REVIEW ON CHEMICAL SOIL DEGRADATION AS A RESULT OF CONTAMINATION

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ABSTRACT: Chemical soil degradation after erosion is the second most abundant form of soil degradation and as such poses a threat to our finite soil resource, as it tends to render it less usable. It is therefore necessary to understand the means by which soils are degraded chemically. This review paper seeks to highlight some of the causes of soil chemical degradation. One way by which soils degrade chemically is through soil contamination; either by diffuse contamination or from localised sources. Drivers such as salinization, acidification of soils, chemical fertilizer application and use of pesticides all tend to aid the process of soil chemical degradation. The review paper sheds light on these drivers of degradation and also discusses some assessment methods developed to determine soil chemical degradation. In assessing chemical degradation, a combination of assessment tools and soil quality indicator parameters or single assessment tools may be employed. Chemically degraded soils may be irreversible in most cases and as such its prevention will aid in agricultural sustainability. The cultivated lands are continuously degrading and the extent is increasing because of different natural environmental and anthropogenic activities. Soil degradation due to salinization, erosion, water logging etc. Saline soils can be cultivated growing different halophyte plants and using modern irrigation practices. Different amendments can provide calcium directly to the soil or indirectly dissolving native calcium from calcium carbonate already resent in the soil. Different studies demonstrate that under adverse conditions where chemical treatments are uneconomical tree plantations provide positive net returns to investment and significant net benefit and social outcomes from these lands.

KEY WORDS: Diffused contamination, localised contamination, soil assessment, soil health, soil quality, Acidification, Salinization.

INTRODUCTION

The practice of agriculture in the 21st century is faced with many challenges. For researchers in the field of agriculture, it has become necessary to understand and be innovative in countering the effects of the problems being faced. These challenges are as a result of the many impeding factors threatening agriculture sustainability either through anthropogenic causes or natural factors. One of these factors is soil degradation. Most often the term soil degradation is conflicted with land degradation, which in academic sense differs greatly. Soil degradation and land degradation have been clearly differentiated by several scientists over the course of time. FAO (2014) defines soil degradation as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries while
land degradation encompasses all the negative changes in the capacity of the ecosystem to provide goods and services. Of the various forms of soil degradation, chemical intrusion in soils as well as chemical soil degradation is of essence and has been noted by most soil researchers lately. According to Logan (1990), chemical soil degradation is of no less importance compared to other Table 1. Continental and global extent of chemical soil degradation in million hectares. Dry land zone is defined as the climatic region with an annual precipitation\evapotranspiration ratio of 0.65 or less. The humid zone has a ratio of more than 0.65.

<table>
<thead>
<tr>
<th>Continent</th>
<th>Loss of nutrients</th>
<th>Salinization</th>
<th>Pollution</th>
<th>Acidification</th>
<th>Total</th>
<th>% of degraded soil</th>
<th>Dryland zone</th>
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<td>6</td>
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</table>

Forms of degradation but it is often overlooked. An assessment report by EC (2013) iterates that, over 200 years of industrialisation has left a widespread of soil contamination, which has led to soils being chemically degraded in Europe. Chemical degradation refers to the accumulation of toxic chemicals and chemical processes which impact on chemical properties that regulates life processes in the soil (Logan, 1990). Suraj et al. (2001) stipulates that, a change in one or more of these soil chemical properties have a direct and indirect adverse effects on the chemical fertility of soils. Chemically degraded soils have the presence of large amounts of toxic chemicals interfering with activities of soil life processes.

These toxic chemicals may also interfere with nutrient availability, nutrient uptake and nutrient element mobility. A report by Oldeman (1992), states that a total of almost 240 M ha of the world soil is chemically degraded and this amounts to about 12% of the total area affected by human induced soil degradation. Overlooking of chemical soil degradation has been due to the fact that its impact is not clearly visible from the onset. In recent times there has been an increase in soil contamination (a major cause of chemical soil degradation in Europe (EC, 2013), arising from persistent human influence. A report by Van-Camp et al. (2004) states that, consumer behaviour and the industrial sector are contributing to the increase in the number of potential sources of contamination. These sources may include municipal waste disposal, energy production and transport, mainly in urban areas. Soil contamination as a form of chemical degradation differs greatly in other part of the world as the chemical sources differ according to location and activity.

The identified cause of soil chemical degradation can be related to the human activities of the inhabitants of that particular region. Many publications pertaining to chemical soil degradation have placed focus on identifying the chemical elements responsible for the degradation. A thorough investigation into assessment methodologies is lacking in most publications. An understanding of the role played by factors such as location and end use of land in assessing degradation is lacking. For this reason standardization of assessment methodologies can not be
Chemical degradation (nutrient depletion) of soil

Generally nutrients are lost through erosion in runoff and in the eroded sediment. Finer soil fractions are the most vulnerable to erosion. Nutrients, being abundant in these finer soil fractions, are also lost to erosion. Further nutrient losses occur through chemical degradation, i.e. deterioration of properties of the soil, that occur as a result of acidification and salination or sodification. The latter is common in arid and semi-arid areas where rainfall is inadequate to leach excess salts down through the profile but is not a concern in this study. The acidification process may be accelerated through burning and clearing of vegetation, continued use of acid containing fertilisers and excessive irrigation (Thomas 1997).

There may be other underlying causes of chemical degradation. In general, soil erosion has received the most attention in Ethiopia as this is seen as the principal form of soil degradation and nutrient loss. Therefore little is known about other nutrient losses processes. For example, Pol (1992) based on a study in southern Mali, reported that loss of nitrogen by erosion accounted for 17% of total nitrogen export and the remainder is lost through other mechanisms. The relationship between soil erosion and nutrient depletion is not widely understood with respect to the Ethiopian situation. It was estimated that the highlands of Ethiopia lost about 41 kg of Nitrogen/ha from agricultural lands between 1982 and 1984 and that the projected loss would reach 47 kg Nitrogen/ha by the year 2000 (Stoorvogel et al. 1993). Other studies have reported nitrogen deficits of over 100 kg/ha per year for the Ethiopian highlands (e.g. Steinfeld et al. 1998).

However, how much of these losses and deficits are due to soil erosion and how much is due to chemical degradation is unclear. In this section, some of the direct or immediate causes of chemical degradation are discussed. Leaching, a process of translocation of nutrients beyond the reach of crops, occurs in areas of heavy rainfall where there are lengthy periods of rain. The Soil Conservation Research Project has indicated that the highlands of Metu area (Illubabor) experienced chemical degradation due to leaching. Although no quantitative evidence is available to substantiate this, there is reason to suspect chemical degradation in areas like these. The nature of the soils, which varies from moderate to strong acidic, is an indication of leaching with more cation absorption sites being occupied by aluminium ions. This also implies potential aluminium toxicity and a decline in available nutrients. Actual aluminium toxicity, however, is not present (Hagmann 1991). Kefeni (1992) found that the loss of nutrients from eroded soil in a 100 ha catchment area in Anjeni in the Amhara region was about 210 kg N, 680 kg P and 160 kg organic matter per hectare per year. Tadesse (1992) found that out of 1000 soil samples collected and analysed from Wellega and Assosa, 68% were classified as strongly acidic having a pH range of 4.5–5.5. At Nejo, liming of acidic soil improved yield significantly. Soils having a low pH can fix nutrients such as P, Mo and Ca thus not making them available to plants while they release Mn and Al into the soil solutions leading to toxicity in crops and animal feeds. Nutrient depletion can be reduced, if not reversed, if adequate additional nutrients are applied to crops to replace potential losses through leaching.
uptake by plants and other processes. The problems related to reduced organic manure application were highlighted earlier.

Inorganic fertiliser application has been increasing slowly and Oromiya region is the largest consumer in Ethiopia utilising over 50% of the imported urea and di-ammonium phosphate. This is in a setting where there commendations have neither been location specific nor periodically assessed for fine toning. Fertiliser use is still not widespread and those farmers who apply inorganic fertilisers continuously to their soils to replace depleted nutrients cannot sustain high crop yields everywhere, perhaps because soil erosion exacerbates nutrient losses that are not fully compensated by current application rates. The length of the fallow period in the cropping cycle also influences the chemical properties of soils. Continuous cultivation leads to deterioration of the essential nutrients. Getachew (1991) showed a sharp decrease in total nitrogen content of Lixisols in Dizi catchment (Illubabor zone) in the first 3 to 5 years of continuous cultivation. This is obviously connected to a decline in organic matter under the same practice.

**Triggers of chemical soil degradation**

Kavvadias (2014) states that, chemical soil degradation is as a result of soil contamination from chemicals. This contamination process can be divided into diffuse contamination and source contamination.

**Diffuse contamination**

Diffuse pollution is an important threat to soil conservation and this is much evident in urban communities with multiple sources of emissions (Biasoli and Ajmone-Marsan, 2007). This is contamination that is associated with atmospheric deposition, certain agricultural practices and inadequate waste and wastewater recycling and treatment (Kavvadias, 2014). According to EEA (2014), most soils contaminated through diffusion of chemicals are often used as sites for the disposal of industrial and urban waste. The most important soil contamination substances from diffuse sources are atmospheric deposition of acidifying and eutrophying compounds or potentially harmful chemicals, deposition of contaminants from flowing water or eroded soils, and direct application of substances such as pesticides, sewage sludge, fertilizers and manure which may contain heavy metals onto the soil (Kavvadias, 2014). In order for diffused chemicals to cause damage in the soil, some characteristic properties of the soil must come into play (EEA, 2014).

One of such soil characteristic property is the soils unique composition. The unique composition of a soil determines how much water it can hold, the living organisms it supports, and which chemical reactions are likely to occur (EC, 2013). Based on the soil properties, the diffused chemicals may either react with other soil factors, get adsorbed to soil substances or may be leached directly into groundwater table thereby causing other forms of pollution. Due to the behaviour of these chemical substances in the soil, it is very difficult to determine their fate in the soil. Researchers often use the adsorption and solubilisation properties of the chemical to determine their fate, but this becomes difficult with diffuse chemicals as they exhibit both partial adsorption as well as partial solubilisation (EEA, 2014). With the onset of diffuse chemical degradation, certain soil functions are hindered.
The most important of these functions are the soil buffering, filtering and transforming capacity (EEA, 2014). With these functions lost or hindered, the soil loses its capacity to eliminate harmful chemical substances or reduce the effect on crop growth and yield. Also, if the accumulation of pollutants exceeds the buffering capacity, then soils of sediments can become the source of diffuse pollution to adjacent compartments such as for groundwater and surface water (Halm and Grathwohl, 2005). According to EEA-UNEP (2000), local contamination is an emerging issue, which usually affects areas with a high density of urban agglomeration and with a long tradition of heavy industry, or vicinities of military installation. The major contaminants observed in these areas are heavy metals, organic contaminants such as chlorinated hydrocarbons and mineral oils (EEA, 2014). The result of all these contaminants present in the soil are, the loss of soil function, uptake of contaminants by plants, or the contaminants posing other forms of environmental threats such as water pollution and affecting human health through direct contact (EEA, 2014).

**DRIVERS OF CHEMICAL DEGRADATION**

**Salinization and sodification**

Salinization is a process of chemical soil degradation, which greatly reduces soil productivity. Kavvadias (2014) defines salinization as the accumulation of water-soluble salts (including sodium, potassium, magnesium and calcium, sulphate, carbonate and bicarbonate) on or near the surface of the soil. Salinization involves the accumulation of different salts, but the increased content of exchangeable sodium (Na⁺) in a soil resulting to a completely unproductive soil is referred to as sodification (Kavvadias, 2014). There are several means by which salt accumulates in the soil and this is compounded by the activities of humans. According to Hedge et al. (2011) the source of soluble salts in the soil besides irrigation water are mineral weathering, fertilizers, salts used on frozen roads, atmospheric transfer of sea spray and lateral movement of ground water from salt containing areas.

Research done by West et al. (1994) identified that, there are three principal mechanisms of salinization. The first is salt accumulation, second is seepage of salt and the third is wind deposition. Salt accumulation occurs when leaching is induced due to reduced soil water, the salt content of the soil then accumulates at the surface or at some depth in the soil structure, and then following erosion, it becomes exposed. According to Ballantyne (1963), salinization can also occur when salt is leached into a perched water table and then seeps to a lower point in the landscape. The wind deposition relies on a suitable source of salt deposits where the wind carries them onto the surface of the soil at another location. Salinization is a common problem in arid and semi-arid regions where the rate of water loss from the soil through evapotranspiration is higher than the amount of rainfall received (Hedge et al., 2011). It is influenced by a number of factors and the main influencing factors according to Kavvadias (2014) are climate, the salt content of the parent material and groundwater, land cover and topography.

The EEA (1995), estimated salinization to affect around 3.8 million ha of land in Europe. This has become significant due to the rapid development of irrigation and increased demand for domestic water supplies causing a decline in conventional water resources. As a result waste

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water reclamation and reuse is increasing (Kavvadias, 2014). Ravilovich (1992) stated that, in clayey soils (Alluvial vertisol) increasing salinity problems are caused by irrigation with domestic effluent water. Salinization caused through irrigation can be prevented with appropriate irrigation patterns and measures that ensure that the right quantity of water required by the soil and plant is what is being supplied and not the excess.

**Soil Salinity**

**Salt Affected Soils:** Salt-affected soils can be divided into three different categories depending upon the nature of salts.

**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 ++ ), magnesium (Mg ++ ) 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 (HCO3 −), nitrate (NO 3 −) and carbonates (CO3 −2) are also present (Appleton et al. 2009; Majerus 1996; Scianna 2002). In saline soils soluble salts are in excess while exchangeable sodium is present in small concentration thus having good physical properties, fl occulated soil structure and high permeability like in normal soils (Appleton et al. 2009; Jim 2002; Majerus 1996; Scianna 2002).

Such soils have electrical conductivity ≥ 4 dS m −1 soil reaction (pH s) < 8.5, sodium adsorption ration (SAR) <13 (mmol L −1 ) 1/2 and exchangeable sodium percentage (ESP) < 15. Patchy crop growth and tip burn or chlorosis of leaves of plants is observed due to salt injury in salt effected soil. These soils are also called white kallar as large quantities of soluble salts on soil surface forms efflorescence. These soils can be identified by “White alkali” which is the white crust of salts on the soil surface.

**Saline-Sodic Soils**
Soil containing both excessive soluble salts and high exchangeable sodium content to adversely affect plant growth; known as saline-sodic soils (Majerus 1996). These soils have electrical conductivity ≥ 4 dS m −1 soil reaction (pH s) > 8.5, sodium adsorption ration (SAR) >13 (mmol L −1 ) 1/2 and exchangeable sodium percentage (ESP) > 15. Saline-sodic soils are converted into sodic soils when excess soluble salts are leached down and the properties of saline sodic soils changes into sodic soils having pH above 8.5, dispersed soil structure and less permeability of air and water (Denise 2003).

Soils having high exchangeable sodium concentration but low total soluble salts are called sodic soils (Jim 2002). Such soils are characterized by having electrical conductivity < 4 dS m −1 soil reaction (pH s) > 8.5, sodium adsorption ration (SAR) > 13 (mmol L −1 ) 1/2 and exchangeable sodium percentage (ESP) > 15. CO3 2− and HCO3 −2 are dominant anions of sodic soils (Qadir and Schubert 2002). At high pH and in the presence of carbonate ions

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magnesium and calcium got precipitated, thus the concentration of sodium ion increased in soil solution compared to other cations concentration (Majerus 1996; Qadir and Schubert 2002). Such soils often occur in semiarid and arid areas, which are frequently mentioned as “slick spots.”

The combination of increased sodium concentration, decreased salt concentration and increase in pH results in the dispersion of soil particles, result in destruction of soil structure (Conway 2001; Denise 2003). Sodic soils are termed as “black alkali” due to the deposition of organic matter on soil surface by evaporation, thus darkening the soil (Denise 2003).

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Causes of Salt Affected Soils
There are two main causes of salinity
1. primary salinity (Natural process)
2. 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 evapo-transpiration rate is high, thus there is not availability of sufficient water to leach salts down to avoid salinization (McDowell 2008). Due to low rainfall, high transpiration and evaporation, salinity rises as salt concentration on soil surface increases while availability of water decreases (Bridgman et al. 2008). It is estimated that 1000 million hectares of world’s total land which is equal to 7% of world’s area is salt affected (Rose 2004). The major contribution in salinity causes is primary salinity which is consequential of natural soil development. It mostly occurs in arid tropical areas where salinity occur naturally (Huumllsebusch 2007). Primary salinity is also caused by natural release of some soluble salts in soil by weathering of parent material during 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 ground water. This high ground-water 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, removal of water from 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 downward movement of water (Ashraf and Harris 2005; 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 2008). Estimated global secondary salinity rate are submitted at around 74 million hectares, with 43 million hectares irrigated land and the remaining area of non-irrigated land (Rose 2004). 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; Munns 2005). In many irrigated areas, the water table has raised due to unjustified amounts of applied water together with poor drainage. Most of the irrigation systems of the world have caused secondary salinity, sodicity or waterlogging (Manchanda and Garg 2008).

Natural salinity has been intensified from plant using more water to plant use less water cause rise in water table, when irrigation water quality is fringe or poorer (Thiruchelvam and Pathmarajah 2003). In addition, when the soil drainage may not be suitable for irrigation, the considerable rise in water table from 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 6 ft of the soil surface, ground water moves upward into the rooted area and to the soil surface. Under such circumstances, both ground water and irrigation water, contributes to the salinity. Another causes of secondary salinity are deforestation, intensive cropping, overgrazing of cattle, use of fertilizer and other amendments (Ashraf and Harris 2005; Thiruchelvam and Pathmarajah 2003).

Deforestation
Deforestation is recognized as a major cause of salinity and alkalinity of soils. Salinity is results due to migration of salts in both the upper and lower layers. That indirectly leads to the increase in temperature of surface water and reduction in average rainfall per year (Hastenrath 1991; Shukla et al. 1990). Tree covers and green vegetation’s act as buffer between soil and rain. In absence of green vegetation cover top thin soil rapidly gets eroded. Rate of water run-off and sedimentation in the rivers and streams is increased due to soil erosion. That leads to flooding and soil Stalinization (Domroes 1991; Shukla et al. 1990).
Accumulation of Air-Borne or Water-Borne Salts in Soils
Different salts and chemicals that release from the industry and factories can enter into the soil and water and thus problem of salinity rises in the soil (Pessarakli 2010). Similarly extra water that came out from municipalities and slush are responsible for the contamination of the soil which then become the part of salinity and or alkalinity causing factors (Bond 1998).

Contamination with Chemicals
In present era use of chemicals and intense agricultural activities especially in green houses and intensive farming system playing important role in the contamination of the soil that leads to the generation of salt affected soils.

Overgrazing
Overgrazing is common where the natural soil cover is poor and hardly satisfies the fodder contents of animal husbandry mainly occur in arid and semiarid regions (Pessarakli 2010). The natural vegetation becomes scanty and salinization develops, and this process ends up in desertification due to overgrazing.

Fallowing
Soil which is uncultivated for longer period of time invites salinity because it alters the net water movement in upwards direction which results in accumulation of salts. On the other hand a soil with green top cover is useful in diverting the hydrological cycle and movements of salts downwards (Hassan et al. 2011). Salts in the soil are electrically charged occur as ions. The main releasing sources of the ions are primary or natural sources and secondary or salinity caused by human influences (Pace and Johnson 2002).

Processes of Land Degradation
Following are the some processes discussed which alone or in combination effect land quality.

Soil Erosion
Soil erosion is one of major factor causing land degradation. Erosion not only removes upper fertile layer but also causes soil crusting or sealing, soil compaction, poor soil structure, low organic matter, poor drainage and run-off. There are two agents of soil erosion i.e. wind and water, each loss significant amount of soil and reduces its productivity and quality (Lal 1990; Troeh et al. 2004). 12% of total land area is affected by erosion globally (Oldeman 1998).

Soil Salinization
Land Degradation occurs due to high concentration of soluble salts, exchangeable sodium or both in such amount that decline the plant growth and soil productivity. According to (FAO 2000), of the world’s cultivated land; $3.97 \times 10^8$ ha is affected by salinity and $4.34 \times 10^8$ ha of land is affected by sodicity, thus making 6% of total land area.
Water Logging
Water logging is the rise of ground water in root zone, thus having adverse effects on plant growth. According to GLASOD assessment, 4.6 M ha area of irrigated land of Pakistan and India is affected by water logging (Bridges et al. 2002).

Decline in Soil Fertility
According to FAO (1994), decline in soil fertility causes land degradation by
(i) lowering soil organic matter,
(ii) deteriorating soil physical properties,
(iii) imbalance in soil nutrient status and
(iv) accumulation of toxic metals. It is said that these processes are caused by natural (erosion, salinity etc), institutional factors (improper land policies, inadequate planning) and socio-economic activities (improper land use, exploitation of forests, contamination of resources etc) (Ezeaku and Davidson 2008).
These phenomena’s have devastating impacts on human-beings and on environment.

Acidification
Acidification is the change in the chemical composition of the soil, which may trigger the circulation of toxic metals (Nagle, 2006). Acidification impacts negatively on the soil ecosystem thereby causing damage to plants. It also results in the alteration of soil water chemistry. Soil acidification results from pH decline or from acid deposition. The phenomenon of acid deposition arises from the deposition of emissions from vehicles such as SO2, power stations, other industrial processes and natural bio-geochemical cycles onto the soil surface mainly via rainfall and dry deposition (EC, 2013). One of the soil types most affected by acidification is acid sulphate soil.

According to Dent (1986), the extreme acidity of these soils is as a result of the oxidation of pyrite when pyrite rich parent materials are drained. Pyrite accumulates in waterlogged soils that are rich in organic matter and also dissolved sulphates from seawater. Upon drainage, oxygen enters the soil system and oxidises pyrite to sulphuric acid causing the pH to drop to less than 4. Acidified soils hinder the availability of some mineral elements in the soil either by reacting to produce forms that become bound to the soil particles or form complexes or the elements are leached further down the soil structure.

Soil Acidity
Acidic soils mostly have pH values less than 7 on the pH scale (Soil Science Society 2008). Acidity of the soil mainly depends on the availability of exchangeable forms of hydrogen and aluminum ions (Brady 2001; Fageria and Baligar 2003). Higher the concentration of these exchangeable ions higher is the amount of acidity in the respective soil. 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).
Causes of Soil Acidity
Both the natural and anthropogenic activities are responsible for soil erosion process. Natural processes happen gradually and affect the soil fertility in a gradual way but the anthropogenic effects are rapid.

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 in nature if the parent rock and material is acidic and more alkaline in nature if the parent material is alkaline. Both the acidic and basic cations are released in soil during weathering. The influx of these nutrients is mostly overcome by leaching basic cation that counter act 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).

Organic Matter Decomposition
Both the plants and animals take nutrients in various forms during the course of their lives. Even after their death when the process of decomposition starts these organic matters along with many sundry chemicals are again handed over to soil. In the course of this eternal process acids are continuously formed and consumed. Usually organic matter has reactive substances like phenolics and carboxylic groups. These reactive substances on dissociation release H+ ions which result in enhanced soil acidity (Seatz and Peterson 1964). Carbonic acid also formed as reaction of CO2 which is released during process of decomposition with water. Brady (2001) reported that very little soil acidity is contributed by decaying organic matter.

Acid Rain
Wherever there are large cities with dense concentration of vehicles and industries, acid rain forms. Rainfall is basically acid due to deposition of oxides of sulphur and nitrogen found in 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 1984). With the excessive accumulation of these acids in the atmosphere, which if not controlled significantly affect the soil and plants growth (Brady and Weil 1984). 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 result in large amount of acid production in form of carbonic acid. Black (1968) reported that this is a very minute factor because most of carbonic acid produced during this process lost in atmosphere as CO2 (Tang and Rengel 2003).

Basic cations that are usually up-taken by plants are Ca2+, Mg2+, K+ and also NH4+, as result more H+ dissociation by plants for their electrical balance specially when nutrients are absorbed in form of NH4+ (Tisdale and Nelson 1975). More the basic cations uptake more the H+ ions release which leads to acidity in the soil. There are basic cations available in

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plant especially in leaves and stem than the grains, these basic cations neutralizes the acidic effect which is develop 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 crop harvested and stage of crop at harvest basically deals with the amount of these nutrient removed. Like grain has comparatively small amount of basic cations than leaves and stem portion of the plant so forages like Hay, bermuda grass and alfalfa show more positive effects on soil acidity comparative to high-yielding grain crops.

Application of Acid Forming Fertilizers
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. Usage of agricultural land without proper management practices results in enhanced soil infertility problems. To overcome these problems most of farmers use fertilizers extensively. Mostly used chemical fertilizers are ammonium sulphate (AS), urea, muriate of potash and trisuperphosphate, etc (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.

Effects of Soil Acidity on Crop Production
Soil acidity significantly affects plants yield and productivity by decaling available nutrient contents. Two major factors associated with soil infertility are 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 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+ (Black 1968; Rao et al. 1993). Acidic soil’s most of the problems are associated with Al 3+. Higher Al 3+ content in acidic soil results in reduced function and root proliferation. Roots mostly observed are stunted and club shaped. This reduces the plants availability to extract nutrients and water from soil. When aluminum is abundant it mostly fixed with phosphate in form of aluminum phosphate and making P unavailable for plant (Black 1968; Rao et al. 1993). Except molybdenum the availability of micro-nutrient boosts the soil acidity.

Management of 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. (Obiri-Nyarko 2012) reported techniques that how such soil acidified land should be used for sustained agricultural purposes. To overcome soil acidity issues use of organic material and lime, 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**

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 are used both separately and in combined forms. These liming materials along with lowering soil acidity also counteract the effect of H$^+$ and Al$^{3+}$ ions (Fageria and Baligar 2005).

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 micro elements (Naidu et al. 1994).

Liming material addition also reduce the leaching and solubility of heavy metals (Lindsay 1979; 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. In Southeast Asia acid sulfate is mostly recommended for this purpose. Application of lime in rice fields results in high Al and Fe precipitation which is responsible for their enhanced yield. Some authors also reported that high amount of Al ions contents result due to use of lime and put deleterious effects on underlying soil.

At pH 5 aluminum ions starts precipitation from soil solution. This happened due to 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 increase in soil acidity is the release of hydroxyl ions on application of ground magnesium Limestone (Fageria and Baligar 2008). (Sadiq and Babagana 2012) reported that application of lime material on paddy fields significantly lowers the soil acidity. In Southeast Asia acid sulfate is mostly recommended for this purpose. Application of lime in rice fields results in high Al and Fe precipitation which is responsible for their enhanced yield. Some authors also reported that high amount of Al ions contents result due to use of lime and put deleterious effects on underlying soil.

It is reported that in Malaysia soil content is poor in organic matter. Application of ground basalt by acid sulphate ameliorate infertile land, is highly recommended for sustained rice yield along with different organic fertilizers few months before 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 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 anions results 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. Plant species of legume plants such as soybean, red clover and acacia found to have higher concentration of Ca, Mg and total cations contents than non-legume crops such as maize and sorghum, also have higher content of ash alkalinity (Bessho and Bell 1992; Pocknee and Summer 1997; Wong et al. 2000). Wong et al. (2000) also indicated that organic material associated functional groups results in increase alkalinity of soil by consuming higher content of protons.

**Chemical fertilizer**

According to Savei (2012), non-organic fertilisers mainly contain phosphates, nitrate, ammonium and potassium salts. The fertiliser also contains large majority of heavy metals like Hg, Cd, Hs, Pb, Cu, Ni, and Cu. All these elements are known to cause soil degradation. Findings from research studies show that, the effects of chemical fertilisers on the soil are not immediately obvious, because the soil has strong buffering power due to their composition. One major component of soil that is degraded through fertiliser use is soil structure. Savei (2012) states that, fertilising soils especially with industrial fertilisers such as NaNO3, NH4NO3, KCl, K2SO4, NH4Cl is known to cause deterioration in the soil structure. The continuous use of acid forming nitrogen fertilizers causes a decrease in soil pH (Moebius-Clune et al., 2011). Savei (2012) also reported a research carried out in the province of Rize in Turkey with one-way ammonium sulphate fertilizer application to tea resulting in an increase in acidity of soils and that 85% of the territory had a dropped pH below 4. The research also identified that, application of large amounts of potassium fertilizer was found to disrupt the balance of nutrients preventing plants from receiving the necessary nutrients for growth (2012). Excessive use of chemical fertilizers in fields also contributes augmentation of salts in soil, yet there input in salinity development is insignificant. Nevertheless addition of some manures like sewage sludge, cow dung or slurry.

**Pesticides**

Pesticides play a major role towards contributing to the modern day agriculture, which in a sense is enduring food security. However, the possibility of applied pesticides reaching the soil and causing degradation of some aspect of soil properties cannot be underestimated. Such possibilities are high when pesticides are applied at high rates over many years (Hance et al., 2001) and this leads to toxicity. Pimentel and Levitan (1986), in their paper stated that, there has been an estimate indicating that less than 0.1% of the pesticides applied to crops actually reach the target pest with the rest finding its way in the environment, contaminating soils, air and water. A concentration of pollutants tends to accumulate in the topsoil where most soil organisms live (Ulrich, 1987).

Pesticides enter soils from spray drift during foliage treatment, wash off from treated foliage, release from granulates or from treated seeds in soils (PAN, 2010) as is shown in Figure 1. Moreover, most of these pesticides become persistent in the soil at varying degrees. The persistence of pesticides also limits the degree to which the chemical composition can be
Degraded as well as transported in the soil. Pesticides in soils have been identified to have a major effect on soil microbes. Pesticides can cause significant irreversible changes in soil microbial populations (PAN, 2010). These soil microbes are important in maintaining soil fertility, thus pesticides, which seriously affect soil micro flora and micro fauna, may harm soil fertility (Nawab et al., 2002). Liebich et al. (2003) state that fungicides have been found to be toxic to soil fungi and actinomycetes, by causing changes in microbial community structure.

Other bacteria species such as nitrification bacteria have also been found to be very sensitive to pesticides influence. According to Gigliotti and Allievi (2001), inhibition of nitrification was proved by sulphonylurea herbicides. PAN (2010) observed in a new study that, some organochlorine pesticides suppress symbiotic nitrogen fixation resulting in lower crop yields. They further report that authors found out that pesticide Pentachlorphenol, DDT and Methyl parathion at levels found in farm soils interfered with signalling from leguminous plant such as alfalfa, peas, and soybeans to symbiotic soil bacteria. Some pesticides (Benomyl, Dimethoate) can also negatively affect symbiotic mycorrhizal fungi, which facilitate plant nutrient uptake (Chiocchio et al., 2000). A laboratory experiment that reproduced vineyard conditions in France showed that mixture of insecticides and/or fungicides at different environmental concentrations caused a neurotoxic effect in earthworms. After a long period of exposure or high concentrations, earthworms were physiologically damaged and could not cope with the high toxicity (Schreck et al., 2008). An integrated study on a roundup resistant soya field in Argentina showed deleterious effect of these pesticides on earthworm population. Earthworms avoided soil with glyphosate; their feeding activity and viability were reduced. Glyphosate and chlorpyrifos also caused several adverse effects at cellular level (DNA damage) that indicated physiological stress. Authors concluded that the effects observed on the reproduction and avoidance caused by glyphosate could contribute to earthworm decrease, with the subsequent loss of their beneficial functions (Casabé et al., 2007)

**ASSESSMENT OF CHEMICALLY DEGRATED SOILS**

In general view, the assessment of degraded soils is

![Figure 1. Pathways of a pesticide applied to a crop. Arias-Este´vez et al. (2008).](https://www.eajournals.org/)

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Table 2. Assessment of chemical soil degradation using chemical indicator parameters.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of nitrogen element (Multiple decrease) N (%)</td>
<td>0.13</td>
<td>0.10-0.13</td>
<td>0.08-0.10</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>Content of phosphorus element (mgkg⁻¹)</td>
<td>8</td>
<td>7-8</td>
<td>6-7</td>
<td>&lt;6</td>
</tr>
<tr>
<td>Content of potassium element (cmolkg⁻¹)</td>
<td>0.16</td>
<td>0.14-0.16</td>
<td>0.12-0.14</td>
<td>&lt;0.12</td>
</tr>
<tr>
<td>Content of readily soluble salts (Increase by %)</td>
<td>&lt;0.20</td>
<td>0.20-0.40</td>
<td>0.40-0.80</td>
<td>&gt;0.8%</td>
</tr>
<tr>
<td>Content of ESP (increase by % of CEC)</td>
<td>&lt;10</td>
<td>0-25</td>
<td>25-50</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Content of base saturation (Decrease of saturation if more than 50%)</td>
<td>&lt;2.5%</td>
<td>2.5-5%</td>
<td>5-10%</td>
<td>&gt;10%</td>
</tr>
<tr>
<td>Excess salts (Salinization) (Increase in Conductivity) mmho/cm/yr</td>
<td>&lt;2</td>
<td>2-3</td>
<td>3-5</td>
<td>&gt;5</td>
</tr>
</tbody>
</table>

Source: Senjobi et al. (2012). *Where 1= none to Slight degraded soils, 2= Moderately degraded soils, 3= Highly degraded soils, 4= Very highly degraded soils.

Seen as a complex issue and other scientific knowledge has kicked against the mono-disciplinarity approach in tackling the issue. According to Moebius et al. (2011), no standardized soil quality tests exist. WOCAT, ISRIC and FAO propose such tools as expert opinion, remote sensing, field monitoring, productivity measurements and participatory surveys as efficient for the assessment of degraded land, but there is no standardized tool for chemical degradation assessment. Table 2 shows one tool used by Senjobi et al. (2012) to assess degradation.

They used soil indicator parameters to estimate the degree of degradation. In other terms, they determined the soil health by assessing certain soil parameters. Another approach defined as an assessment tool for soil contamination is the ecotoxicological approach.

**Eco toxicological approach**

This is a science that deals with the ecological effects of potentially toxic substances (Van Straalen, 2002). This approach seeks to shed light on the ecological role of soils during contamination. In ecological risk assessment, the analyst has two possible argument options; either argues the effect of pollutants and the risk to concentration or from concentration to risk. In the first approach, the analyst must define a certain maximally accepted risk of substances in the environment. This is done using toxicity tests in which organisms are exposed to graded series of concentrations and effects are measured at each concentration. The concentrations corresponding to the maximally accepted effect is then estimated from the results by regression technique and expressed as EC10 (10% Effect concentration).

In the second approach that is from concentration to risk the initiation of this approach begins with a site where certain concentrations of pollutants are present (Van Straalen, 2002). The objective is to determine the risk associated with the contamination. The scientific bases on which effective soil assessment tests can be run is not fully developed therefore posing a number of challenges on conducting and accepting test results. Rutgers et al. (2000) proposed another ecotoxicological soil assessment approach. In this approach they argued that, soil evaluations should be contingent on the intended land use of the site depending on whether the
site is going to be used as a residential area, industrial estate or an agricultural field. This argument further raises the problem of non-standardisation of assessment methodologies for soil pollution. Their approach consisted of a triad dimension. In this method, an important role is played by bioassays in which soil organisms are exposed to samples taken from the site and their response is observed under standardized conditions.

**Terrestrial mode ecosystem**

There is a significant effort by the international community to standardise the soil assessment evaluations. According to Van Straalen (2002), in International co-operation programs sponsored by the European Union, a significant progress has so far been made in the standardisation and field validation of a type of soil microcosm called the Terrestrial Model Ecosystem (TME). This is an ecotoxicological risk assessment approach, which is gaining grounds in the scientific community.

![Terrestrial Model Ecosystem Diagram](image)

**Figure 2. General design of a terrestrial model ecosystem, Sheppard (1997).**

This approach is characterised by a number of factors,

(i) It is necessary to use undisturbed soil columns taken from the field rather than artificially reconstructing a soil column from separate materials.
(ii) There is the inclusion of living vegetation growing on the soil rather than using only the soil itself or only the litter layer. This will allow for interactions between soil living organisms and plant roots.

(iii) It is necessary to take a column with a content of several litters rather than the small systems of a few centimetres used as microcosms. This will allow for larger organisms such as earthworms to develop more or less normally and it also takes away part of the micro scale variability.

Meeting these conditions then requires carrying out the actual test. The TME samples are then incubated for a period of time in the laboratory under artificial daylight and constant ambient temperature. While carrying out these processes, measurements are made. The soil columns taken from the field are equipped with funnels, which will allow the soil leachates to be contained in a flask.

A number of variables are then measured such as, nutrient concentrations in the leachate (e.g. ammonium, nitrate, sulphate), evolution of gases (e.g. CO2, Nitrous oxide), decomposition of organic matter, microbial biomass, microbial community structure, enzyme activities, and invertebrate populations. Differences in the performance of systems taken at different locations may be evidence of altered ecological functioning of the soil (Van Straalen, 2002). With many ways to determine the state of a soil health without any standardised system, there have been some conflicting interests with many proposals to consider.

Van Straalen (2002) argues that, in soil assessment, the exceedance or non exceedance of standards used are often insufficient argument to conclude on the presence or the absence of risks because site specific factors such as microbial activity, age of pollution, pH, clay content may modify the risk associated to and extent that, it is not simply related to the chemically determined total concentration in the soil.

RESULTS/DISCUSSION

Chemical soil degradation after erosion is the second most abundant form of soil degradation and as such poses a threat to our finite soil resource, as it tends to render it less usable. It is therefore necessary to understand the means by which soils are degraded chemically. This review paper seeks to highlight some of the causes of soil chemical degradation. One way by which soils degrade chemically is through soil contamination; either by diffuse contamination or from localised sources.

Chemically degraded soils may be irreversible in most cases and as such its prevention will aid in agricultural sustainability. The cultivated lands are continuously degrading and the extent is increasing because of different natural environmental and anthropogenic activities. Soil degradation due to salinization, erosion, water logging etc. Saline soils can be cultivated growing different halophyte plants and using modern irrigation practices. Conservation and effective and efficient use of good quality water help proper leaching of soluble salts in saline soils.

Generally nutrients are lost through erosion in runoff and in the eroded sediment. Finer soil fractions are the most vulnerable to erosion. Nutrients, being abundant in these finer soil fractions, are also lost to erosion. Further nutrient losses occur through chemical degradation,
i.e. deterioration of properties of the soil, that occur as a result of acidification and salination or sodification. The latter is common in arid and semi-arid areas where rainfall is inadequate to leach excess salts down through the profile but is not a concern in this study. The acidification process may be accelerated through burning and clearing of vegetation, continued use of acid containing fertilisers and excessive irrigation.

CONCLUSION

Due to the diversified forms of the causes of chemical soil degradation, generalisation of the assessment procedure may tend to underestimate the real condition of degradation; therefore in order to fully ascertain the extent of chemical degradation, it is best to first identify the type as well as the causal factors for the degradation. Having this information at hand will give a credible assessment result. 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.

In instances where we combine soil quality indicators as well as assessment methods, priority must be given to the identified causal factor of the degradation. This is because there are always variations in the indicators we select which may be as a result of different impacts from different causal factors in the same locality. In recent times the extent to which humans influence chemical soil degradation poses more challenges in determining the standardised assessment tool. It is therefore necessary to develop assessment tools based on the location and activities in the vicinity under review.

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REFERENCES


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