salinity has been intensified from the plant using more water to the plant using less water which cause rise in the water table when irrigation water quality is fringe or poorer (Thiruchelvam and Pathmarajah, 2003). Also, when the soil drainage may not be suitable for irrigation, the considerable rise in water table from a depth of few inches to a few feet of the soil surface is occurred mainly due to irrigation. When the water table rises to 5 or 6ft of the soil surface, groundwater moves upward into the rooted area and to the soil surface. Under such circumstances, both groundwater and irrigation water contribute to the salinity. Other causes of secondary salinity are deforestation, intensive cropping, overgrazing of cattle, use of fertilizer and other amendments (Ashraf and Harris, 2005).

Practical methods of managing Saline Soils

Irrigation Method

It is very important in irrigating the soil to check down the high concentration of the salt in the root zone. It is reported that application of a large amount of water for the irrigation purposes plays a supportive role for the adequate uptake of water by plants. Sprinkler irrigation is one of the best methods for irrigation especially when water shortage and salinity are the major problems. Soluble salts leach down from the root zone when irrigation is applied to the soil for the maximum time and quantity. Thus sprinkler irrigation ranks high in efficiency as compared to the flooding. It is reported by Nielsen *et al.* (1966) that requirement of water becomes 3 times more in flood irrigation when compared with the sprinkler irrigation for lowering the same amount of the salts. It is also beneficial that land leveling is not required for the uniform application of the water which is the basic necessity in the flooding irrigation. Similarly, drip irrigation which is sometimes also called trickle irrigation is the best method of irrigation for the perennial crops and seasonal row crops. As it supplies the water at one point the problem of salinity become minimized. The salt concentration will become low by this method of keeping the water table low. When water table is low, the risk of salinity development reduces up to great extent.

Mulching

Salts come at the surface of the soil when the process of the evaporation becomes faster that application of water. Even the leached down salts can come at the surface along with water with capillary rise process when irrigation will not be applied for a long time especially during the fallowing of the land. Soil salinity is the major problem when the water table is shallow along with the high EC of the irrigation water. But the problem salinity can be reduced by lowering the evaporation process. Evaporation becomes limited when soil remains covered with vegetation. It is recommended that the salinity problem becomes less when the process of evaporation will be lowered by mulching or covering the soil (Sandoval and Benz, 1966). Thus, after the fallowing of land, mulching help control the salinity problem.

Adaptations of Salt Tolerant Plants

To choose the plants that have tolerance against the salinity is the major step in reclamation of the salt-affected soils. It is because different plants have different potential to uptake and accumulation of the salts to minimize the salinity problem (Conway, 2001). Different species of plants show salt tolerance against salinity by developing the mechanisms like salt exclusion, uptake, and compartmentalization of salts and extrusion of salts (Holly, 2004). These salt tolerant plants are also referred toas the halophytes. Physiological property of halophytes is usually expressed as morphological features like salt glands, salt hairs, and succulence. Plants depend on more than one tolerance mechanism for salt tolerance (Naidoo and Naidoo, 1999). Halophytes can adjust osmotic effects internally by accumulating high salt concentrations or they may become able to absorb more water from saline soils (Azevedo Neto *et al.,* 2004). Salt exclusion permits plants to maintain and reduces the quantity of salts that go to growing leaves and young fruits. A few species have adopted excluder mechanisms to tolerate salinity stress. Through this mechanism, plants filter the salts in their roots and resist against the salt uptake towards the upper parts. Salt stress is tolerated by the plants by reducing germination, growth, and reproduction to specific seasons during the year and by growing roots into non-saline soil layers, or by fewer uptakes of the salts from the soil (BPMC, 1996). Plants accumulate the salts into their vascular tissues and try to avoid the exposure of chloroplast to the salts (Misra*et al.,* 2001). Production of organic solutes also helps the plants to retain the water balance between the cytoplasm and vacuoles (Holly, 2004). Plants can uptake more water from the soil when water potential of the soil will be higher than the water potential of the cells of the plant (Taiz and Eduardo, 1998).

Sodic Soils

Soils containing high exchangeable sodium concentration but low total soluble salts are called sodic soils (Jim, 2002). Such soils are characterized by having electrical conductivity < 4 dSm^{-1} soil reaction (pH)> 8.5, sodium adsorption ratio (SAR) > 13 and exchangeable sodium percentage (ESP) > 15. The CO_3^{2-} and HCO_3^{-2} are dominant anions of sodic soils (Qadir and Schubert, 2002). Excess Na^+ on the cation exchange sites causes clay particles to disperse or swell, and as a consequence, these soils have poor structure, low aggregate stability, and reduced water infiltration (Rengasamy and Olsson, 1991). Globally, sodic soils are known asa poor rooting medium for plant growth and provide insufficient nutrients. Rao and Pathak, (1996) stated that sodic soils also have reduced biological activity and function due to the limited availability of C substrates that are likely the result of lowered net primary productivity in these soils. Soils containing considerable amounts of sodium are not flocculated. This hinders the movement of air and water through the soil. The absorption of sodium by soil clay and organic colloids causes dispersion of clay which results in degradation of soil structure (Tan *et al.,* 2015). Poor soil structure reduces drainage, aeration and microbial activity.

Origin and Distribution of Sodic Soils

In most areas with sodicsoils,sodicity originated from the nature of the parent material and pedogenic processes. There are also sodic soilswhich arise from anthropogenic processes and this is termed secondary sodification. Practices such as irrigating farmland without proper drainage with sodic water, destruction of forest, and other land management practices that encourages waterlogging are key activities that may lead to rapid secondary sodification. Levy and Shainberg (2005) observed that the spatial and temporal distribution of sodic soils shows that they occur within intervals of climates. However, the distribution of sodic soils and the conditions promoting their formation are based on a pedological process. Following the increase in the contribution of human activity to soil sodification, the definition of sodic soils is now based on soil behavior.

Practical methods of managing Sodic Soils

Remediating the effects of excess Na^+ in sodic soils can be accomplished with soil amendments and land management. Reclamation of the sodic soil is very difficult and mostly expenses become high than income. By following the above procedures reclamation of the sodic soil is possible but it took many years to completely reclaim this problem while following the good crop management practices.

Drainage

The problem associated with soil sodicitycan be controlled by removing the high concentration of sodium from the root zone by good drainage practice. The low water table helps reduce this problem. By the development of the tile drains and by changing the topography sodic soils can be reclaimed up to the great extent. The problem of the sodicity can be supportively controlled by sealing of canals or lining of canals. However, soils with good drainage property are very important in controlling the problem of the sodicity.

Tillage and Amendments

Tillage practice is considered as the physical practice in reclaiming the problem of sodicity. Tillage causes the fragmentation of the big soil colloids having the high concentration of the sodium and amendments will become the part of the soil and reclaiming process becomes faster. Large organic matter which has the property of slow decomposition like straw, cornstalks, sawdust, or wood shavings used for animal bedding is reported beneficial for improving soil structure and infiltration properties of soil along with the other reclamation activities.

Organic matter application

Addition of organic amendments improves soil structure increasing soil permeability (Tejada*et al.,* 2006). Schnürer and Rosswall, (1985) revealed that there is a positive correlation between organic matter and microbial activity. Microbial population improved soil physical properties which accelerate the ameliorative process of salt-affected soils. (McCormick and Wolf, 1980) observed that alfalfa residues used as an organic amendment can reduce the deleterious effects of soil sodicity. Biochar is widely used as an organic amendment nowadays, has beneficial effect in ameliorating salt-affected soils. Biochar improves soil structure having positive on bulk density, pore-size distribution and particle size distribution (Roberts *et al.,* 2009; Sohi *et al.,* 2009).

Biochar benefits biophysical properties of soils increasing the availability of air and water in rhizosphere which in turn improves germination and plant survival (Zhang *et al.,* 2014).

Supplying Calcium to Improve Water Infiltration

Refining water infiltration property of soil requires lowering of the exchangeable sodium percentage (ESP) along with raising the electrical conductivity (EC) to more than 4 dS/m. It can be determined by the soil texture and irrigation method that how much exchangeable sodium percentage (ESP) is required to make the better infiltration. Sandy textured soils can bear the exchangeable sodium percentage (ESP) up to the 12 % while still having good infiltration and percolation. Surface irrigation similarly can retain good infiltration and percolation with high exchangeable sodium percentage (ESP) as compared to the sprinkler irrigation. Calcium is a basic need in the reclamation process of the sodic soils as it can replace the sodium and that lowering the ESP as well as SAR.

Irrigation Water Management

Irrigation water that comes from the deep wells has a great concentration of bicarbonate and thus high sodium concentration as compared to the calcium and magnesium. Irrigation with such type of water for a long time creates the problem of sodicity. EC and SAR are used to evaluate the infiltration problems by the application of the irrigation water.

Soil Acidity

Soil acidity is among the major land degradation problems, which affects about 50% of the world's potentially arable soils (Kochian *et al.,* 2004). Soil acidity is among the major land degradation problem worldwide. Tropical and sub-tropical regions as well as areas with moderate climatic conditions are mostly affected by soil acidity. Acidic soil is observed to have low fertility rates, poor in physical, biological, and chemical properties. Poor management of such areas results in depressed crop yield to a significant level (He *et al.,* 2003). Soil acidity significantly affects plants yield and productivity by declining available nutrient contents. Two major factors associated with soil infertility are the presence of phytotoxic substances like Al and Mn, and P, Ca, and Mg nutrient deficiency. Mostly plants uptake the nutrient in soluble form. Soil acidification cause profusion availability of elements such as Al and Mn and result in a shortage of plant's essential nutrients such as P, Ca, and Mg. it is noted previously that soil acidity is associated with H^+ and Al^{3+}. Surprisingly, there is no deleterious effect found on plants growth by H^+ (Rao*et al.,* 1993). Acidic soil's most of the problems are associated with Al^{3+}. The high concentration of Al^{3+} content in acidic soil results in reduced function and root proliferation. Roots mostly observed are stunted and club-shaped. This reduces the plant's capability to extract nutrients and water from the soil.

Causes of Soil Acidity

Both the natural and anthropogenic activities are responsible for soil acidity. Natural processes happen gradually and gradually affect the soil fertility but the anthropogenic effects are rapid. The factors that cause soil acidity are as follows;

Weathering and Leaching

The present soil is formed from the parent rocks which contain both the essential and non-essential nutrients of plants. The soil form is more acidic if the parent rock and material is acidic and more alkaline if the parent material is alkaline. Both the acidic and basic cations are released in the soil during weathering. Soils that develop from weathered granite are likely to be more acidic than those developed from shale or limestone (Agegnehu*et al.,* 2019). There are large areas of siliceous and sandy soils produced from acid parent rocks, which have always been in need of lime. The influx of these nutrients is mostly overcome by leaching basic cations that counteract with acidic cations and the preponderance of the acidic ions enhances soil acidity. The process is more active where precipitation rate is higher than evaporation, plant's transpiration rate and high temperature boost the process of weathering and leaching (Nyarko, 2012). Wet climates have a greater potential for acidic soils (Tadesse, 2001). Over time, excessive rainfall leaches the soil profile's basic elements (Ca, Mg, Na, and K) that prevent soil acidity. High rainfall leaches soluble nutrients such as Ca and Mg which are specifically replaced by Al from the exchange sites (Brady and Weil, 2016).

Organic matter decomposition

The decomposition of organic matter produces H+ ions, which are responsible for acidity. The development of soil acidity from the decomposition of organic matter is insignificant in the short-term. Large quantities of carbonic acid produced by microorganisms and higher plants including through other physicochemical and biological processes are the causes of soil acidity although the effect from its dissociation is relatively small as most of it is lost to the atmosphere as CO_2 (Kochian *et* *al.,* 2004; Paul, 2014). Soil organic matter or humus contains reactive carboxylic, enolic and phenolic groups that behave as weak acids. During their dissociation they release H+ ions. Further, the formation of CO_2 and organic acids during the decomposition also result in replacement of bases on exchange complex with H+ ions (Somani*et al.,* 1996).

Acid Rain

The areas under metropolitan or cosmopolitan with a dense concentration of vehicles and industries experience the formation of acid rain. Rainfall is acidic due to deposition of oxides of sulphur and nitrogen found in the atmosphere due to combustion, burning of coal/petroleum products, and agricultural activities. Due to these factors pH of rainwater becomes acidic and is found between 4 and 4.5 (Brady and Weil, 2002). With the excessive accumulation of these acids in the atmosphere, which if not controlled significantly affect the soil and plants growth (Brady and Weil, 2002). Precipitation is also an enhancing factor in soil acidity (Donahue *et al.,* 1983).

Crop Production and Removal

The main goal of any agricultural system is to produce saleable products. Soil acidification suffers as a limiting factor in this way. Respiration is necessary for both plants and microbes for their survival but it results in a large amount of acid production in the form of the carbonic acid. Tang and Rengel, (2003) reported that this is a very minute factor because most of carbonic acid produced during this process lost in the atmosphere as CO_2. According to Tisdale and Nelson, (1975), basic cations that are usually up-taken by plants are Ca^{2+}, Mg^{2+} , K^+, and also NH_4^+, as a result more H^+ dissociation by plants for their electrical balance especially when nutrients are absorbed in form of NH_4^+. The more the uptake of basic cations, the more the H^+ ions release which leads to acidity in the soil. There are basic cations available in plant especially in leaves and stem than the grains, these basic cations neutralizes the acidic effect which is developed by different processes but when these crops are removed from field either burnt, or harvested or washed away by run-off this counter effect of basic cations is gone and ultimately soil acidity increases (Chen and Barber, 1990). Type and part of the crop harvested and stage of the crop at harvest deals with the amount of these nutrients removed.

Application of Acid Forming Fertilizers

Continuous application of inorganic fertilizer without soil test, in the end, can increase soil acidity. The use of N fertilizers in ammonia form is a source of acidification (Fageria and Nascente, 2014; Guo *et al.,* 2010). The soils' inherent capacity is severely deteriorated by the result of high temperature, precipitation and incessant leaching of nutrients. This deteriorated land is unable to support any vegetative crop. The Use of agricultural land without sustainable management practices results in enhanced soil nutrient deterioration. However, to overcome these problems most the farmers use fertilizers extensively. Mostly used chemical fertilizers are ammonium sulphate (AS), urea, muriate of potash, and trisuperphosphateetc (FAO, 2004). Usage of these chemical fertilizers results in enhanced crop yield. As these fertilizers are essential for high production along with this, these chemical fertilizers significantly increase the soil acidification.

Practical methods of managing Soil Acidity

Soil acidification is a natural ongoing phenomenon which is aggravated by human activities. With the usage of proper irrigation techniques and practices, soil acidification and its harmful effects should be controlled. To overcome soil acidity issues use of the organic materials, lime materials, and acid-tolerant crop varieties are used. Among which use of lime and organic material combination is best in combating soil acidification problems and making soil vulnerable for irrigation practices. There is also an immense need to limit the extensive use of chemical fertilizers for combating soil acidification problems because such practices extensively enhanced soil acidity. In such areas where extensive use of lime along with organic material is a problem best remedy, there is to use acid resistant crop verities.

Liming

Liming is a major and effective practice to overcome soil acidity constraints and improve crop production on acid soils. Lime is called the foundation of crop production or ‟workhorse'' in acid soils (Fageria and Baligar, 2008). Lime requirement for crops grown on acid soils is determined by the quality of liming material, status of soil fertility, crop species and varieties, crop management practices, and economic considerations. Different liming materials such as dolomite lime ($CaMgCO_3$), limestone ($CaCO_3$), quick lime (CaO), slaked lime {$Ca(OH)_2$} usage are best remedies for overcoming soil acidity problems. They can use separately and in combined forms. Several other advantages of liming materials include increasing the plants essential nutrient such as Ca, P and Mg availability and reducing the toxic effect of various microelements (Naidu *et al.,* 1994). Liming material addition also reduces the leaching and solubility of heavy metals (Sauve *et al.,* 2000). Excessive nutrient availability significantly improve crop yield to substantial amounts by addition of liming materials. Soil texture, soil fertility, crop rotation, crop species and usage of organic manure are the several factors which affect the application of liming materials (Fageria and Baligar, 2008). (Sadiq and Babagana, 2012) reported that application of lime material on paddy fields significantly lowers the soil acidity. Application of lime in rice fields results in high Al and Fe precipitation which is responsible for their enhanced yield. Brady and Weil (2002) also reported that a high amount of Al ions contents result due to the use of lime and put deleterious effects on the underlying soil. At pH 5 aluminum ions start precipitation from the soil solution. This happened due to the reaction of ground magnesium limestone (GML) was combined with acid sulfate soil; both of these disintegrated immediately and start releasing hydroxyl ions. Shazana *et al.* (2013) reported that the actual reason behind the increase in soil acidity is the release of hydroxyl ions on the application of ground magnesium limestone. The ground basalt is advantageous for plants as it contains the plant's essential nutrients like K and P than ground magnesium limestone (Shazana *et al.,* 2013). The one disadvantage of ground basalt applications is it takes time to completely dissolve in soil. It is reported that in Malaysia soil content is poor in organic matter. The application of ground basalt by acid sulphate ameliorates nutrient deterioration in soil and it is highly recommended for sustained rice yield along with different organic fertilizers a few months before the growing season.

Application of Organic Materials

The organic material usage defines simply all the forms of organic materials originated from both the plants and animals. Application of organic material where improves soil's properties and fertility along with it also reduces the effect of soil acidity and aluminum ions concentration. Plants usually contain an excessive amount of cations, synthesis of organic acid anions simply used for balancing cations and anions (De Wit *et al.,* 1963). Decarboxylation of these organic acid anion result due to microbial decomposition (Tang *et al.,* 1999; Yan *et al.,* 1996). It was reported that anion organic acid decarboxylation requires proton to complete its reaction during microbial decomposition (Noble *et al.,* 1996). By up taking such proton, hydroxyl ions concentration increases which results in increase soil alkalinity. Higher the amount of cations in soil greater is the effect found on soil acidity. Wong *et al.* (2000) also indicated that organic material associated functional groups results in increase alkalinity of soil by consuming higher content of protons.

Use of Acid Tolerant Crops

Several plants grow well in acidic soil due to their variant degree of acidity tolerance. Thus, we can lower the acidification rate by using acid-tolerant crops. Acid-tolerant crops are very helpful because:

- They reduce the rate of acidification by efficiently using the nitrate and soil moisture
- Limestone if not added where and when is required, the acid-tolerant crops continue the cash flow.
- In the liming cycle of 10–15 years, acid-tolerant crops are trying to match up with the declined pH.
- On the soils having acidic sub-surface layers, it is more suitable or economical to use acid-tolerant crops rather than liming them (Upjohn, 2005).

Cassava and rice are best-grown crops for such acidified lands (Rao *et al.,* 1993). Upon the growth of most of the crops, soil acidity and aluminum toxicity put a limiting factor over their yield. Aluminum puts very hazardous effects on root growth and extension, significantly effecting roots water and ions uptake capacity. Usage of genetically adapted plants for aluminum toxicity is the best remedy to use on such affected land under low environmental impact. The availability of aluminum tolerant germplasm of maize had made it a suitable crop for this practice. Crops that exhibit tolerance to aluminum toxicity are the best options to be chosen as acid-tolerant crops (Kochian *et al.,* 2004; Ma *et al.,* 2001). No doubt, acid-tolerant crops reduce the rate of acidification but they cannot stop the process.

CONCLUSIONS

Nutrient depletion, organic matter loss, soil acidification, sodicity, and salinization are among serious prevailing issues in our modern era. It is badly affecting soil's natural fertility to enhance our economic values along with ecological issues. It is being caused due to natural and anthropogenic activities. The degradation processes depend on the rate of degradation; duration of usage of such degraded land and its management. Nutrient depletion, organic matter loss, soil acidification, sodicity, and salinization causes exploitation of soil resources, reduces soil productivity and alters the composition of vegetation; thus influencing billions of people around the globe directly or indirectly. Degradation of soils can considerably decrease the soil's capacity to produce food.

However, integrated soil fertility/quality management approach such as cover cropping, crop rotation, minimum/zero tillage, application of OM, use of irrigation, appropriate use of pesticides, mulching, and liming as required should be prioritized and adopted in agricultural soil use to ensure sustainable agricultural productivity, food security and environmental conservation.

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