Chapter

Soil Management and Conservation: An Approach to Mitigate and Ameliorate Soil Contamination

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Abstract

The chapter mainstreamed Soil Management and Conservation approach as a potent remedy for Soil Contamination. Largely, microbial activities play significant role in maintaining balance within the ecosystem however changes in Land-use has a direct influence on soil biota, including the floral and fauna components. The introduction of contaminants, from varying sources such as agrochemicals, petrochemicals, landfills, sludge, effluents, etc., into the soil builds up the amount of heavy metals present in the deposits hence degrading the soil and polluting groundwater. Integrating soil management options to enhance biodiversity and strengthen microbial activities improve the soil ecology thus creating a buffer for neutralizing potential contaminants.

Keywords: degradation, land-use, ecology, biodiversity, soil conservation

1. Introduction

One of the central component of terrestrial ecosystem is soil. Loss in ecosystem is a representation of the degradation of soil. The soil plays a key role in the health of ecosystem, however, over-exploitation of these ecosystem by humans causes considerable degradation and migration of contaminants. The use of land for agriculture occupies 36.5% of the earth's land mass [1]. Though this human activities may be justified to provide greater benefit in other services termed development, but consistent degradation of this ecosystem and exposure of it to various contaminants is not in the best interest of the society and it is detrimental to the environment that sustains all life forms.

Soil conservation are various practices of farming operations and management strategies which are conducted with the purpose of controlling soil erosion by avoiding or minimizing soil particle detachment and movement of water or/and air. It also helps in preventing the loss of the top-most layer of the soil and fertility which could also be caused by soil contamination. Understanding the processes and factors that govern soil erosion is very important to implementing its control practice and will help to manage soil erosion thus leading to soil conservation. The mechanics involve fluid (wind/water) detachment or entrainment which is being accompanied by the transportation of soil particles and its subsequent deposition as soil sediments. Conservation approaches and management strategies that ensures these include crop rotation, cover cropping, planting windbreaks and conservation tillage, which have been harnessed for millennia. Soil conservation practices are said to be farming operations and soil management strategies carried out with the aim of achieving a goal which is to control soil erosion by preventing or reducing soil particle detachment and transport in air or water [2]. Soil conservation started with the aim to protect an ecology from agricultural production by making use of largely unproven technology that failed to adapt with the natural requirements of the land. The evolving land degradation trend could only be understood by determining if the causes were as a result of natural occurrences or by unwise use [3].

In Europe, Common Agricultural Policy (CAP) is put in place in a bid to target the application of best management practices such as winter cover crops, reduced tillage, plant residues and grass margins in order to address conservation [4]. This traditional approaches which enhanced the productivity, environmental benefits and profits are based on procedures of no-tillage, and the broader concepts of agricultural conservation and land management sustainability. These concepts are one and not divided, but part of a continuous land management practices which range from detailed soil management practices such as zero-tillage, to the enhnaced concepts, principles and objectives of agricultural conservation and land management for sustainability.

2. Soil conservation methods

2.1 Cover cropping and mulching

This method is effective in reducing migration of top soil by leaving a cover over the soil in a bid to reduce soil displacement which is associated with the impacts from raindrops on the soil particles. Cover crops and mulching also reduces the amount of runoff and its velocity over the soil. Mulching, which is the application of organic materials over exposed soil to confer a form of covering to it over a period before decomposing. Straw can be used as mulch but hay is proven to be the best and it is important to ensure that it is harvested before the weeds mature. These crops are necessary to control erosion especially when the main crops planted do not give sufficient residue for more conventional residue management-based erosion control [5]. Where precipitation is adequate, cover crops like peas can help protect against wind erosion and also add nitrogen to the soil. The nitrogen released from the roots of these legumes are energy source for microbial metabolic activities hence such live mulch or cover crop give rise to an active microbial community in the rhizosphere soil.

2.2 Crop rotation

Crop rotation is an indigenous and practical way for managing agro-ecosystem biodiversity by enhancing soil health, minimizing pests and disease outbreaks [6]. This method enables farmers to improve the structure of the soil, increase the soil organic matter and rooting depth. This happens when secondary crops are grown in order to enhance soil health. As a result of the extensive shattering of soil aggregrates during seedbed preparation and harvesting, root crops are particularly destructive to the soil structure. Therefore, it is advised that root crops should be grown once in every three years. Corn can be grown in the following year with two years of silage followed in succession by three or more years of forage. Leguminous crops (such as pea and chickpea) during crop rotation helps in modifying soil functional microbial communities. In the rotation, cover cropping or mulching, and zero tillage should be incorporated too. Crop rotations can provide better opportunities for the growth of some soil functional microorganisms. This brings about rich biodiversity within the soil ecosystem as both the shallow feeding crops and deep rooted crops activates varying species of microorganismsper time thus creating a build up of microbes exhibiting varying characteristics to colonize the soil. Thus, different crops can produce various residues and root exudates to boost soil microbial diversity and activity, and increase soil microbial biomass as well as enhance C and N cycling [7, 8].

2.3 Conservation tillage

This method is aimed atpreserving soil aggregates, organic matter and crop residues [9, 10]. Conservation tillage include changes in making use of less destructive tillage implements (for instance, instead of using mouldboard plow, use chisel plow), minimum tillage (that is, one turn instead of two), leaving crop residue on the soil surface to prevent erosion. Plowing and tilling land for the preparation of the seed bed are basis of the traditional agricultural practices. However, these practices have been proven to be highly destructive to the soil with 24% of global agricultural land degraded as a result of this [11]. New approach which is centered on conserving and improving soil is gradually replacing soil tillage. The soil is typically inverted to a depth of less than 20 cm using mouldboard plow during conventional tillage system, however, in conservation tillage system, the soil is not disturbed or disturbed to a lesser degree [12]. This conservation method has shown to improve soil structure, reduce soil erosion, improve drainage and water holding capacity of the soil, increase soil organic matter and also increase microbial and earthworm activity [13].

2.4 Ridges, terraces and contours

The ridges are made across wind and they consist of tall listed seed beds that are being formed over the entire field or as trap strips which is in a position perpendicular to the direction of the prevailing wind. The formation of an earthen embankment along a common elevation contour gives an elevated terrace structure that can directly reduce wind erosion by potential reduction in wind speed and interception of soil particles. Indirect wind erosion control benefits of terraces and the related contour tillage and cropping practices expand overall crop grain and residue productivity by controlling runoff for increased water storage in the soil [14]. The underlying layer of soil becomes relatively less disturbed by the action of erosion hence making room for an increased microbial population within the micro-climate.

2.5 Strip cropping/planting windbreaks

This is another method of conserving the soil and for controlling wind erosion. A windbreak serves as a barrier with the purpose of deflecting the flow of air and reducing leeward wind speed [15]. However, the availability of irrigation makes this conservation method useful in a difficult environment. The crops may be cultured in strips perpendicular to the prevailing wind where field orientation is not restricted as a means to reduce the near surface wind speed [16]. This practice is broadly accommodating of various width of crop strips depending on the crop tolerance to eroding soil or potential to trap soil grains. The interplay between erosivity and erodibility potential of soil determines the gradient of detachment experienced within varying soil types. This confers significance on the efficacy of windbreaks/strip crops to band soil particles together thereby curtailing dislodgement.

2.6 Residue management

This is the most preferred method for controlling wind erosion for most crops and climates [17]. It is made up of several tillage practices that maintain residue from a previously harvested crop as a surface cover to prevent soil erosion. Residue management also maintains mulches which may be standing or flat to intercept soil grains by trapping their movement [18]. Leaving the residue of the previous crop on the surface of the soil is beneficial in that it improves soil water storage regardless of the runoff controlling contours, it helps to increase rain infiltration and reduce evaporation from the soil. The micro-climate here is well adapted for microbial activities as there exists a steady retrieval of energy from the decomposing biomass of residues thereby giving rise to mineralization of organic compounds and disintegration of complex molecules.

3. Effects of agriculture on environmental health

Soil health is the innate potential of a soil to function within ecosystem boundaries (either natural or managed), sustain plant productivity, maintain water and air quality, support human well-being, and provide habitats for biodiversity [19–21]. Agricultural intensification is placing huge pressure on the soil's potential to maintain its functions which is progressively leading to large-scale ecosystem degradation and loss of productivity in the long term [22–24]. Over a few decades, significant efforts have been made to enhance agricultural productivity through increased fertilization and pesticide application, improved irrigation, soil management regimes and crops, and massive land conversions [25]. However, there is a growing concern that the use of natural ecosystems for agricultural purposes has incurred substantial environmental costs, including desertification, increased emissions of greenhouse gasses, decreased organic matter in soils, loss of biodiversity, and alterations to biogeochemical and hydrological cycles [26, 27].

The quality of the soil, conversely, is an extrinsic feature of soils and changes with the desired usage of that soil by humans. This may be related to agricultural production and its capacity to support wildlife, watershed production, or recreation outputs provision. Some of the environmental challenges that are related to agriculture are expressed as pollutants, climate change, soil degradation, and deforestation [28].

3.1 Climate change

Climate is described as general or average weather conditions of a certain region, including temperature, rainfall and wind, over a long period. Climate change has direct and indirect effect in speeding up or slowing down terrestrial microbial community composition and their functional activities. Climatic change alters the relative population of microorganisms and their functions within soil communities since soil community members differ in their physiology, temperature sensitivity, and growth rates [29–34]. The direct effects of climatic change on microbial population, composition and function have been reviewed extensively [35–39]. Temperature and water are essential environmental factors for microbial growth. Increased temperature alters microbial community structures and processes such as respiration, fermentation and methanogenesis are also accelerated. This directly affects enzyme activity and microbial physiological property. Both agriculture and climate change are interrelated processes, of which they both take place on a global scale. Climate change impacts microbial community structure and activities both directly, through alteration of the soil chemical and physical environment, and indirectly through changes in land use. Environmental changes such as global warming are directly altering microbial soil respiration rates because soil microorganisms, and the processes they mediate, are temperature sensitive. The role of the prevailing changing climate, visibly expressed with elevated temperature, in microbial metabolism has been accorded considerable attention of recent [40–43]. This stresses the effects of climatic changes on soil microorganisms which are essential components in the ecosystem since they play a key role in maintaining soil health through ecological intensification.

3.2 Deforestation

Deforestation is a major driver of climate change and cause of the loss of habitat for millions of species. The soil is the basis for agriculture, natural plant communities and natural climate regulation, with 75% organic carbon stored in terrestrial habitat [44–46]. Vegetation has extensive contribution in sustaining ecosystem services of both surface and subsurface soil. Deforestation exacerbates climate change in that trees are completely or selectively removed to create farmland. Land use changes have several undesirable consequences, with significant effect on radical losses in soil fertility, soil carbon and nitrogen stocks have been recorded in the first 20–25 years after deforestation [47, 48].

3.3 Pollutants

Synthetic pesticides are the most common and widely use method of controlling pests in agriculture. A large number of agricultural chemicals (such as fertilizer, pesticides, etc.) are used and some become pollutants through their use, misuse or ignorance hence leaching through the soil to pollute the groundwater. Soil erosion has been instrumental in the horizontal and vertical movement of these pollutants (earlier bonded with soil particles but displaced) from agricultural fields to other places, especially water bodies (both surface and underground). Consequently, pollutants from agricultural fields do have large effect on the quality of water. Poorly managed animal feeding operations, overgrazing, heavy use of fertilizers, plowing, and improper, heavy use, or wrongly timed use of pesticides, causes pollution. These pollutants find their ways through the soil profile and across the gradient of slope hence affecting rivers, groundwater, wetlands, lakes, and estuaries [28] through continued deposition over a long period. In the same vein, untreated industrial pollutants discharged from the industries and factories have prevalent toxic concentration. Oftentimes, these wastes are discharged into the water body and affect aquatic cultures as well as flora and fauna life cycles. Usage of unsuitable contaminated water and the discharge of untreated industrial wastewater into water bodies form a main source of water pollution. Soil pollution occurs due to untreated disposal of industrial wastes (laden with high toxic contaminants) into soil. Wastes from industries have varying amount of toxic chemicals such that when deposited in soil, they cause the soil layer strength in the top soil to deteriorate, thus reducing fertility and microbial activity of the soil. In addition, the hazardous effect of these pollutants leads to ecological imbalances within the soil ecosystem.

3.4 Soil degradation

Soil degradation is the decrease in the quality of soil that can be as a result of many factors, most especially from agriculture. Soils hold the majority of the world's biodiversity, and healthy soils are essential for food production and adequate water supply [49]. Soil degradation shows expression in salting, waterlogging, compaction, pesticide contamination, decline in soil structure, loss of fertility, increase in soil acidity, alkalinity, salinity, and prevalence of erosion. Soil erosion is the wearing away of topsoil by water, wind, or farming activities [50]. At the same time, agriculture has been shown to contribute significantly to degradation, mainly through the continued dependence and improper use of inorganic fertilizers, synthetic pesticides, etc., which culminates in production and release of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. Moreover, agriculture that practices conventional practices such as tillage, fertilization, and pesticide application also release ammonia, nitrate, phosphorus, and many other gases that pollute the air, water, and soil quality, as well as biodiversity. Agriculture also changes the land cover of the Earth, which can change its ability to absorb or reflect heat and light, hence contributing to radiative forcing. Soil degradation also has a large impact on biological degradation, which influence the microbial community of the soil negatively and alters nutrient cycling, pest and disease control, and chemical transformation properties of the soil.

4. Effects of microbial activities on soil contaminants

By 2050, it is projected that the world population will increase to 8.9 billion people and this will lead to higher demand for agricultural produce [51]. In the future, the high demand of food and shortage of new agricultural land development will require increasing crop yields making use of sustainable means. Improvement of soil conservation increases soil organic matter and reduces erosion in other to have a sustainable agricultural land management and improved soil health [52]. Assessment of soil is based on the quality of soil variables that guarantee crop production sustainability in agricultural lands [19, 53]. Soil biota components such as microbial community, activity, abundance, stability and diversity which are improved by soil conservation have been discussed in several studies to be important indicators of soil quality [19, 54]. The rhizosphere of the plant is the narrow zone of the soil that is closed to the root system and sustains the production of crops with agrochemical inputs level that is balance or minimized [55]. Rhizoremediation of organic pollutants [8] and organic compounds creates nutrient-rich environment that influence microbial communities and the degradation of organic contaminants [56]. Soil biota plays a great role in residues of plant mineralization to form plants nutrients which can be easily absorbed by the plants for their growth and development [57]. Also, soil biota increases the rate of decomposition by excreting different enzymes that support plants's nutrients kinetics in the soil [58]. Microorganisms in the soil especially bacteria and fungi, transforms N between organic and inorganic forms which improves plant minerals uptake [59]. Microbial communities support the fundamental processes that provide productivity and stability of agroecosystems [60].

Soil conservation activities such as cover crops and minimum tillage as earlier mentioned can favorably improve soil health by increasing the number of soil organisms that break down organic matter, and in the process, release nutrients for the plant uptake. This soil organism breaks organic soil contaminants and several factors can interfere with the soil–microbe–plant complex hence influencing its functionality. Soil type [61], organic carbon level [60], temperature and moisture [62], oxygen level [63], electrical conductivity, calcium level and pH [64] are all factors that can change the composition and functionality of soil microbial communities. Of the soil macrofauna, earthworms are a major component and are very important in the soil fertility dynamics as their burrowing activities helps in improving the soil aeration and infiltration of water into the soil. The population of earthworm is influenced by soil conservation. [65, 66] discussed how minimum tillage which is part of soil conservation affects the population of earthworm. The increase of earthworms could encourage biological-remediation of contaminated soil known as vermiremediation [67]; soils contaminated with metallic contaminants [68] and organic pollutants and some chlorinated compounds inclusive [69]. The earthworms makes holes through the soil, mix the soil, affects its structure, and alters its nutritional profile and fungal and bacterial communities [70].

Fungi are chemoorganotrophic organism that are present everywhere and plays fundamental roles in geological and ecological processes [71, 72]. They can transform a large varieties of organic substrates, in addition with natural polymers not only lignin, cellulose, starch and chitin, but also other anthropogenic products such as explosives, pesticides and other xenobiotics [73, 74]. Mycoremediation, that is, the use of fungi to remove soil contaminant, has emerged as one of the most promising and cost-effective soil remediation techniques [75–79]. Bacterial genera, namely, *Gordonia*, *Brevibacterium*, *Aeromicrobium, Dietzia*, *Burkholderia,* and *Mycobacterium*, Fungal genera, namely, *Amorphoteca*, *Neosartorya*, *Talaromyces,* and *Graphium* as well as terrestrial fungi, namely, *Aspergillus*, *Cephalosporium,* and *Penicillium* and yeast genera, namely, *Candida, Yarrowia,* and *Pichia* which were isolated from soil that has been contaminated by petroleum proved to be organisms that has the potential for degrading hydrocarbon while yeast species, namely, *Candida lipolytica, Rhodotorula mucilaginosa, Geotrichum* spp.*, and Trichosporon mucoides* isolated from water that has been contaminated were discovered to degrade petroleum compounds [80–82]. When soil microorganism is improved by soil conservation, mycoremediation will be facilitated in order to remove soil contaminant. For instance, fungi is a potential approach for specific site Arsenic bioremediation [78, 79]. This adaptation of fungi towards soil that has been contaminated could be the high surface area to volume ratio and their various detoxification of metal mechanisms [83].

The physical and chemical properties of the soil significantly influence the soil fungal community structure and this is determined by agricultural practices [84, 85]. Increase in fungal biomass and bacterial is termed as changes in soil microbial communities and it has been observed in zero tillage than in conventional tillage practices [86]. Various land management practices has been examined to increase fungal biomass in the soil. Total fungal hyphal biomass and fungal propagules were discovered to be more in soil collected from organically managed agricultural systems [87–89]. The density of fungi in soil were found to be affected by crop rotation, animal grazing and soil tillage [90–98].

5. Conclusion

The type of land management practices in agroecosystems as an impacts on the structure of microbial community and function through a variety of different mechanisms. Land-use changes also impact on soil microbial community structure through alterations in carbon availability and quality, pH and nutrient availability. Since the ratio of fungal population to bacterial population are commonly measured as indicators of microbial community structure, and the relative proportions of fungi are increased by no-till practices, crop rotations, and use of cover crops, thus biological mechanisms are regulating carbon and nitrogen exchanges between the land, water and atmosphere. This reveals the importance of soil management and conservation approach in enhancing microbial activity for soil ecological intensification as well as buffering the soil to neutralize contaminants. Albeit, microbial ecology to assess terrestrial carbon cycle plays a crucial role in maintaining balance within the ecosystem.

Conflict of interest

There is no conflict of interest.

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References

[1] FAOSTAT. (2008). Fact sheet. *FAO, Rome, Italy*.

[2] Dabney, S.M., Shields, F.D., Binger, R.L., Kuhnle, R.A., Rigby, J.R. 2012. Watershed management for erosion and sedimentation control case study. Godwin Creek, Panola County, MS. In: Lal R., Stewart, B.A. (Eds.) Advances in Soil Science: Soil Water and Agronomic Productivity. Boca Raton, FL: Taylor and Francis. Pp; 539-568.

[3] Tanner, T. (Ed.), (2012). Aldo Leopold: The Man and His Legacy. Ankeny, IA Soil and Water Conservation society.

[4] Panagos, Panos; Borrelli, Pasquale; Meusburger, Katrin; Alewell, Christine; Lugato, Emanuele; Montanarella, Luca. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy, 48*, 38-50. doi:doi:10.1016/j.landusepol.2015.05.021

[5] Keeling, W., Segarra, E., Abernathy, J.R 1989. Evaluation of conservation tillage cropping systems for cotton on the Texas High Plains. *Journal of Production Agriculture*. 2; 269-273.

[6] Barbieri, P., S. Pellerin, V. Seufert, T. Nesme (2019). Changes in crop rotations would impact food production in an organically farmed world*Nat. Sustain*., 2, pp. 378-385.

[7] Gurr,G.M., Z. Lu, X. Zheng, H. Xu, P. Zhu, G. Chen, X. Yao, J. Cheng, Z. Zhu, J.L. Catindig, S. Villareal, H. VanChien, L.Q. Cuong, C. Channoo, N. Chengwattana, L.P. Lan, L.H. Hai, J. Chaiwong, H.I. Nicol, D.J. Perovic, S.D. Wratten, K.L. Heong (2016). Multi-country evidence that crop diversification promotes ecological intensification of agriculture *Nature Plants*, 2.

[8] Liu, S.H., G.M. Z.-Y.-H. (2017). Bioremediation mechanisms of combined pollution of PAHs and heavy metals by bacteria and fungi: a mini review. *Bioresources Technology, 224*, 25-33.

[9] Lal, R., D. R. (2007). Evolution of the plow over 10,000 years and the rationale for no-till farming. *Soil Tillage Resources, 93*, 1-12.

[10] Skaalsveen, K., J. I. (2019). The effect of no-till farming on the soil functions of water purification and retention in north-western Europe: a literature review. *Soil Tillage Resources, 189*, 98-109.

[11] Bai, Z.G., D.L. Olson, Schaepman, M.E. (2008). Report 2008/01. *Global assessment of land degradation and improvement., ISRIC-World Soil Information Report, Wageningen*.

[12] Morris, N., Miller, P., Orson, J., & Froud-Williams, R. (2010). The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment—a review. *Soil Tillage Resources*, 1-15.

[13] Abdollahi, L., & Munkholm, L. (2014). Tillage system and cover crop effects on soil quality: I. Chemical, mechanical, and biological properties. *Soil Water Management Conservation*, 9.

[14] Duncan, D., Burns, K. (2012). The Dust Bowl: An Illustrated History. San Francisco, FL: Chronicle Books LLC.

[15] Brandle, J.R., Hodges, L., Zhou, X.H. (2004). Windbreaks in North American agricultural systems. *Agroforestry Systems* 61, 65-78.

[16] Woodruff, N.P., Lyles, L., Siddoway, F.H, Fryrear, D.W., 1972. How to Control Wind Erosion Washington DC: Government Print Office US Department of Agriculture Bulletin. 354.

[17] Fryrear, D.W., Skidmore, E.L. 1985. Methods for controlling wind erosion.

In: Follett, R.F., Stewart B.A (Eds.), Soil Erosion and Crop Productivity. Madison, Wl: *American Society of Agronomy, Crop Science Society of America, Soil Science Society of America*, pp. 443-457.

[18] Miner, G.L., Hansen, N.C., Inman, D., Sherrod, L.A., Peterson, G.A. 2013. Constraints of no-till dryland agroecosystems as bioenergy production systems. *Agronomy Journal*; 105, 364-376.

[19] Doran, J., & Zeiss, M. (2000). Soil health and sustainability: Managing the biotic component of soil quality. *Applied Soil Ecology, 15*, 3-11. doi: 10.1016/S0929-1393(00)00067-6

[20] Doran, J.W. (2002). Soil health and global sustainability: translating science into practice. *Agric. Ecosyst. Environ.* 88, 119-127. doi: 10.1016/S0167-8809(01)00246-8

[21] Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolfe, D.W., Moebius, B.N. (2009). *Cornell Soil Health Assessment Training Manual*, 2nd Edn. Geneva: Cornell University.

[22] Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R. (2001). Forecasting agriculturally driven global environmental change. *Science* 292, 281-284. doi: 10.1126/science.1057544

[23] Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R. (2005). Global consequences of land use. *Science* 309, 570-574. doi: 10.1126/science.1111772

[24] Vitousek, P.M., Naylor, R., Crews, T., David, M.B., Drinkwater, L.E., Holland, E. (2009). Nutrient imbalances in agricultural development. *Science* 324:1519. doi: 10.1126/science.1170261

[25] Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature* 418, 671-677. doi: 10.1038/nature01014

[26] Balmford, A., Bennun, L., Brink, B.T., Cooper, D., Cote, I.M., Crane, P. (2005). The convention on biological diversity's 2010 target. *Science* 307, 212-213. doi: 10.1126/science.1106281

[27] Trivedi, P., Delgado-Baquerizo, M., Anderson, I.C, and Singh, B.K. (2016). Response of Soil Properties and Microbial Communities to Agriculture: Implications for Primary Productivity and Soil Health Indicators. *Front. Plant Sci.* 7:990. doi: 10.3389/fpls.2016.00990

[28] van der Warf, Hayo; Petit, Jean (2002). "Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods". *Agriculture, Ecosystems and Environment.* **93** (1-3): 131-145. doi:10.1016/S0167-8809(01)00354-1.

[29] Castro, H.F., A.T. Classen, E.E. Austin, R.J. Norby, and C.W. Schadt. (2010). Soil microbial community responses to multiple experimental climate change drivers. *Applied and Environmental Microbiology* **76**: 999-1007.

[30] Gray, S.B., A.T. Classen, P. Kardol, Z. Yermakov, and R.M. Miller. (2011). Multiple climate change factors interact to alter soil microbial community structure in an old-field ecosystem. *Soil Science Society of America Journal* **75**: 2217-2226.

[31] Lennon, J.T., Z.T. Aanderud, B.K. Lehmkuhl, and D.R. Schoolmaster, Jr. (2012). Mapping the niche space of soil microorganisms using taxonomy and traits. *Ecology* **93**: 1867-1879.

[32] Briones, M.J.I., N.P. McNamara, J. Poskitt, S.E. Crow, and N.J. Ostle. (2014). Interactive biotic and abiotic regulators of soil carbon cycling: evidence from controlled climate experiments on peatland and boreal soils. *Global Change Biology* **20**: 2971-2982.

[33] Delgado-Baquerizo, M., F.T. Maestre, C. Escolar, A. Gallardo, V. Ochoa, B.

Gozalo, and A. Prado-Comesana. (2014). Direct and indirect impacts of climate change on microbial and biocrust communities alter the resistance of the N cycle in a semiarid grassland. *Journal of Ecology* **102**: 1592-1605.

[34] Whitaker, J., N. Ostle, A.T. Nottingham, A. Ccahuana, N. Salinas, R.D. Bardgett, P. Meir, and N. P. McNamara. (2014). Microbial community composition explains soil respiration responses to changing carbon inputs along an Andes-to-Amazon elevation gradient. *Journal of Ecology* **102**: 1058-1071.

[35] Blankinship, J.C., P.A. Niklaus, and B.A. Hungate. (2011). A meta-analysis of responses of soil biota to global change. *Oecologia* **165**: 553-565.

[36] Henry, H.A.L. (2012). Soil extracellular enzyme dynamics in a changing climate. *Soil Biology and Biochemistry* **47**: 53-59.

[37] Manzoni, S., J.P. Schimel, and A. Porporato. (2012). Responses of soil microbial communities to water stress: results from a meta-analysis. *Ecology* **93**: 930-938.

[38] A'Bear, A.D., T.H. Jones, and L. Boddy. (2014). Potential impacts of climate change on interactions among saprotrophic cord-forming fungal mycelia and grazing soil invertebrates. *Fungal Ecology* **10**: 34-43.

[39] Chen, S., J. Zou, Z. Hu, H. Chen, and Y. Lu. (2014). Global annual soil respiration in relation to climate, soil properties and vegetation characteristics: summary of available data. *Agricultural and Forest Meteorology* **198**: 335-346.

[40] Bradford, M.A. (2013). Thermal adaptation of decomposer communities in warming soils. *Frontiers in Microbiology*. doi: http://dx.doi.org/10.3389/fmicb.2013.00333

[41] Frey, S.D., J. Lee, J.M. Melillo, and J. Six. (2013). The temperature response of soil microbial efficiency and its feedback to climate. *Nature Climate Change* **3**: 395-398.

[42] Hagerty, S.B., K.J. van Groenigen, S.D. Allison, B.A. Hungate, E. Schwartz, G.W. Koch, R.K. Kolka, and P. Dijkstra. (2014). Accelerated microbial turnover but constant growth efficiency with warming in soil. *Nature Climate Change* **4**: 903-906.

[43] Karhu, K. (2014). Temperature sensitivity of soil respiration rates enhanced by microbial community response. *Nature* **513**: 81-84.

[44] Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security *Science*, 304, pp. 1623-1627.

[45] Lemenih, M. and Itanna, F. (2004). Soil carbon stocks and turnovers in various vegetation types and arable lands along an elevation gradient in southern Ethiopia *Geoderma*, 123, pp. 177-188

[46] Lemenih, M. (2004). Effects of Land use Changes on Soil Quality and Native Flora Degradation and Restoration in the Highlands of Ethiopia. Implication for Sustainable Land Management. Doctoral thesis Swedish University of Agricultural Sciences, Sweden.

[47] Tesfaye, M.A., F. Bravo, R. Ruiz-Peinado, V. Pando, A. Bravo-Oviedo (2016) Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands *Geoderma*, 261, pp. 70-79.

[48] Henok, K., S. Dondeyne, J. Poesen, A. Frankl, J. Nyssen (2017) Transition from Forest-based to Cereal-based Agricultural Systems: A Review of the Drivers of Land use Change and Degradation in Southwest Ethiopia

Land Degradation and Development, 28, pp. 431-449.

[49] Hemphill, D. (1993). “Agricultural Plastics as Solid Waste: What are the Options for Disposal?”. *Hort Technology*. **3** (1): 70-73. Retrieved 23 April 2015.

[50] Kidd, G. (2000). “Pesticides and Plastic Mulch Threaten the Health of Maryland and Virginia East Shore Waters”(PDF). Pesticides and You. **19** (4): 22-23. Retrieved 23 April 2015.

[51] Lichtfouse, E., Navarrete, M., Debaeke, P., Souchere, V., Alberola, C., & Menassieu, J. (2009). Agronomy for sustainable. *A review Agron. Seustain. Dev., 29*, 1-6.

[52] Doran, J. (2002). Soil health and global sustainability: Translating science into practice. *Agric. Ecosyst. Environ., 88*, 119-127.

[53] Sahu, P., Singh, D., Prabha, R., Meena, K., & Abhilash, P. (2019). Connecting microbial capabilities with the soil and plant health: Options for agricultural sustainability. *Ecol. Indic., 105*, 601-612.

[54] Leskovar, D., Othman, Y., & Dong, X. (2016). Strip tillage improves soil biological activity, fruit yield and sugar content of triploid watermelon. *Soil Tillage Res., 163*, 266-273.

[55] Berendsen, R., Pieterse, C., & Bakker, P. (2012). The rhizosphere microbiome and plant health. *Trends Plant Science, 17*, 478-486.

[56] Kuiper, I., E. L. (2004). Rhizo-remediation: a beneficial plant-microbe interaction. *Mol. Plant Microbe Interact., 17*, 6-15.

[57] Meena, R., Bohra, J., Singh, S., Meena, V., Verma, J., Verma, S., & Sihag, S. (2016). Towards the prime response of manure to enhance nutrient use efficiency and soil sustainability a current need: A book Review.. *J. Clean. Prod.*, 1258-1260.

[58] Dotaniya, M., Meena, V., Basak, B., & Meena, R. (2016). Potassium uptake by crops as well as microorganisms. *n Potassium Solubilizing Microorganisms for Sustainable Agriculture; Springer*, 267-280.

[59] Van der Heijden, M., Bardgett, R., & van Straalen, N. (2008). The unseen majority: Soil microbes as drivers of plant diversity and productivity in terrestrial Ecosystems. *Ecol. Lett., 11*, 296-310.

[60] Singh, J. (2015). Plant–Microbe Interactions: A Viable Tool for Agricultural Sustainability Plant Microbes Symbiosis: Applied Facets. (N. E. Arora, Ed.) *Springer*, 384.

[61] Dai,M., C. Hamel, M.S.Arnaud, Y. He, C. Grant, N. Lupwayi, H. Janzen, S.S. Malhi, X. Yang, Z. Zhou (2012). Arbuscular mycorrhizal fungi assemblages in chernozem great groups revealed by massively parallel pyrosequencing *Can. J. Microbiol.*, 58, pp. 81-92.

[62] Wu, X., T. Ge, W. Wang, H. Yuan, C.E. Wegner, Z. Zhu, A.S. Whiteley, J. Wu (2015). Cropping systems modulate the rate and magnitude of soil microbial autotrophic CO_2 fixation in soil *Front. Microbiol*., 6.

[63] Yang, C., C. Hamel, M.P. Schellenberg, J.C. Perez, R.L. Berbara (2010). Diversity and functionality of arbuscular mycorrhizal fungi in three plant communities in semiarid Grasslands National Park, Canada *Microb. Ecol.,* 59, pp. 724-733.

[64] Maarastawi, S.A., K. Frindte, M. Linnartz, C. Knief (2018). Crop rotation and straw application impact microbial communities in Italian and Philippine Soils and the rhizosphere of *Zea mays Front. Microbiol*., 9.

[65] Bainard,L.D., P.L. Chagnon, B.J. CadeMenun, E.G. Lamb, K. LaForge, M. Schellenberg, C. Hamel (2017). Plant communities and soil properties mediate agricultural land use impacts on arbuscular mycorrhizal fungi in the Mixed Prairie ecoregion of the North American Great Plains *Agric. Ecosyst. Environ.,* 249, pp. 187-195.

[66] Rasmussen, K. (1999). Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. *Soil and Tillage Research, 53*, 3-14.

[67] Anderson, E. (1987). Corn root growth and distribution as influenced by tillage and nitrogen fertilization. *Agronomy Journal, 79*, 544-549.

[68] Sinha, R.K., G. B. (2008). Converting wasteland into wonderland by earthworms—a low-cost nature's technology for soil remediation: a case study of vermiremediation of PAHs contaminated soil. *Environmentalist, 28*, 466-475.

[69] Suthar, S. (2008). Metal remediation from partially composted distillery sludge using composting earthworm Eisenia fetida. *Journal of Environmenal Monitor, 10*, 1099-1106.

[70] Shi Z., J. L. (2020). Vermiremediation of organically contaminated soils: concepts, current status, and future perspectives. *Applied Soil Ecology, 147*, 103,377.

[71] Rodriguez-Campos J., L. D.-B.-R. (2014). Potential of earthworms to accelerate removal of organic contaminants from soil: a review. *Applied Soil Ecology, 79*, 10-25.

[72] Gadd, G.M. (2010). Metals, minerals and microbes: geomicrobiology and bioremediation. *Microbiology*, 609-643. doi:https://doi.org/10.1016/j.mycres.2006.12.001

[73] Gadd, G.M., R. Y. (2012). Geomycology: metals, actinides and biominerals. *Environmetal Microbiology Reports, 4*(3), 270-296. doi:https://doi.org/10.1111/j.1758-2229.2011.00283.x

[74] Gadd, G.M. (2013). Geomycology: fungi as agents of biogeochemical change. *PRAEGER REVIEW, 113B*(2), 139-153. Retrieved from https://www.jstor.org/stable/42912447

[75] Harms H, S. D. (2011). Untapped potential: exploiting fungi in bioremediation of hazardous chemicals. *Nature Reviews Microbiology, 9*, 177-192.

[76] Caporale, G., A., Sommella, A., Lorito, M., Lombardi, N., M.G.G., S., Azam,. .. Ruocco, M. (2014). Trichoderma spp. alleviate phytotoxicity in lettuce plants (Lactucasativa L.) irrigated with arsenic-contaminated water. *Journal of Plant Phsiology, 171*(15), 1378-1384. doi:https://doi.org/10.1016/j.jplph.2014.05.011

[77] Govarthanan, M., R. Mythili, T. Selvankumar, S. Kamala-Kannan, & H. Han. (2018). Myco-phytoremediation of arsenic-and lead-contaminated soils by *Helianthus annuus* and wood rot fungi, Trichoderma sp. isolated from decayed wood. *Ecotoxicology and Environmental Safety, 151*(30), 279-284. doi:https://doi.org/10.1016/j.ecoenv.2018.01.020

[78] Srivastava, P. K., Vaish, A., Dwivedi, S., Chakrabarty, D., Singh, N., & Tripathi, R. D. (2011). Biological removal of arsenic pollution by soil fungi. *Science of The Total Environment, 409*(12), 2430-2442. doi:https://doi.org/10.1016/j.scitotenv.2011.03.002

[79] Singh, M., P. S. (2015). Soil fungi for mycoremediation of arsenic pollution in agricultural soils. *Journal of Applied Microbiology, 119*, 1278-1290. doi:doi:10.1111/jam.12948

[80] Singh, R.K., R. T. (2020). Fungi as potential candidates for bioremediation. *Abatement of Environmental Pollutants, Elsevier*, 177-191.

[81] Chaillan, F., A. Le Flèche, E. Bury, Y.-H. Phantavong, P. Grimont, A. Saliot, and J. Oudot (2004). "Identification and biodegradation potential of tropical aerobic hydrocarbon-degrading microorganisms," *Research in Microbiology*, vol. 155, no. 7, pp. 587-595.

[82] Singh, H. (2006). *Mycoremediation: Fungal Bioremediation*, Wiley-Interscience, New York, NY, USA.

[83] Bogusławska-Was, E., and W. Dąbrowski (2001). "The seasonal variability of yeasts and yeast-like organisms in water and bottom sediment of the Szczecin Lagoon," *International Journal of Hygiene and Environmental Health*, vol. 203, no. 5-6, pp. 451-458.

[84] Kapoor, A., T. V. (1999). Removal of heavy metals using the fungus Aspergillus niger. *Bioresources Technology, 70*, 95-104.

[85] Wu, T., O. Chellemi, D., J. Martin, K., H. Graham, J., & N. Rosskopf, E. (2007). Discriminating the effects of agricultural land management practices on soil fungal communities. *Soil Biology and Biochemistry, 39*(5), 1139-1155. doi:https://doi.org/10.1016/j.soilbio.2006.11.024

[86] Jirout, J., Šimek, M., & Elhottová, D. (2011). Inputs of nitrogen and organic matter govern the composition of fungal communities in soil disturbed by overwintering cattle. *Soil Biology and Biochemistry, 43*(3), 647-656.

[87] Minoshima, H., L. J.-M. (2007, May 01). soil food webs and carbon dynamics in response to conservation tillage in California. *Soil Science Society of America Journal, 71*(3), 952-963. doi:https://doi.org/10.2136/sssaj2006.0174

[88] Sivapalan, A., W. M. (1993). Monitoring Populations of Soil Microorganisms during a Conversion from a Conventional to an Organic System of Vegetable Growing. *Biological Agriculture and Horticulture, 10*(1), 9-27. doi:https://doi.org/10.1080/01448765.1993.9754647

[89] Fließbach, A., P. M. (2000). Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. *Soil Biology & Biochemistry*, 757-768.

[90] Shannon, D., A. S. (2002). A comparative study of the microbiology of soils managed under organic and conventional regimes. *Soil Use & Management, 18*, 274-283.

[91] Wicklow, D. (1973). Microfungal populations in surface soils of manipulated prairie stands. *Ecology, 54*, 1302-1310.

[92] Martyniuk, S., & Wagner., G. (1978). Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Science, 125*, 343-350.

[93] Ploetz, R.C., D. M. (1985). Population dynamics of soilborne fungi in a field multicropped to rye and soybeans under reduced tillage in Florida. *Phytopathology*, 1447-1451.

[94] Beare, M., Parmelee, R., Hendrix, P., Cheng, W., Coleman, D., & Crossley, D. (1992). Microbial and Faunal interactions and effects on litter nitrogen and decomposition in agroecosystems. *Ecological Monograph, 62*, 569-591.

[95] Frey, S., Elliott, E., & Paustian, K. (1999). Bacterial and fungal abudance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. *Soil Biology & Biochemistry, 31*, 573-585.

[96] Mazzola, M. (1999). Transformation of soil microbial community structure and Rhizoctonia-suppressive potential in response to apple roots. *Phytopathology, 89*, 920-927.

[97] Hedlund, K. (2002). Soil microbial community structure in relation to vegetation management on former agricultural land. *Soil Biology & Biochemistry, 34*, 1299-1307.

[98] Singh, S., & Rai, J. (2004). Soil microbial population and enzyme activity related to grazing pressure in alpine meadows of Nanda Devi Biosphere Reserve. *Journal of Environmental Biology, 25*, 103-107.