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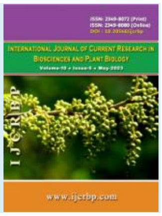

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Impact of anthropogenic activities on soil microorganisms: A review

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Abstract

In the world, since the beginning of mankind soil has been the basis for the sustenance of life. The discovery of microorganisms within soil and their importance in recycling organic matter dates back to the 17th century when John Evelyn stated that soil fertility could be maintained by the addition of organic materials. By the 20th century, large farming devices and chemicals for improving the production of crops on a large scale had been developed and the utilization of these resources resulted in drastic increases in land areas under cultivation. Although agricultural chemicals and machinery increased crop productivity exponentially, the intensive application of these agricultural management tools has also had many negative effects on agricultural soils. As a result the impacts of human activities on soil microorganisms are many and varied. The effects of human activities vary with land use, ranging from agricultural wastes such as farm animal sewerage and fertilizer runoff, to commercial and industrial wastes of every conceivable type and magnitude. A better understanding of the linkages between soil life and ecosystem function and the impact of human interventions will enable the reduction of negative impacts and the more effective capture of the benefits of soil biological activity for sustainable and productive agriculture. Therefore the objective of this review was to summarize the literatures and the current knowledge on the impact of different anthropogenic activities on soil microorganisms.

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Introduction

In the world, since the beginning of mankind soil has been the basis for the sustenance of life. In early times modification of the soil by man must have been mostly unintentional, induced largely by vegetation changes, many of them caused by fire. With the advent of agriculture and the first domestication of plants and animals, there has been increased intensity of the use of soil resources. Human interventions were either direct – through plowing, liming, manuring, fertilizing – or indirect through changing the natural soil forming factors – changing the vegetation by deforestation, changing the relief by leveling and terracing, changing the moisture regime through irrigation and drainage, changing the parent material through transport, dumping or the exploitation of peat and rocks, through erosion and sedimentation (Brussard et al., 2004).

The discovery of microorganisms within soil and their importance in recycling organic matter dates back to the 17th century when John Evelyn stated that soil fertility could be maintained by the addition of organic materials (Magdoff and Vanes, 2000). By the 20th century, large farming devices and chemicals for improving the production of crops on a large scale had been developed and the utilization of these resources resulted in drastic increases in land areas under cultivation (Magdoff and Vanes, 2000).

Although agricultural chemicals and machinery increased crop productivity exponentially, the intensive application of these agricultural management tools has also had many negative effects on agricultural soils (Doran and Zeiss, 2000). Agricultural practices have resulted in considerable capital degradation in terms of: erosion of the top soil; increased nitrogen concentration within soil; and the build-up of various chemicals in the soil and groundwater (Doran and Zeiss, 2000).

Agricultural practices negatively affect many soil organisms that are known to play key roles in the maintenance of soil fertility (Doran and Zeiss, 2000). A reduction in soil quality on farms is therefore the greatest challenge facing food security worldwide in this century. Specific attention will be given to the effect that different agricultural management practices have on soil dynamics in terms of their positive and negative impact on temporal and spatial interactions among soil biota and their a biotic environment (Hung, 2012).

Soil microorganisms maintain the majority of enzymatic processes in soil and preserve energy and nutrients in their biomass (Jenkinson, 1988). The soil microbial community is organized in complex food webs, controlled by soil animals and stabilizing soil biological processes (Brussard et al., 2004). This is assured by the habitat function of soil. Human impact on this habitat function of soil leads to adverse effects on soil processes, which is the driving force behind many research activities. The habitat is usually a highly variable, complex structured and patchy environment for soil organisms. This variability may mask damage to important soil functions. In addition, the habitat soil needs long periods for formation, but also for recovery and restoration. In contrast, soil organisms are generally recognized as highly dynamic, reacting rapidly to environmental conditions (Brussard et al., 2004). Jenkinson (1988) reported that microbial biomass indicates sensitively changes due to soil management; long before other measures such as soil organic Carbon or total Nitrogen.

The impacts of human activities on soil contamination are many and varied. The extent of human impact is now so pervasive and profound that there is currently much discussion about the "Anthropocene", a new geologic era characterized by anthropogenic disturbances of the geologic record. Many of the problems recognized during the 1970s linger on, including the effects of acid rain and airborne deposition of soot, fly ash, and other potentially toxic particulates. Further, the scope of the problem has grown significantly with economic growth in previously less developed nations such as China and India.

The effects of human activities vary with land use, ranging from agricultural wastes such as farm animal sewerage and fertilizer runoff, to commercial and industrial wastes of every conceivable type and magnitude (Garbuio et al., 2012).

A better understanding of the linkages between soil life and ecosystem function and the impact of human interventions will enable the reduction of negative impacts and the more effective capture of the benefits of soil biological activity for sustainable and productive agriculture (Brussard et al., 2004).

Objectives

To review the impact of different anthropogenic activities on soil microorganisms

Types of Anthropogenic Activities

a) Agricultural activities

b) Non-agricultural activities

a) Agricultural activities

Agricultural practices such as soil cultivation and fallow periods, crop rotations, Monoculture, non-host crops, crop breeding programs, and the indiscriminate use of fertilizers and pesticides affect the diversity and activity of soil microorganisms (Xavier and Germida, 1999).

According to Xavier and Germida (1999), the major pressures brought to bear on the composition of the soil microbial community are:

- Cultivation – disruption of fungal networks are significant and long-lasting

- Fertilization – altering nutrient balance in the soil impacts on the composition of the microbial biomass

- Pesticides – affect microbial community directly by acting as food sources, or indirectly as they impact on other components of soil food webs and plant communities

- Veterinary medicines – in livestock production these compounds have a significant effect on the soil microbial community antibiotics.

b) Non-agricultural activities

Land and air pollution, mining, deforestation caused by slash and burn strategies and accidental forest fires constitute some of the most important non-agricultural activities that impact on the activity and diversity of soil microorganisms (Xavier and Germida, 1999).

Effect of agricultural activities on soil microbes

Humans impact the soil microorganisms in several ways. Common effects include Agricultural activities such as Application of Agrochemicals, Cultural practices, genetically modified crops, soil erosion, grazing and non-agricultural activities such as mining, deforestation, wild fires, and environmental pollution (Xavier and Germida, 1999).

Application of agro-chemicals

External inputs to agricultural production systems include mineral fertilizers such as urea, ammonium nitrate, sulfates, and phosphates; and pesticides including herbicides, insecticides, fungicides. All these products are applied with the ultimate goal of maximizing productivity and economic returns, while side effects on soil organisms are often neglected (Bünemann et al., 2006).

Chemical fertilizers

Inorganic inputs such as nitrogen, phosphorus, boron and potassium play an important role in enhancing the production of crop plants by serving as essential elements required for plant growth and the maintenance of soil fertility (Bünemann et al., 2006). Apart from their direct benefits to crops, these chemical amendments also affect microorganisms within the soil. Although inorganic fertilizers may influence the crop production positively, applying too much can result in negative effects on the target crop. Overuse of chemical fertilizers in soil with high fertility can decrease the diversity of microorganism communities within the soil. This leads to the deterioration of biological and biochemical properties (Bünemann et al., 2006).

Application of K and P fertilizers impacts on the community structure of specific microbial groups by increasing bacterial populations which utilize K and P, thus leading to a decrease in other microorganisms due to competition. Höflich et al., (1999) showed stimulation in the growth of legumes, graminaceae and crucifers by the application of high amounts of N fertilizers in both pot trials and long-term field experiments.

The addition of micronutrients such as boron combined with excessive soil salinity can also alter microbial diversity within soil. The application of high amounts of boron to soil significantly decreases the functional diversity and the richness of microbes in the rhizosphere (Nelson and Mele, 2006). Changes in the NaCl content in soil leads to a change in the moisture content and pH of soil, which in turn can significantly alter microbial diversity (Nelson and Mele, 2006). Other than the direct change in physical status of the soil, NaCl can also alter the permeability of plant roots thus increasing osmotic pressure which will directly affect soil microbial communities (Hung, 2012).

Although direct effects of fertilizers are sometimes difficult to clearly identify, addition of nitrogen in almost any form affects the carbon-to-nitrogen ratio and increases the degradability of soil organic matter stocks. Also, an indirect effect of nitrogen addition is that of acidification, which tends to result in decreased biomass over long periods of time, unless countered with applications of lime (which in itself may not be a sustainable practice in the long-term). Nitrogen management is of central importance in productive systems and there has been serious effort to develop chemical interventions to inhibit nitrification (Bünemann et al., 2006).

Pesticides

Pesticides affect microbial community directly by acting as food sources, or indirectly as they impact on other components of soil food webs and plant communities. The application of pesticides (fungicides, herbicides and insecticides) to soil can result in the reduction of soil microbial biomass, diversity and activity (Crecchio et al., 2006).

Fungicides

Many studies have demonstrated that microorganism communities in soil are significantly affected by the addition of fungicides (Demanou et al., 2006; Niemi et al., 2008; Lupwayi et al., 2009) as cited in (Hung, 2012). Fungicides affect non target soil microorganisms such as non-pathogenic fungi and microbes that are beneficial to the productivity of crops (Niemi et al., 2008). For example, high application rates of captan and chlorothalonil have been shown to cause shifts in soil nitrogen dynamics and destroy microorganism communities leading to a loss of soil fertility (Niemi et al., 2008). Wakelin et al., (2007b) as mentioned in Hung (2012) showed that application of the fungicide tolclofosmethyl to maize seeds reduces the number of microorganisms competing with *Fusarium oxysporum* Scheldt and *F. verticillioides* Nirenberg thus increasing the possibility of disease. Ferreira et al., (2009) used PCR-DGGE fingerprinting to show that application of the fungicides tebuconazole and mancozeb to crop plants, significantly affected the community structure of soil microorganisms.

Insecticides

Pesticides which target insects and arthropods that exist within and above soil may also alter non-target soil microorganisms. The application of pesticides such as λ-cyhalothrin (Lupwayi et al., 2009), azadirachtin (Gopal et al., 2006) and nemacur (Abramovich and Steinberger, 2006) as cited in (Hung,2012) cause changes to bacterial community structures in soil at a functional level that leads to a decline in soil fertility. Applications of organophosphate and chlorinated hydrocarbon based insecticides are found to directly kill non-target organisms in soil (Das and Mukherjee, 1999).

This leads to increases of available N and P in soil. Fungi are generally more resistant to insecticides. The increase in N and P following insecticide addition can lead to shifts in fungal diversity due to the increased food source (Das and Mukherjee, 1999). Biodegradable residues which remain in soil can serve as a food source for certain microorganisms which favours certain microorganisms that can lead to a change in the microorganism community (Hung, 2012).

Herbicides

Herbicides such as 2, 4-dicholorophenoxy-acetic acid (2, 4-D) can lead to an increase in microorganisms which degrade the herbicide; a phenomenon that can significantly affect microorganism community structure in soil. Glyphosate has been reported to either increase or decrease populations of soil microorganisms (Lupwayi et al., 2008). Direct toxic effects of herbicides on soil microorganisms have also been observed immediately after application. Glyphosate, 2, 4-D and metsulfuron methyl are found to have direct toxic effects on microorganisms (Lupwayi et al., 2008). Exposure to low concentrations of herbicide over a long period of time can also influence microbial communities in soil. The *in situ* application of phenoxy acid herbicides over 216 days stresses microorganisms and thus changes their functional diversity. Herbicide induced effects on soil microorganisms can also result in changes to N and P activity in the soil (Perucci et al., 1999).

Cultural practices

Conventional farming systems such as tillage, monocropping, soil fumigation and solarization can eventually lead to the deterioration of biological, physical and chemical properties of soil. This is mainly due to the continuous removal of nutrients and the use of insecticides, pesticides and other agricultural chemicals which deplete soil fertility by reducing population of beneficial soil micro biota (Zong-pei et al., 2007). The control of soilborne diseases is often performed by using fumigants and solarization, which can impact further on microorganism communities.

Other practices such as crop rotation can have beneficial effects on soil fertility and the judicious integration of cultural practices is therefore crucial for achieving sustainable soil fertility (Zong-pei et al., 2007).

Tillage

Tillage practices impact negatively on soil structure, soil organic matter content and soil moisture; factors which directly influence microbial diversity in soil. Tillage also results in physical relocation of food sources of microorganisms, impacting directly on the distribution and diversity of macro and microorganisms in soil (Simmons and Coleman, 2008). Comparisons between the effect of traditional tillage and conservation tillage on microorganism activity and biomass shows increased storage of organic matter and enhanced microorganism biomass in the latter (Govaerts et al., 2007).

According to Simmons and Coleman (2008), reduced tillage leads to greater soil microbial diversity than in soils in surrounding grassland areas. Different tillage practices produce consistent differences in enzyme activities in soil. Soil microbial diversity is also influenced by combining residue management practices. For example, the combination of zero tillage and residue retention significantly increases microbial biomass (Govaerts et al., 2007).

Microbial fatty acids are significantly influenced by different conventional tillage practices. This is mostly due to the effects of tillage on nutrient concentration and soil moisture (Simmons and Coleman, 2008). Zero-tillage and fallowing are often included in rotation systems instead of bare-soil fallow treatments. This preserves soil fertility, reduces soil erosion and accumulates soil water (Simmons and Coleman, 2008).

Monocropping

Monocropping often leads to the increased incidence of pathogens, weeds, pests and ultimately degradation and loss of soil fertility. Monocropping and the repeated use of resistant cultivars, crop rotation and soil fumigation can also lead to a reduction in crop production. This may be due to an imbalance in the physical and chemical properties of the soil, the allelopathic effects of root exudates and residues of crop plants and weeds, and the build-up of pests and pathogens. Monocropping favors the development of soilborne pathogens such as *F. oxysporum*, which causes wilt diseases on a wide variety of crop plants (Hung, 2012).

Various kinds of organic compounds are released by different crops. This is a vital factor influencing the functional diversity of microorganisms in the soil (Olsson and Alström, 2000). Monocropping may therefore favor the development of specific soil microorganisms. Long-term monocropping may lead to a depletion of organic C and N in soil and directly affect soil microorganism communities, both quantitatively and qualitatively. An 11-year-long study on monoculture wheat showed a significant decrease in soil organic C and a clear decrease in microbial biomass (Chen et al., 2009).

Crop rotation

Crop rotation affects the biological and biochemical properties of soil by changing the C content (Zong-pei et al., 2007). A change in C content, combined with a change in soil temperature and soil moisture dynamics due to crop rotation, will consequently lead to shifts in microbial populations (Bucher and Lanyon, 2004). Javier and Germida (1999) showed that crop rotation has significant effects on arbuscular mycorrhizal communities in soil. Compared to crop rotation, land-use intensification can lead to decreased microbial diversity.

A successful crop rotation programme may have the same positive effects on functional diversity of soil organisms as zero tillage. The chemical and physical properties of soil under rotation cropping are of a much higher quality than under conventional tillage and higher yields can therefore be achieved (Govaerts et al., 2007). Zero tillage, plant residue retention and crop rotation in combination can result in higher microbial biomass and more micro-flora activity than in soil under conventional tillage (Govaerts et al., 2007).

Genetically modified crops/Transgenic plants

Plant genetic modification (also known as genetic engineering) may be defined as the manipulation of plant development, structure or composition by the insertion of specific DNA sequences. These sequences may be derived from the same species or even variety of plant. This may be done with the aim of altering the levels or patterns of expression of specific endogenous genes, in other words to make them more or less active or to alter when and where in the plant they are 'switched' on or off. Alternatively, the aim may be to change the biological (i.e. regulatory or catalytic) properties of the proteins that they encode. However, in many cases, the genes are derived from other species, which may be plants, animals or microbes, and the aim is to introduce novel biological properties or activities (Halford and Shewry, 2000)

The worldwide cultivation of transgenic crops not only provides tremendous economic benefits, but also induces the concern about the potential risks of transgenic crops on soil ecosystem in which microorganisms are involved. The potential effects of transgenic crops on soil microorganisms include the direct effects of the transgenic proteins on non-target soil microorganisms, and the indirect effects of the unintentional changes in the chemical compositions of root exudates induced by the introduction of the exogenous transgenic proteins. Most of the studies on transgenic crops suggested that transgenic crops could affect the quantity and structure of soil microbial populations. However, the perceivable effects on the soil microorganisms are inconsistent, with some in significant and others in non-significant, or some with persistent and others with non-persistent (Motavalli et al., 2004)

Transgenic or genetically modified plants possess novel genes that impart beneficial characteristics such as herbicide resistance. One of the least understood areas in the environmental risk assessment of genetically modified crops is their impact on soil- and plant-associated microbial communities. The potential for interaction between transgenic plants and plant residues and the soil microbial community is not well understood. The recognition that these interactions could change microbial biodiversity and affect ecosystem functioning has initiated a limited number of studies in the area. At this time, studies have shown the possibility that transgenic can be transferred to native soil microorganisms through horizontal gene transfer, although there is no evidence of this occurring in the soil. Furthermore, novel proteins have been shown to be released from transgenic plants into the soil ecosystem, and their presence can influence the biodiversity of the microbial community by selectively stimulating the growth of organisms that can use them. Microbial diversity can be altered when associated with transgenic plants; however, these effects are both variable and transient (Dunfield and Germida, 2004).

Genetically modified (GM) crops pose a significant threat to the environment through pollution by GM pollen and the consequent flow of modified genes into the wider plant community. However, GM crops may also pose hazards to the ecology of soil through changes in agrochemical usage on GM crops with knock-on implications for soil microbes, genetic contamination of the soil and associated microorganisms as a result of horizontal gene transfer, changes to the soil ecosystem through the changed characteristics of GM plants and soil contamination through GM seeds remaining in the soil after harvest (Motavalli et al., 2004).

Dunfield and Germida (2004) demonstrated that field site influenced microbial community composition and interacted with plant varieties in their influence on the microbial community. The effect of plant variety on the microbial community at one field site was sometimes entirely different at another field site, suggesting that the environment will play a major role in determining the potential ecological significance of growing genetically modified plants. A time course study examining genetically modified plants over an entire field season suggests that changes to the microbial community structure associated with genetically modified plants are not permanent. From these assessments we now understand that transgenic plants and plant litter can influence the composition of the plant associated microbial communities. The changes in microbial communities associated with growing transgenic crops are relatively variable and transient in comparison to some other well accepted agricultural practices such as crop rotation, tillage, herbicide usage and irrigation (Dunfield and Germida, 2004).

According to Dunfield and Germida (2004), the potential impacts of transgenic plant on soil microorganisms depend on the characteristics of the gene transferred into the crops and the soil properties. The change of soil ecosystem affected by many factors, and among them, the complex and stability of the ecosystem are the most important. The ecological effects of transgenic crops on the soil ecosystem need to be evaluated more fully before they are planted over extensive areas.

Solarization

The technique involves covering soil with clear plastic for periods of time to allow heat build-up. It produces effects similar to that of a chemically fumigated soil by reducing the incidence of pests and pathogens (Tamiette and Valentino, 2005). It can increase crop yield and by heating the soil, not only removes pathogens in the soil but other beneficial microorganisms as well. This leads to rapid recolonization by fast growing microorganisms and leads to a change in the microbial diversity of the soil. Solarization increases soil temperature which induces changes in the physical and chemical properties of the soil, soil structure, water potential and soil pH (Gelsomino and Cacco, 2005). Microorganisms are also very sensitive to physical changes of soil, e.g. surrounding temperature and moisture level, and there is a significant compositional shift of bacterial communities within soil that has been solarized (Gelsomino and Cacco, 2005).

Soil erosion

The loss of soil from land surfaces by erosion is widespread and reduces the productivity of all natural ecosystems as well as agricultural, forest, and pasture ecosystems (Hobbs et al., 2004). Concurrently with the growing human population, soil erosion, water availability, climate change due to fossil fuel consumption, eutrophication of inland and coastal marine bodies of water, and loss of biodiversity rank as the prime environmental problems throughout the world (Hobbs et al., 2004).

Human induced soil erosion and associated damage to all agricultural land over many years have resulted in the loss of valuable agricultural land due to abandonment and reduced productivity of the remaining land which is partly made up for by the addition of nitrogen and phosphate fertilizers (Hobbs et al., 2004). This loss of cropland to the effects of soil erosion often results in the creation of new cropland out of forestland and pastureland and the need to enrich these new croplands with inputs of nitrogen and phosphate fertilizers. In addition, soil erosion reduces the valuable diversity of plants, animals, and soil microorganisms (Hobbs et al., 2004).

Soil erosion reduces the general productivity of terrestrial ecosystems (Lal et al., 1997). In the order of importance, soil erosion increases water runoff thereby decreasing water infiltration and the water-storage capacity of the soil. In addition, during the erosion process organic matter and essential plant nutrients are removed from the soil and soil depth is reduced. These changes not only inhibit vegetative growth but reduce the presence of valuable biota and the overall biodiversity of the soil (Lal et al., 1997). These factors interact, making it almost impossible to separate the specific impacts of one factor from another. For example, the loss of soil organic matter increases water runoff which reduces the soil's water-storage capacity, which diminishes nutrient levels in the soil and also reduces the natural biota biomass and the biodiversity of soil ecosystems (Lal et al., 1997).

Soil is one of the major habitats for microorganisms. The majority of microorganisms live in the first layer of soil, which represents a dynamic interface between plant and soil. Fungi and bacteria represent an essential functional component of terrestrial ecosystem, involved in a variety of biogeochemical processes such as C (Carbon), N (Nitrogen), S (Sulfur) and Fe (Iron) cycling and they carry out important functions inside the soil, playing a key role in the food web chain, where they occupy the lowest level of the trophic chain. For this reason the protection and conservation of soil biodiversity have an economical and ecological impact and the soil monitoring represents a valuable approach to determine the soil variables affecting the biodiversity (Cornio et al., 2012).

Grazing

The effect of grazing is not simply the removal of herbage from grass plants (Manske, 1998 as cited in Girma et al., 2007**)**, grazing also changes physiological processes in all parts of the plants; alters the plant community microclimate; the climatic conditions around parts of a plant or within a small area of a plant community by changing light transmission, moisture relations and temperature; and changes the soil environment, thereby affecting soil organism activity. Low water availability can inhibit microbial activity by lowering intracellular water potential and thus reducing hydration and activity of enzymes. In solid matrices, low water content may also reduce microbial activity by restricting substrate supply.

Grazing may affect the organic matter status of soils which may increase its susceptibility to erosion. This may be of particular importance on steep alpine slopes, or in tree line forests where the climatic stress is strong and the forest has an important protective function. Intimately linked with the organic matter status are the soil microorganisms, frequently referred to as microbial biomass. Microorganisms are the main mediator of organic matter turnover, and the C.mic fraction of organic carbon (Corg) is considered a very sensitive parameter for changes in the organic matter status (Insam et al., 1996). Over-grazing leads to soil erosion.

When herbivores are reared on a small piece of grassland, the rate of consumption of grass is usually faster than the rate of recovery. Eventually, the grass becomes too short or dies off. The process of erosion is speeded up as the soil is exposed. In addition, the trampling of the grassland by large populations of animals will make the soil compact. Rainwater cannot be easily absorbed by the soil. As a result, the soil becomes dry and loose, and soil erosion is speeded up and it affects the microbes in the soil (Insam et al., 1996).

Effect of non-agricultural activities on soil microbes

Environmental pollution, mining, deforestation caused by slash and burn strategies and accidental forest fires constitute some of the most important non-agricultural activities that impact on the activity and diversity of soil microorganisms (Xavier and Germida, 1999).

Mining

Adverse effect of mining includes erosion, formation of sink holders, loss of biodiversity, and contamination of soil, ground water, surface water by chemicals from mining process. In some cases, additional forest logging is done in the vicinity of mines to increase the available room for the storage of the created debris and soil. Besides creating environmental damage, the contamination resulting from leakage of chemicals also affects the health of the local population. Mining companies in some countries are required to follow environmental and rehabilitation codes, ensuring the area mined is returned to close to its original state (Talule and Naik, 2014).

Wild fires

Many physical, chemical, mineralogical, and biological soil properties can be affected by forest fires. The effects are chiefly a result of burn severity, which consists of peak temperatures and duration of the fire. Climate, vegetation, and topography of the burnt area control the resilience of the soil system; some fire-induced changes can even be permanent. Low to moderate severity fires, such as most of those prescribed in forest management; promote renovation of the dominant vegetation through elimination of undesired species and transient increase of pH and available nutrients. No irreversible ecosystem change occurs, but the enhancement of hydrophobicity can render the soil less able to soak up water and more prone to erosion. Severe fires, such as wildfires, generally have several negative effects on soil. They cause significant removal of organic matter, deterioration of both structure and porosity, considerable loss of nutrients through volatilization, ash entrapment in smoke columns, leaching and erosion, and marked alteration of both quantity and specific composition of microbial and soil-dwelling invertebrate communities (Certini, 2005). Vegetation fires have several ecological and environmental impacts. Biomass burning is a significant global source of atmospheric gases such as carbon dioxide (CO_2) and methane (CH_4), which green-house gases are contributing to global warming. During forest fires large amounts of CO_2 are released to the atmosphere. As the vegetation in the burned ecosystems regrows, CO_2 is again removed from the atmosphere via photosynthesis and incorporated into the new vegetative growth with a neat C balance that has been considered null (Levine et al., 1995 as cited in Perez et al., 2004)

Occurrence of wildfires in forest ecosystems has lasting effects on both the microbial composition and the OM, and hence on the whole soil dynamics. The alteration of natural ecosystems affects OM turnover and therefore productivity and community structure may be also affected (Perez et al., 2004).

After a forest fire there are several interactive factors that affect soil biota and, in turn, the evolution of OM may also be affected. These factors include direct sterilization, formation of ash, charcoal and fire-altered OM, and modifications of the soil forming factors and structure of the micro flora and the whole trophic system i.e. changes in canopy and vegetation affecting soil properties. In the short term, fire causes a drastic reduction in soil microbial biomass (Perez et al.,2004).Finally, forest fires exert many changes on physical and chemical soil properties that, in turn, affect the soil's water infiltration capability and hence its ability to absorb rainfall and snow melt and to support plants and other life and resistance to erosion. Forest clearance after fire reduces the vegetation canopy and litter layers and undoubtedly affects the processes, microclimate and biodiversity of the soil (Perez et al., 2004).

Fire can affect soil microbes directly through heating and indirectly by modifying soil properties. Microbes will also be affected by post-fire environmental factors and the reestablishment of vegetation. The most important factor affecting soil microbes seems to be the burn severity, which is controlled by such factors as fire intensity, duration, and soil properties which normally causes a decrease in the numbers of microbes. The temperatures reached in the topsoil are often sufficient to affect soil microorganisms and other soil properties related to the post-fire microbial recolonization. In extreme cases, the topsoil can undergo complete sterilization. Fungi seem to be more sensitive to heating than bacteria and actinomycetes, and a higher impact under wet soil conditions has been reported (Solera et al., 2009). The immediate effect of fire on soil microorganisms is a reduction of their biomass. In fact, the peak temperatures often considerably exceed those required for killing most living beings (Solera et al., 2009).

Deforestation

Forests around the world have undergone severe disturbances due to anthropogenic factors. An ever increasing human population has migrated into forested zones and cleared the forest to facilitate economic activities such as farming, grazing, and establishment of settlements and industries. The conversion of forestland to cropland, grazing land, and settlements has often resulted in soil degradation and nutrient losses (Dinesh et al., 2003 as cited in An et al., 2008). Clearing and cultivation of forested land has resulted in negative impacts to soil properties including the degradation of organic C and N and decreases in soil microbial biomass compared to land under natural forest, reforestation, and grassland (An et al.,2008). Deforestation occurs relatively quickly, and in contrast to some other transitions (e.g., from crop land to pasture, or from productive land to degraded land), is easily observable by the human eye. Deforestation can lead to soil erosion or impoverishment; especially in tropical areas where soils tend to be thin and nutrient-poor, habitat loss; which is a leading cause of species endangerment and biodiversity loss; particularly in humid tropical forests, affects the hydrological cycle through changes in evapo-transpiration and run-off; and Deforestation, and particularly forest burning, contributes to green-house gas emissions that bring about climate change (Crowther et al., 2014)

The obvious effect of deforestation in most places is the complete loss of trees with understory vegetation and in some places only bushy vegetation without continuous tree cover. The deforested areas are under intense pressure of repeated grazing from nearby densely populated villages. The other effects are loss of forest litter, compaction and erosion of soil, formation of gullies between the hill slopes and deposition of sediments on valleys and channels. Deforestation also degrades soil quality through loss of organic matter and nutrient elements with the removal of forest vegetation and fertile topsoil (Pritchett and Fisher 1987 as cited in Haque et al., 2014). Changes in soil physico chemical and biological properties due to deforestation have been reported (Sahani and Behara, 2001). Bulk density is usually higher in deforested sites due to the compaction caused by mechanical harvesting. Opening of the canopy through deforestation changes the microclimatic condition and causes abrupt shifts in soil temperatures, moisture, and the biogeochemical processes dependent on these environmental factors. Soil respiration is one of the important processes affected by vegetation removal. Soil respiration reflects the capacity of soil to sustain plant growth, soil fauna, and microorganisms. It indicates the level of microbial activity and soil organic matter content and its decomposition stage (Sahani and Behara, 2001).

Good forest cover contains high levels of organic matter, possesses more roots and plant residues, and favors high levels of microbial activity (Sahani and Behara, 2001).

Deforestation, in contrast, ceases litter input and changes soil respiration by moderating litter decomposition rates. Soil respiration is usually higher during the first few years after deforestation due to the higher temperatures and moisture content that favor microbial degradation of residual organic matter from timber harvest. However, soil respiration can be lower where all or most of the organic matter is removed during deforestation. Litter decomposition, a major pathway of soil respiration, releases CO_2 to the environment, simultaneously releasing or immobilizing mineralized nutrients. Depending on the substrate quality, these nutrients, especially N can be immobilized by microbes and subsequently released to the environment after the death of microbial cells (Sahani and Behara, 2001).

According to Haque et al. (2014), reduced active microbial biomass and basal respiration in deforested land was related to lower organic matter and microbial activity compared to natural forest containing significantly higher amount of organic matter. Similarly, reduced aggregate stability of deforested land is associated with lower input of labile C having lower amounts of litter-fall and root exudates compared to natural forest that is rich in both of the organic substances. Active microbial biomass is usually limited by the availability of labile C (Islam and Weil 2000 as cited in Haque et al., 2014). Thus, lower abundance of active microbial biomass is an indication of lower aggradations of organic C in deforested land and the reverse is true for natural forest or plantation containing higher amounts of organic carbon. Microbial respiration was higher at all natural forest sites than on their adjacent deforested lands. High amounts of respiration in forests might be due to high levels of organic matter (litter) inputs that are annually added to the soil surface. Microbial metabolic quotient is an index of evaluation of substrate utilization efficiency in microbial communities (Insam 1990 as cited in Haque et al., 2014). The more efficient functioning of microorganisms is related with greater fractionation of substrate C incorporated into biomass and less C loss from biomass through respiration, which results in a low metabolic quotient. A high metabolic quotient on deforested land indicated a low efficiency of substrate utilization by soil microbes (Haque et al., 2014).

Environmental pollution

The environment is polluted by numerous organic and inorganic compounds, heavy metals in particular. Rapid industrialization has led to increased disposal of heavy metals and radio nuclides into the environment. Heavy metal resistance is a widespread attribute among acidophilic heterotrophic bacteria isolated from mining environments (Xavier and Germida, 1999).

Sources of soil heavy metal pollution

Chemical compounds, entering the ecosystem as a result of different human activities, may accumulate in soil and water environments. Therefore, soil may be regarded as a long term reservoir of pollutants, from which these compounds may be introduced to food chains or groundwater (Boron and Boron, 2014). Inappropriate and careless disposal of industrial waste often results in environmental pollution. The pollution includes point sources such as emission, effluents and solid discharge from industry, vehicle exhaustion and metal smelting or mining, as well as nonpoint sources (e.g. the use of pesticides or excessive use of fertilizers) (Mc Grath et al., 2001). Each of the sources have their own damaging effects on plant, animal and human health, but those that add heavy metals to soils are of serious concern due to the persistence of these elements in the environment. They cannot be destroyed, but are only transformed from one state to another (Mc Grath et al., 2001).

Soil pollution may be defined as presence of xenobiotics (e.g. chemical compounds, radioactive elements) that alters the soil chemical, physical and biological properties. Soil pollution, including heavy metals, may be of natural origin, like volcanic eruptions, animal excrements or ore leaching. Nevertheless, human activity and mostly chemical industry, mining and metallurgy, as well as municipal management and traffic emissions are the main source of environmental pollution. Some authors also mention that waste disposal, waste incineration, fertilizer application and long-term application of wastewater in agricultural lands may result in heavy metal pollution, Communication routes, such as roads, railways etc., are an important source of soil pollution, especially in the case of lead and zinc. Despite restricted use of leaded gasoline adopted in most countries, lead remains one of the most serious automotive-originating metal pollutants. The areas located nearby roads, particularly in urban sites, are the most vulnerable to automotive pollution. Apart from lead and zinc, chromium, cadmium, nickel and platinum are among the pollutants emitted by combustion engine-powered vehicles (Indeka and Karczun, 1999). The changes in the concentrations of lead, nickel, cadmium, copper and zinc in roadside soils are frequently attributed to traffic density (Indeka and Karczun, 1999).

Standard agricultural practices are also a significant source of heavy metals in soils, as application of fertilizers and pesticides has contributed to a continuous accumulation of these elements. Heavy metals can accumulate in soils due to the application of liquid and solid manure, as well as inorganic fertilizers (McGrath et al., 2001). The application of numerous biosolids, such as livestock manures, composts and municipal sewage sludge on agricultural soils leads to the accumulation of various heavy metals, such as, Cd, Cr, Cu, Hg, Mo, Ni, and Zn (Mc Grath et al., 2001).

Lime and superphosphate fertilizers contain not only major elements necessary for plant nutrition and growth but also trace metal impurities such as cadmium. The presence of high concentrations of Cd in some fertilizers (particularly in phosphatic fertilizers) is of most concern due to the toxicity of this metal and its ability to accumulate in soils as well as due to its bioaccumulation in plant and consequently in animal tissues (Boron and Boron, 2014).

High fertilizer applications and acid atmospheric deposition, combined with insufficient liming, may also cause a decrease in pH and thus increase heavy metal bioavailability, aggravating the problem of deteriorating food quality, metal leaching and impact on soil organisms. Another, and one of the most significant sources of heavy metal pollution of soils, includes heavy industry, e.g. mining and metallurgy (Boron and Boron, 2014).

The effects of heavy metals on soil microorganisms

Metals without biological function are generally tolerated only in minute concentrations, whereas essential metals with biological functions, are usually tolerated in higher concentrations (Hafeburg et al., 2007). They have either metabolic functions as constituents of enzymes or meet structural demands, e.g. by supporting the cell envelope. Frequently the concentration and the speciation of metal determine whether it is useful or harmful to microbial cells (Hafeburg et al., 2007).

Microorganisms are the first biota that undergoes direct and indirect impacts of heavy metals. Some metals (e.g. Fe, Zn, Cu, Ni, Co) are of vital importance for many microbial activities when occur at low concentrations. These metals are often involved in the metabolism and redox processes. Metals facilitate secondary metabolism in bacteria, actinomycetes and fungi (Hafeburg et al., 2007). E.g.: chromium is known to have stimulatory effect on both actinorhodin production and growth yield of the model actinomycetes *S. coelicolor* (Boron and Boron, 2014). However, high concentrations of heavy metals may have inhibitory or even toxic effects on living organisms (Bruins et al., 2000). Adverse effects of metals on soil microbes result in decreased decomposition of organic matter, reduced soil respiration, decreased diversity and declined activity of several soil enzymes (Boron and Boron, 2014). Some of the general changes in morphology, the disruption of the life cycle and the increase or decrease of pigmentation are easy to observe and evaluate (Hafeburg et al., 2007).

Rajapaksha et al. (2004) compared the reactions of bacteria and fungi to toxic metals in soils (Zn and Cu). They concluded that bacterial community is more sensitive to increased concentrations of heavy metals in soils than the fungal community. The relative fungal/bacterial ratio increased with increasing metal levels. Those authors also noticed the varying effect of soil pH on the microbial reaction to soil pollution, i.e. that lower pH in contaminated soils enhanced the negative effect on bacteria, but not on fungi. The toxic concentration of heavy metals may cause enzyme damage and consequently their inactivation, as the enzymes associated metals can be displaced by toxic metals with similar structure (Bruins et al., 2000). Moreover, heavy metals alter the conformational structures of nucleic acids and proteins, and consequently form complexes with protein molecules which render them inactive. Those effects result in disruption of microbial cell membrane integrity or destruction of entire cell. Heavy metals also form precipitates or chelates with essential metabolites (Rajapaksha et al., 2004).

Various metals may affect different microbial populations and the resulting impact may vary depending on the metal whose limit concentrations in soils were exceeded. For instance, the pollution of soils with copper affects microorganisms that take part in nitrification and mineralization of protein compounds (Kabata et al., 1999). Silver is one of the most toxic metals to heterotrophic bacteria. This effect is used for the production of antiseptic preparations. However, there are some silver-resistant bacteria, both in clinical and natural conditions. Some strains of *Thiobacillus ferrooxidans* are able to accumulate particularly large amounts of silver (Kabata et al., 1999).

Microorganisms play vital role in circulation and transformation of mercury compounds in the environment. Numerous bacteria and fungi show high tolerance (also acquired) to increased concentrations of mercury in soils. However, some microorganisms are sensitive to excess mercury, e.g. the concentration of <10 ppm Hg may have toxic effects on nitrifies in soils (Kabata et al., 1999). Increased concentrations of lead in surface soil layers negatively affect soil micro flora. Processes of organic matter decomposition, particularly cellulose, are inhibited as a result of decreased enzymatic activity of microorganisms. This results in soil degradation. Biosorption of lead by soil microorganisms reaches on average 0.2% of this metal, but in some cases it may reach even 40% of biomass and may be used for biological remediation (Boron and Boron, 2014).

Impact of climate change on soil microorganisms

In recent years concerns on climate change and in particular the increase of global temperature and the altered precipitations are inflaming the public debate among scientist, especially regarding the possible effect on the environment, animals, plants and biodiversity (Cornio et al., 2012). Anthropogenic disturbances led to a rise in levels of atmospheric CO_2, with a consequent increase of temperatures and an effect on nutrient cycles (IPCC 2007 as cited in Cornio et al., 2012). These effects along with altered levels of precipitations could affect the ecosystem equilibrium in the long term and in particular plant productivity. Microbial populations in soil are climate dependent. Changes in soil microbial population could slightly influence plant growth and cause non-visible effects on agriculture system in the short-term; however they can dramatically change the soil ecosystem in the long run. Soil processes involving soil microorganisms, such as mineralization, decomposition, nutrient cycling, could be affected by the a biotic changes in the climate, so altering the soil processes and influencing the organisms that take part in them. In this way climate change could influence the microbial community's structure and alter the level of interaction among microorganisms (Cornio et al., 2012).

Changes in soil temperature and precipitation levels could affect microorganisms' growth rate, their respiration and activity (Cornio et al., 2012). Temperature is one of the most important environmental factors regulating the activity and determining the composition of bacterial and fungal communities. Temperature shifts can affect microbial activity, processing and turnover causing the microbial community to shift in favour of species adapted respectively to higher or lower temperatures and faster or slower growth rate. Changes in temperature affect heterotrophic respiration and induce a modification in the ability to metabolize substrates. These effects could be the result of a direct action of the temperature on soil community or an indirect result of the temperature effect on plant (Cornio et al., 2012).

According to De Vries and Bardget (2015), Climate change drivers predicted for the UK have the potential to impact soil biota directly, through increased and decreased precipitation, and/or warming, and indirectly, through changes in plant growth and physiology and vegetation structure, due to altered precipitation, warming, and elevated atmospheric CO_2. Changes in precipitation, including drought and flooding, affect soil biota directly by changing soil water availability, but also indirectly by changes in the soil habitat, for instance as result of shrinkage and swelling of clay rich soils. Little is known about the impact on flooding on soil organisms, but immediate effects of drought on soil communities are well documented and can be severe, with declines in microbial biomass and activity, and even death of larger soil organisms, being observed (DeVries and Bardgett, 2015).

Climate change and act can also impact soil biota by increasing water and wind erosion of soil, especially where the frequency and intensity of extreme rainfall events increases and where climate-change driven changes in land use make soils more vulnerable to erosion (Nearing et al., 2004 as cited in DeVries and Bardgett, 2015). The impact of warming on soil biota, in contrast, is more gradual, causing stimulation of physiological processes, and hence rates of microbial respiration and nutrient mineralization (Blank ship et al., 2011).

Drought and warming can also indirectly affect soil biota through their impact on the growth of individual plants and plant community structure, which alters the supply of organic matter to soil from plant litter and root exudates, and through changes in root growth and exudation which can modify soil structure, thereby affecting soil water and gas fluxes, and the movement of soil organisms through soil (Bardgett et al., 201 3). Likewise, the effects of elevated atmospheric CO2 on soil biota are indirect, through changes in plant physiological processes and carbon allocation, and changes in plant community composition (Bardgett et al., 2013). In particular, elevated CO2 typically increases plant photosynthesis and growth, and the amount of carbon pumped into the soil by plant roots, which in turn strongly modifies the growth and activity of soil biota (Blank ship et al., 2011).

Summary and recommendations

Although the presence of soil microorganisms was discovered in the 17th century, they have only recently been considered of significant importance to agricultural systems. Their presence is vital to maintain regulatory functions in soil that determine soil fertility and quality. Many biotic and a biotic factors however, have a direct and indirect impact on their functional and structural diversity and biomass in soil. These factors influence their interactions with plants both above and below ground. These interactions occur both temporally and spatially and can be either beneficial to plant health and yield, or result in disease-associated losses.

Agricultural management practices, such as tillage and various soil amendments, which are used to enhance crop yields, can influence the chemical and physical environment of soil resulting in direct impacts on microorganisms. Although the positive effects of these practices can be seen immediately, the negative effects may cause more damage to the soil ecosystem in the long run.

The negative effects of chemical amendments which remove specific organisms from soil i.e. herbicides, pesticides or fungicides may lead to opportunistic pathogens or weeds developing due to vacant niches and increased food sources. Effects of heavy metals upon the community of microbes responsible for nitrogen cycle are still largely unknown. Chemical fertilizers not only nourish plants and microbes, but also may have harmful effects on the soil and its life, especially when they are very concentrated and water soluble. Although the use of pesticides is intended to provide satisfactory crop yields by controlling commonly occurring pests and disease in production fields, some may be toxic to the environment, as well as to humans. Continual soil inversion can in some situations lead to a degradation of soil structure leading to a compacted soil composed of fine particles with low levels of soil organic matter (SOM).

A combination of management practices and soil amendments should therefore be considered. Combined management systems not only remove unwanted organisms but also enhance microbial diversity in order to prevent the outbreak of disease. A successful combination of management practices and amendments will encourage the recovery of functional systems in soil and also improve the potential yield of crops. Therefore future investigations and comparisons of various combinations and their effects on soil microorganisms is therefore of the utmost importance.

References

Abawi G. S., and Widmer, T.L., 2000. Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops. Applied Soil Ecology 15: 37-47.

Anna Lenart-Boroń and Piotr Boroń (2014). A review on The Effect of Industrial Heavy Metal Pollution on Microbial Abundance and Diversity in Soils.

Bardgett, R. D., P. Manning, E. Morriën, and F. T. de Vries. 2013. Hierarchical responses of plant–soil interactions to climate change: consequences for the global carbon cycle. Journal of Ecology 101:334-343.

Bashan Y (1999) Interactions of Azospirillum spp. in soils: a review. Biology and Fertility of Soils 29, 246–256.

Bruins M.R., Kapil S., Oehme F.W. Microbial resistance to metals in the environment. Ecotoxicology and Environmental Safety 2000; 45: 198-207.

Brussard, L., Kuyper, T. W., Didden, W. A. M., de Goede, R. G. M., Bloem, J. 2004. Biological soil quality from biomass to biodiversity – Importance and resilience to management stress and disturbance, in Schjønning, P., Elmholt, S., Christensen, B. T.: Challenges in Modern Agriculture. CABI, Wallingford, pp. 139–161.

Bucher, A. E., and Lanyon, L. E., 2004. Evaluating soil management with microbial community-level physiological profiles. Applied Soil Ecology 29: 59-71.

Bünemann, E. K., G. D. Schwenke, and L. Van Zwieten.2006. Impact of agricultural inputs on soil organisms—a review. Australian Journal of Soil Research, 2006, 44, 379–406

Chen, H., Hou, R., Gong, Y., Li, H., Fan, M., and Kuzyakov, Y., 2009. Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess Plateau in China. Soil & Tillage Research 106: 85-94.

Chinalia, F.A., and Killham, K.S., 2006. 2,4 Dichlorophenoxyacetic acid (2,4 D) biodegradation in river sediments of Northeast-Scotland and its effect on the microbial communities (PLFA and DGGE). Chemosphere 64: 1675-1683.

Crecchio, C., Curci, M., Pellegrino, A., Ricciuti, P., Tursi, N., and Ruggiero, P., 2006. Soil microbial dynamics and genetic diversity in soil under monoculture wheat grown in different long-term management systems. Soil Biology & Biochemistry 39: 1391-1400.

Das, A.C., and Mukherjee, D., 1999. Soil application of insecticides influences microorganisms and plant nutrients. Applied Soil Ecology 14: 55-62.

Dnyandev C. Talule, Guruprasad R. Naik.2014. Impacts of Indiscriminate Mining on Agriculture and Biodiversity in the State of Goa in India. Universal Journal of Agricultural Research 2(6): 211-215.

Doran, J. W., and Zeiss, M.R., 2000. Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology 15: 3-11.

Dunfield, K.E. and J.J. Germida. 2004. Impact of genetically modified crops on soil- and plant associated microbial communities. J. Eniron. Qual.

33: 806-815

Fernando José Garbuio, Jeffrey L. Howard, and Larissa Macedo dos Santos,(2012).Impact of Human Activities on Soil Contamination. Applied and Environmental Soil Science, Volume 2012, Article I D 619548, 2 pages

Ferreira, E.P. de B., Dusi, A.N., Costa, J.R., Xavier, G.R., and Rumjanek, N.G., 2009. Assessing insecticide and fungicide effects on the culturable soil bacterial community by analyses of variance of their DGGE fingerprinting data. European Journal of Soil Biology 45: 1-7.

Franciscka T. de Vries and Richard D. Bardgett.2015. Climate change effects on soil biota in the UK, Biodiversity Report Card 16 2015

Gelsomino, A., and Cacco, G., 2005. Compositional shifts of bacterial groups in a solarized and amended soil as determined by denaturing gradient gel electrophoresis. Soil Biology & Biochemistry 38: 91-102.

Giacomo Certini, 2005.Effects of fire on properties of forest soils: a review.Oecologia (2005) 143:1–10

Girma Taddese, Don Peden, Asfaw Hailemariam, Yilma Jobre and WagnewAyalneh.2007.Effect of livestock grazing on soil micro-organisms ofcracking and self mulching vertisol. Ethiop. Vet. J., 11 (1), 141-150.

Govaerts, B., Mezzalama, M., Unno, Y., Sayre, K.D., Luna-Guido, M., Vanherk, K., Dendooven, L., and Deckers, J., 2007. Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. Applied Soil Ecology 37: 18- 30.

Hafeburg G., Kothe E. Microbes and metals: interactions in the environment. Journal of Basic Microbiology 2007; 47:453-467.

Höflich, G., Tauschke, M., Kühn, G., and Rogasik, J., 1999. Influence of agricultural crops and fertilization on microbial activity and microorganisms in the rhizosphere. Journal of Agronomy & Crop Science 184: 49-54.

Hung Yu Chung, 2012.The Influence of Agricultural Soil Amendments on the Diversity Of Soil Micro-Organisms And Disease Incidence. Submitted In Partial Fulfillment Of The Requirements For The Degree Magister Scientiae In The Faculty Of Natural And Agricultural Sciences, Department Of Plant Sciences, University Of The Free State Bloemfontein, South Africa.

Indeka L., Karczun Z. Accumulation of selected heavy metals in soils along busy traffic routes. Ecology and Technology 1999; 6: 174-180.

Insam H., Rangger A., Henrich M. & Hltzl W. 1996. The effect of grazing on soil microbial biomass and community on alpine pastures. - Phyton (Horn, Austria) 36 (4): 205 - 216.

Jenkinson, D. S. (1988): The determination of microbial biomass carbon and nitrogen in soil, in Wilson, J. R.: Advances in Nitrogen Cycling in Agricultural Ecosystems. CABI, Wallingford, pp. 368–386.

Jones, A.J.; Lal, R.; Huggins, D.R. Soil erosion and productivity research: A regional approach. Am. J. Altern. Agric. 1997, 12, 183–192.

Jorge Mataix-Solera, César Guerrero, Fuensanta García-Orenes,Gema M. Bárcenas and M. Pilar Torres, 2009. Forest Fire Effects on Soil Microbiology. Fire Effects on Soils and Restoration Strategies 5:134-175.

Jose´A. Gonza´lez-Perez, Francisco J.Gonza´lez-Vila, Gonzalo Almendros, Heike Knicker, 2004. The effect of fire on soil organic matter—a review. Environment International 30: 855 – 870

Joseph C. Blankinship, Pascal A. Niklaus, Bruce A. Hungate (2011). A meta-analysis of responses of soil biota to global change. Oecologia (2011) 165: 553–565

Kabata-Pendias A., Pendias H. Biogeochemistry of trace elements. Warsaw: PWN Scientific Publishing House; 1999.

L.J.C. Xavier and J. J. Germida, (1999). Impact of human activities on mycorrhizae. Department of Soil Science, University of Saskatchewan, 51, Campus Drive, Saskatoon, SK S7N 5A8, Canada

Lupwayi, N.Z., Harker, K.N., Clayton, G.W., O'Donovan, J.T., and Blackshaw, R.E., 2008. Soil microbial response to herbicides applied to glyphosate-resistant canola. Agriculture, Ecosystems and Environment 129: 171 -176.

Magdoff, F., and Vanes, H., 2000. Building Soils for Better Crops. Sustainable agriculture network handbook series, book 4. Publisher: SARE Outreach.

McGrath S.P., Zhao F.J., Lombi E. Plant and rhizosphere process involved in phytore-mediation of metal-contaminated soils. Plant and Soil 2001; 232: 207-214.

Motavalli, P. P., R. J. Kremer, M. Fang, and N. E. Means.2004. Impact of Genetically Modified Crops and Their Management on Soil Microbially Mediated Plant Nutrient Transformations. J. Environ. Qual. 33: 816–824

Nelson, D.R., and Mele, P.M., 2006. Subtle changes in rhizosphere microbial community structure in response to increased boron and sodium chloride concentrations. Soil Biology & Biochemistry 39: 340-351.

Niemi, R.M., Heiskanen, I., Ahtiainen, J.H., Rahkonen, A., Mäntykoski, K., Welling, L., Laitinen, P., and Ruttunen, P., 2008. Microbial toxicity and impacts on soil enzyme activities of pesticides used in potato cultivation. Applied Soil Ecology 41: 293-304.

Nigel G. Halford and Peter R. Shewry.2000. Genetically modified crops: methodology, benefits, regulation and public concerns. Bntish Medical Bulletin 56 (No 1) 62-73

Olsson, S., and Alström, S., 2000. Characterization of bacteria in soils under barley monoculture and crop rotation. Soil Biology & Biochemistry 32: 1443-1451.

Paola Elisa Corneo, Noemi Herrero Asensio, Claudia Maria Longa, Alberto Pellegrini, Michele Perazzolli and IlariaPertot (2012) Climate Change and Possible Impacts on Soil.

Perucci, P., Dumontet, S., Bufo, S. A., Mazzatura, A., and Casucci, C., 1999. Effects of organic amendment and herbicide treatment on soil microbial biomass. Biology and Fertility of Soils 32: 17-23. 23.

Rajapaksha R.M.C.P. Tabor-Kapłon M.A., Bååth E. Metal toxicity affects fungal and bacterial activities in soil differently. Applied and Environmental Microbiology 2004; 70: 2966-2973.

Sahani U, Behera N. 2001. Impact of deforestation on soil physicochemical characteristics, microbial biomass and microbial activity of tropical soil. Land Degradation and Development, 12: 93–105.

Shaoshan An, Fenli Zheng, Feng Zhang, Scott Van Pelt, Ute Hamer, Franz Makeschin.2008.Soil quality degradation processes along a deforestation chronosequence in the Ziwuling area, China. Catena 75: 248–256.

Simmons, B.L., and Coleman, D.C., 2008. Microbial community response to transition from conventional to conservation tillage in cotton fields. Applied Soil Ecology 40, 518-528.

Sirajul Haque, S.M., Sanatan Das Gupta and Sohag Miah.2014.Deforestation effects on biological and other important soil properties inan upland watershed of Bangladesh. Journal of Forestry Research 25(4): 877−885.

Slattery JF, Coventry DR, Slattery WJ (2001) Rhizobial ecology as affected by the soil environment. Australian Journal of Experimental Agriculture 41, 289–298.

Tamiette, G., and Valentino, D., 2005. Soil solarization as an ecological method for the control of Fusarium wilt of melon in Italy. Crop Protection 25: 389-397.

Thomas W. Crowther, Daniel S. Maynard, Jonathan W. Leff, Emily Eoldfield, Rebecca L. Mc Culley, Noah Fierer and Mark A. Bradford. 2014. Predicting the responsiveness of soil biodiversity to deforestation: a cross-biome study. Global Change Biology (2014)

Troeh, F.R.; Hobbs, A.H.; Donahue, R.L. Soil and Water Conservation: For Productivity and Environmental Protection; Prentice Hall: Upper Saddle River, NJ, USA, 2004.

Zong-pei, L., Xiao-cheng, W., and Bi-yun, C., 2007. Changes in transformation of soil organic C and functional diversity of soil microbial community under different land uses. Agricultural Sciences in China 6: 1235-1245.

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