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SOIL DEGRADATION PROCESSES UNDER AGRICULTURE AND THE PRACTICES TO REVERSE THE DEGRADATION PROCESSES FOR ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT

The aim of this review paper is to understand more about soil degradation process under global agriculture and the practices to reverse the degradation process for environmental sustainability. The data and relevant information have been collected from a range of printed and online sources which then represented to fulfill the aim of this review paper. The overall economic growth of an agro-based country depends on the sustainable agricultural ecosystem in connection with the proper management of agricultural soil. Soil degradation is a global crisis that affects the world food economy in terms of improper agricultural practices. The huge population pressure in the developing countries, inequity and poverty in some parts of the world have influenced the farmers for increasing the cultivable land connected to agricultural production. Therefore, the degradation rate in agricultural soil has significantly increased both in developed and developing countries. The EU (European Union) in 2012 has identified eight different threats reducing normal function of the soils. These threats are water and wind erosion, reduction of soil organic matter (SOM), contamination, sealing, compaction, loss of soil biodiversity, salinisation, landslides and floods, desertification and acidification. However, The concept of conservation agriculture (CA) and organic farming are the major issues of the practices to reverse the degradation process of soil although some others practices such as ridge tillage, contour farming, sub-soiling, intercropping, grasslands, agro-forestry, conservation buffers and terracing have been proved beneficial directly in the field. However, improvement and amendment of many suggested technologies considering the adaptation to local physiographic and climatic conditions should be reconsidered soon. Political commitment and government willingness are also

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important issues for the practices of soil conservation under agriculture. Also, policy makers should be aware of giving emphasis on policy formulation to practice sustainable agriculture in the world because sound soil management policies could be the ways of proper solution to reverse the soil degradation processes under agriculture to ensure environmental sustainability.

Keywords: Soil, degradation, agriculture, reverse process, sustainability

1. INTRODUCTION

Soil is the top layer of the earth's crust consisting of mineral matter (MM), organic matter (OM), water, air and living organisms (EEB, 2006; SoCo Project Team, 2009). In other words, soil is a complex living resource that has a key role in the production of foods and biomass in association with transformation of materials that includes carbon (C), nitrogen (N) and water (H_2O) (EEB, 2006). However, soil is an inevitable part of the agricultural practices in both developed and developing World (Pimentel, 1993; Karamesouti *et al*., 2015). The overall economic growth of an agro-based country depends on the sustainable agricultural ecosystem in connection with the proper management of agricultural soil (Costantini and Lorenzetti, 2013). EEB (2006) reported that the long term economic development is not possible if the agricultural countries do not maintain the sustainability in production due to the pollution, erosion, salinisation, sodification or compaction and loss of organic matter into the soil (SoCo Project Team, 2009).

However, soil degradation is the process of reducing productive capacity of soil due to natural and anthropogenic factors (Robinson *et al.*, 2009; Karamesouti *et al*., 2015). According to the Organisation for Economic Co-operation and Development (OECD), soil degradation is the loss of soil functions, where the quality of soil is reduced making the soil unfit for production of crops and other ecosystem services in agriculture (OECD, 2001). However, no continent of the World is undisturbed in regard to soil degradation (Figure 1) which is caused by both natural and anthropogenic means amounting almost one third of the total soil degradation under agricultural practices (Mackenzie, 1995). Approximately 75% of the top soil consisting both developed and developing World have already been lost by the end of 1990s (Costantini and Lorenzetti, 2013). From the 20th century till now, there is no significant improvement of soil conservation under agricultural practices (Costantini and Lorenzetti, 2013). Oldeman *et al*. (1990) reported that almost 28% of the soil degradation in the World is caused by the agricultural activities, whereas North America (66%) and Central America (45%) showed the highest intensity of soil degradation under agriculture followed by Europe (29%), Asia (27%), South America (26%), Africa (24%) and Oceania (8%) respectively (Figure 2). The concept of conservation agriculture (CA), organic farming, terracing, tillage and agroforestry systems has been addressed by several authors and researchers to reverse the soil degradation process under agriculture (Costantini and Lorenzetti, 2013). However, this review paper has addressed to better understand the principal

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soil degradation processes under agricultural practices and the steps of recovery from degradation of soil for environmental sustainability.

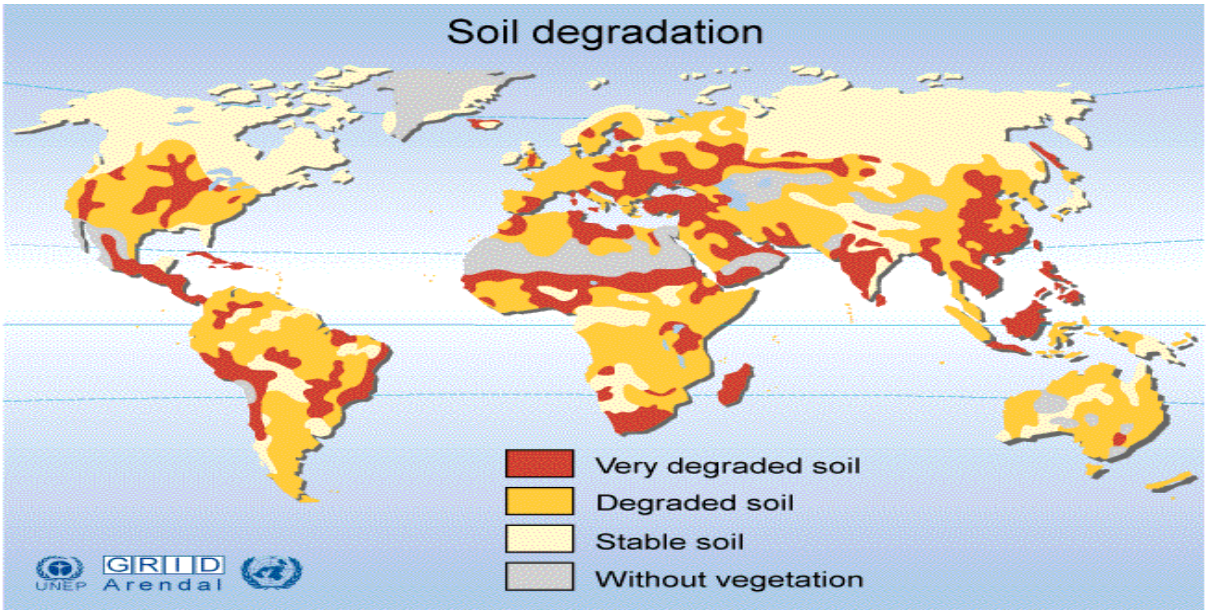

Figure 1: Soil degradation zones in the World (Mackenzie, 1995)

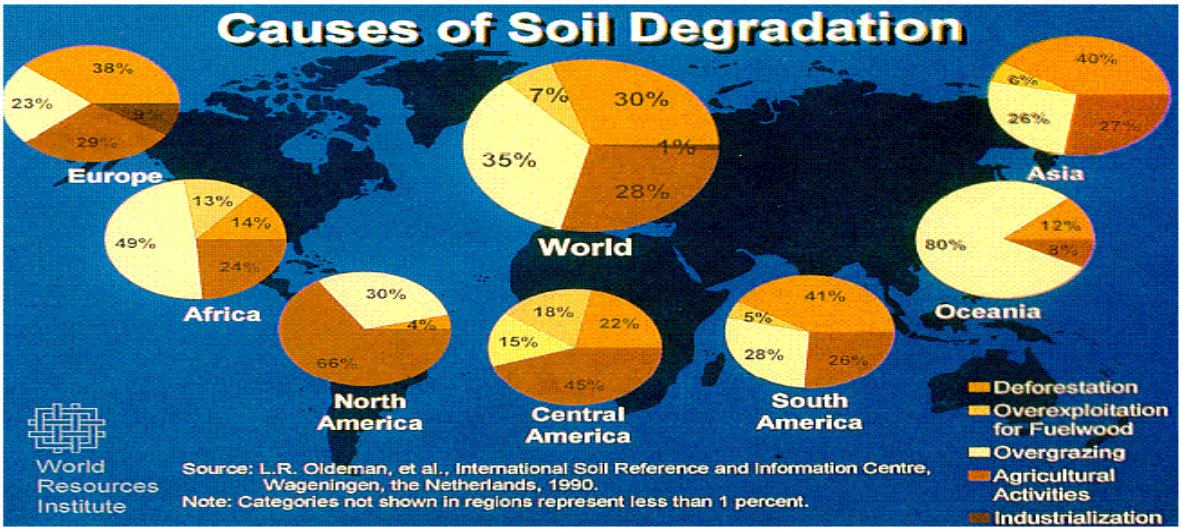

Figure 2: Global soil degradation scenarios (Oldeman *et al*., 1990)

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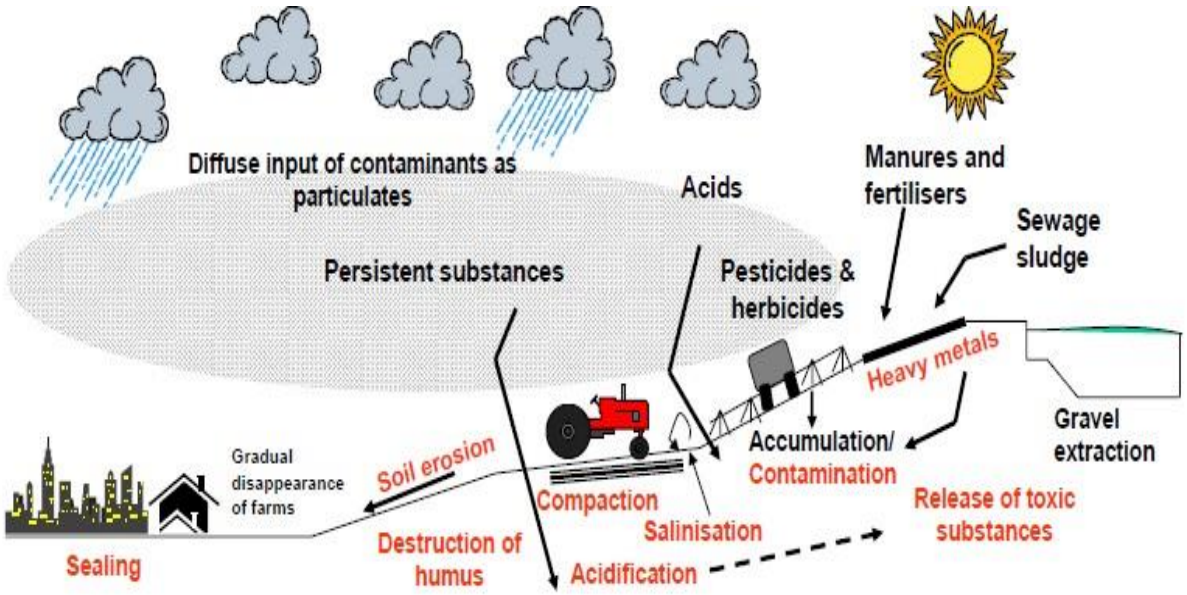

Figure 3: Soil degradation causes (Dent, 2007; Hurni and Meyer, 2002)

2. MATERIALS AND METHODS

A range of peer reviewed national and international published books and articles from both printed and online sources have been reviewed and then the relevant data and information have been collected which then organized by the authors. For better understanding of the soil degradation and the practices to reverse the degradation processes, the reviewed data and information was then compiled and presented in a scientific manner.

3. SOIL DEGRADATION PROCESSES UNDER AGRICULTURE

Soils under agriculture are considered to be degraded when different functions of soil are disturbed either by natural or anthropogenic means (Costantini and Lorenzetti, 2013). The important soil functions related to the agricultural ecosystem are production of biomass, storing, filtration, transformation of nutrients and water, biodiversity pool like habitats, genes and species, raw material sources and carbon pool (European Commission, 2006a; JRC, 2011). However, some factors influence the soil functions negatively that accelerates soil degradation process in agriculture (JRC, 2011). The EU (European Union) has identified eight different threats that reduce the normal function of the soils (European Commission, 2012). The threats related to the soil degradation processes in agriculture are water and wind erosion, reduction of soil organic matter (SOM), contamination, sealing, compaction, loss of soil biodiversity, salinisation, landslides and floods, desertification and acidification (European Commission,

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2012). Additionally, several authors have described the soil degradation process (Figure 3) in different ways although the principal degradation processes are almost similar (Hurni and Meyer, 2002; Li and Zhou, 1999; Dent, 2007). However, based on the climate and agricultural practices, SoCo project team (2009) has addressed six different soil degradation processes, which are (i) erosion in association with water, wind and tillage (ii) declining the content of organic carbon (OC) (iii) compaction (iv) salinisation and sodification (v) contamination in relation to heavy metals and pesticides, excess amount of nitrate (NO_3) and phosphate (PO_4) and (vi) declining biodiversity. The important soil degradation processes under agriculture have been summarized below.

3.1 Erosion

Erosion is one of the most important soil degradation processes under agricultural activities throughout the developed and developing World (Mabbutt, 1984; Pimentel, 1993; Busari *et al*., 2015). The principal types of erosions in agriculture are water, wind and tillage related erosions (SoCo Project Team, 2009). Each of the principal erosions under agriculture is briefly described below.

3.1.1 Water erosion

Soil particles are separated by raindrops and transported by the water flow across the surface of the agricultural lands (Van-Camp et al., 2004). Raindrops accelerate the breakdown of soil aggregates causing the surface sealing, limiting infiltration and increasing surface run off (Van-Camp et al., 2004). Water erosion enhances the loss of top soil in agricultural lands reducing the soil fertility and thus agricultural ecosystem is rapidly degraded (Van-Camp et al., 2004). However, the climatic conditions, topography, structure of the soil influence the water erosion (SoCo Project Team, 2009). Important water erosions like rills, gullies and sediment accumulation on the agricultural land surface have been addressed by agriculturists, soil scientist and researchers (Costantini and Lorenzetti, 2013). Recent research showed that the soil degradation rate in Europe due to the water erosion is high. Again, Mediterranean regions of agriculture are under serious threat of water erosion (Costantini and Lorenzetti, 2013). Approximately 115 million hectares of agricultural lands in Europe are under the threat to water erosion, whereas a single robust rainfall could cause the loss of 40 – 100 tonnes per hectare of soil (SoCo Project Team, 2009). Both on-site and off-site effects of water erosion have been noticed by SoCo Project Team (2009) throughout the Europe and Mediterranean zones (Table 1).

3.1.2 Wind erosion

Wind erosion is an important consideration of soil degradation process in which the soil particles are transported by wind action removing mainly the finest type of soil particles resulting the

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gradual reduction of soil fertility under agricultural practices (EEA, 2003; Warren and Barring, 2003; Funk and Reuter, 2006).

Table 1: On-site and off-site damages caused by water erosion in Europe and Mediterranean regions (Source: SoCo Project Team, 2009)

Erosion type	On-site damages	Off-site damages
Water erosion	➢ Loss of OM (Organic matter) ➢ Degradation of soil structure ➢ Compaction of soil surface ➢ Reduction of water table ➢ Surface erosion ➢ Removal of nutrients ➢ Increasing coarse fraction of soil ➢ Rill and gully formation ➢ Uprooting of plants ➢ Soil productivity reduction	➢ Flooding ➢ Pollution of water ➢ Burial of infrastructures ➢ Obstruction to drainage networks ➢ Changes in the shape of watercourses ➢ Eutrophication of water

EEA (2003) reported that almost 4% (42 million hectares of land) of the total European territory is affected by wind erosion. Wind erosion depends on meteorological conditions along with favourable ground conditions although it is sometimes accelerated by human induced causes like improper cultivation techniques and overgrazing (Funk and Reuter, 2006). Funk and Reuter (2006) also reported that the influencing factors of wind erosion are soil texture, content of the organic matter (OM), vegetation cover, roughness, filed size and local climatic conditions. Overall, wind erosion damages the arable crops and pollutes nearby areas removing the soil OM that affects the biomass production and storage of OM in soil for climate change mitigation (Goossens, 2003).

3.1.3 Tillage related erosion

The tillage related erosion of soil degradation is caused by the displacement of cultivation layer under agriculture along with the loss of soil due to harvesting which is mostly influenced by the crops harvesting techniques of the farmers (Van Oost and Govers, 2006). The tools used for tillage and the slope have a strong influence on tillage related soil degradation process (Funk and Reuter, 2006). Tillage erosion is influenced by the reduction of tillage depth and speed, ploughing on consolidated soils in lieu of pre-tilled agricultural soils and ploughing along the lines of contour. In a study, the rate of tillage related erosion throughout the Europe was recorded

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as 10 tonnes/ha/year, whereas erosion due to the improper harvesting technique was calculated as 2 tonnes/ha/year and 9 t/ha/year for potato and sugar beet respectively (Van Oost and Govers, 2006).

3.2 Declining soil organic carbon (SOC)

Land use change and improper management practices are mostly responsible for declining soil organic carbon (SOC) (Smith et al., 2012; Costantini and Lorenzetti, 2013). SOC includes residues of crops and all carbon containing materials along with soil fauna and humus (Chan, 2008). It is the uneven mixture of simple and heterogeneous materials containing carbon (C) (Chan, 2008; Van-Camp et al., 2004). Water retention, soil texture and structure and cation exchange capacity of soil depend on the availability of SOC (Smith et al., 2012). SOC is also an important nutrients' (N, P, K and Ca) source needed by agricultural crops (Smith et al., 2012). However, declining soil organic matter causes the reduction of agricultural soil quality and thus crops productivity is affected (Costantini and Lorenzetti, 2013). The soil organic carbon is mostly affected by the existing land use, climate and hydrological condition of the land used for agricultural practices (Van-Camp et al., 2004). Carbon accumulation in the soil is affected by the temperature and precipitation. Again, soil degradation due to carbon loss is mainly related to the climatic gradient from north to south (Van-Camp et al., 2004). For example, the concentration of C is high in the cold and northern part of Europe, whereas it is comparatively lower in the hot, semi arid southern part like Mediterranean regions (Van-Camp et al., 2004). For instance, 74% of the agricultural soils in the southern Europe consist of less than 2% organic carbon (Smith et al., 2006). JRC (2011) and Schils et al. (2008) reported that approximately 45% of European soils consist of very low amount (0-2 g.100 g^{-1}) of carbon content in the agricultural soil.

3.3 Compaction

Soil is degraded under agriculture due to the compaction of soil (Pagliai et al., 2000). Soil compaction is the rearrangement of soil particles where the pores between the aggregates or particles are significantly reduced because of natural and manmade causes (Costantini and Lorenzetti, 2013). Natural compaction of soil is related to the topography, soil texture or structure and climatic condition of the lands used for agricultural practices (Costantini and Lorenzetti, 2013). The manmade causes of compaction are improper practices of agriculture soil, land use pattern, rotation of crops and use of heavy machineries (Costantini and Lorenzetti, 2013). For example, if the land is ploughed repeatedly for crops production prior to maintaining short rotation then the soil compaction process is accelerated (Munafo, 2013).

3.4 Salinisation, sodification and alkalinisation

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The deposition of soluble salts like chloride (Cl), sulphate (SO_4), carbonate (CO_3) and bicarbonate (HCO_3) of sodium (Na), magnesium (Mg), calcium (Ca), and potassium (K) in the profile of soil is termed as salinisation (Toth et al., 2008). Again, sodification is the gradual saturation of sodium bicarbonate ($NaHCO_3$) in the soil, whereas alkalinisation is the state of soil increasing the P^H level (Dazzi, 2006). However, the impermeability of soil layer is increased due to the salinisation of soil and hence the agricultural lands become less suitable for cultivation (JRC, 2011). Both natural and human induced factors influence the soil degradation process caused by salinisation (Dazzi, 2006). Natural factors are climate, salts accumulation of parent material (PM), ground water, topography and land cover, whereas human induced factors are land use practices and land management system such as irrigation with salt water and improper drainage (Crescimanno et al., 2009). In case of alkalinisation, the high P^H level in the agricultural soil does not permit the optimum growth and development of the agricultural crops (Crescimanno et al., 2009). Again, excess amount of sodium destruct the arrangement of soil particles due to the lack of oxygen (O_2) and hence normal growth of the crops is disturbed (Szabolcs, 1974; Baruth et al., 2006).

3.5 Contamination

Soil degradation process due to contamination is caused by the contribution of the heavy metals, pesticides, excess amount of nitrates (NO_3) and phosphates (PO_4) in the agricultural soil (SoCo Project Team, 2009). Human activities are mainly responsible for contamination of agricultural soil increasing the amount of NO_3 and PO_4 prior to the application of fertilizers for accelerating the productivity of soil (SoCo Project Team, 2009).

3.6 Declining soil biodiversity

The loss of soil biodiversity is also a matter of concern regarding soil degradation process under agriculture (Hassan et al., 2005; European Commission, 2006a). The land use practices and management of agricultural crops have both positive and negative impacts on soil biodiversity (Pimentel et al., 1997). The soil is degraded due to the improper ploughing, use of excessive pesticides, fertilizers, organic wastes and the operation of tillage (UNEP/CBD/SBSTTA/13/2, 2007). The operation of tillage and inappropriate practices of farming modify the soil structure, porosity, bulk density, and water holding capacity and thus the agricultural soils are degraded (FAO, 2007; FAO, 2008c).

4. PRACTICES TO REVERSE THE DEGRADATION PROCESS

Agriculturists, researchers, soil scientists and climatologists have suggested several practices to reverse the soil degradation processes under agriculture (SoCo Project Team, 2009). The concept of conservation agriculture (CA) and organic farming are the major issues related to soil

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conservation practices although some others farming practices have been proved beneficial directly in the field (FAO, 2008a). The important concepts and filed practices of soil conservation under agriculture are briefly described below.

4.1 Conservation agriculture (CA) and organic farming

Conservation agriculture (CA) and organic farming amongst others can mostly reduce soil degradation under agriculture (FAO, 2008a). CA consists of a combination of several practices that minimise the alteration of soil composition and structure reducing the erosion and degradation and hence the biodiversity of the soils is conserved (Panettieri *et al*., 2014). Ghosh *et al.* (2015) reported that average runoff coefficients and loss of soil under CA plots of maize-wheat crop rotation were reduced to 45% and 54% respectively in comparison to conventional system. The most important practices in CA are no-tillage and reduced tillage in association with practicing cover crops and crops rotation (FAO, 1993; USDA, 1996; Gilliam *et al*., 1997; Boame, 2005; Beck, 2005; FFTC, 2007; ECAF, 2008a). Almost 4.5 – 10% of the total arable lands in Finland and Greece and 2.5 – 4.5% in the Czech Republic, Slovakia, Spain and in the United Kingdom are under the practice of no-tillage, whereas approximately 40 – 55% of the total arable lands in Finland and in the UK and 20 – 25% in France, Germany and Portugal are under the practice of reduced tillage, where the practices have been proved beneficial (SoCo Project Team, 2009). The practices of no-tillage and reduced tillage help to reverse the soil degradation process by increasing the content of SOC (Soil Organic Carbon) (ECAF, 2008a; Kassam *et al*., 2014). As a result, the biological functions along with soil structure, fertility and water retention capacity of soil are enhanced and thus the soil erosion and nutrient run-off are reduced and resistance to soil compaction is improved (Ancelin *et al*., 2007; Labreuche *et al*., 2007b).

However, organic farming is an integrated approach of managing farm and producing foods that consists of environment friendly practices, maintaining highest level of biodiversity and conservation of natural resources (Melero *et al*., 2006; FAO, 2008b). Likewise conservation agriculture, organic farming also helps to increase the content of organic carbon and other nutrients (N, P, K) in the soil and conserve the biodiversity (Hole *et al*., 2005; Eurostat, 2007b; Monokrousos *et al*., 2008; Truu *et al*., 2008). For example, from the study of coffee agro-ecosystem performance in Central America, Hagger *et al.* (2011) reported the higher level of soil phosphorus (P) and potassium (K) in organic farming in comparison to conventional system.

4.2 Other farming practices

SoCo Project Team (2009) reported that the other important practices that reverse the rate of soil degradation process are ridge tillage, contour farming, sub-soiling, intercropping, grasslands,

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agroforestry, conservation buffers and terracing. Ridge tillage is the pre-formed ridges which can be used in the agricultural fields as an alternative of traditional furrows (Henriksen *et al*., 2006; Schlinker *et al.*, 2007). Ridge tillage increases the moisture holding capacity, soil fertility in association with soil organic carbon (SOC) content and functions of biological activities, which reduces the water erosion and nutrient run-off (Stathakos *et al*., 2006). However, contour farming is another way of reversing soil degradation process under agriculture (IIRR, 2008). It involves the ploughing, furrowing and cultivating the crops along the lines of contours in lieu of up and down slopes (IIRR, 2008). Due to the practices of contour farming, the infiltration capacity of soil is increased in association with increasing carbon content in the soil (De Alba *et al*., 2006). As a result, water and tillage erosions are reduced remarkably although the suitability of the agricultural practices depend on the soil types, topographic condition, land use pattern and climate (De Alba *et al*., 2006; Terzoudi *et al*., 2007; IIRR, 2008). Furthermore, sub-soiling can also be practiced to reverse the process of soil degradation in agriculture (FAO, 2000). It is the process of loosening deep hardpans of the soil (Pagliai *et al*., 2000). Under the practice of sub-soiling, the infiltration rate and root penetration of the agricultural soils are increased (Spoor *et al*., 2003). In fact, sub-soiling is also influenced by soil texture and structure, types of crops, period of cultivation and micro-climate (Henriksen *et al*., 2007). Intercropping is another concept reducing the soil degradation process in agriculture (Hauggaard- Nielsen *et al*., 2001). It is the cultivation of two or more crops during the growing season on the same land (Intercrop, 2008). The interaction between two or more crops increases the stability the resilience against the pests, diseases and weeds in agricultural ecosystem (Intercrop, 2008). The practice of intercropping enhances the soil porosity and supports the cycles of organic carbon (OC) and nitrogen (N) along with conserving the soil biodiversity and increasing the function of soil biology (Fenandez-Aparicio *et al.*, 2007; Whitmore and Schroder, 2007). Soil degradation process can also be reduced by establishing temporary and permanent grass land (IFAD, 2008). The establishment of temporary grassland in agriculture is suggested by several authors to combat the degradation process (EGF, 2007). Establishing grass lands increase the content of nutrients (OC, N, P and K) in the soil along with reducing the risk of water and wind erosion (Plassart *et al*., 2008).

However, agroforestry can be practiced as a significant soil conservation technique for sustainable land use in agriculture both in developed and developing countries compared to traditional farming in agriculture (ICRAF, 1993; Stephen, 2014). Agroforestry includes trees along with crops, pastures and livestock (Stephen, 2014). The practice of agroforestry helps in maintaining soil fertility, water holding capacity, erosion control, biodiversity, carbon sequestration and leaching of nitrate (NO_3) (Reisner et al., 2007). However, the environmental benefits of agroforestry depend on the topographic condition, intensity of management and selection of crops and tree species (Palma et al., 2007b). Agroforestry is more effective way than non-agroforestry practices to achieve the objectives of soil conservation by using the land

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resources effectively (Stephen, 2014). Several strata of trees with crops ensure proper use of above ground materials such as sunlight from the sun while different patterns of rooting in regard to the trees and crops help to accelerate efficient use of underground resources like nutrients and water (Kawy and Ali, 2012). The NFTS (nitrogen fixing tree species) agroforestry system provides nitrogen (N) to the soil under agricultural practices (Kawy and Ali). Additionally, litter fall along with pruning from the plants provide OM (organic matter) to the soil (Stephen, 2014). Organic matter enhances soil physical characteristics like structure, aeration and drainage of soil (Kawy and Ali, 2012).

Furthermore, buffer strips and bench terracing are two important concepts of soil conservation practices in agriculture (NRCS, 2008). Buffer strips consisting of filter strips, field borders, windbreaks, grassed waterways and riparian zones significantly decrease approximately 70 – 90% of the suspended solid materials along with nitrates (NO_3) and phosphates (PO_4) which are carried out by agricultural run-off to the nearby water bodies (Probst *et al*., 2005; NRCS, 2008). Additionally, practicing buffer strips decreases the soil erosion caused by wind and takes part in maintaining biodiversity along with aesthetics of landscapes (Schou *et al*., 2006). Again, bench terraces consisting of a series of nearly labeled surface at reasonable intervals increase the rate of soil infiltration capacity and thus the water erosion is controlled under agriculture (Dorren and Rey, 2004; FFTC, 2007). However, several authors reported the adverse impacts of terracing if it is not properly practiced (Dorren and Rey, 2004; Diaz *et al*., 2007). In addition to the above soil conservation practices, several authors have suggested to reduce human induced soil degradation causes like contamination (use of pesticides and discharge of industrial wastes), compaction (use of heavy machineries) and salinisation (improper irrigation practices) (Bellows, 2004; JRC, 2008a).

5. CONCLUSION

Soil degradation is a global crisis that affects the World food economy in terms of improper agricultural practices. The huge population pressure in the developing World need sufficient agricultural productions for their basic needs. Additionally, inequity and poverty in some parts of the World have influenced the farmers for increasing the cultivable land along with increasing agricultural crops production. As a result, the degradation rate in agricultural soil has significantly increased both in developed and developing countries. However, researchers, soil scientists, agriculturists, extension workers and climatologists have suggested many options to reverse the degradation process under agriculture. Many of the technological suggestions have been attempted by the land practitioners or farmers to combat the soil degradation rate in agriculture. However, improvement and amendment of many suggested technologies considering the adaptation to local physiographic and climatic conditions should be reconsidered soon.

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