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Soil management practices that improve soil health: Elucidating their implications on biological indicators

REVIEW PAPER

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1 SUMMARY

The growing interest in low input agricultural practices, coupled with challenges in the agro-ecosystems, which are accelerated by population pressure, poor soil management practices and climate change calls for a holistic approach to soil management and agricultural production as a whole. The holistic approach considers soil management as a way of enhancing agricultural production while not forgetting environmental quality, human and animal health. This leads to the concept of soil health. Changes in soil health are estimated by using physical, chemical and biological indicators. This review is aimed at highlighting some soil management practices that improve soil health by taking into account their effects on the biological indicators. Biological indicators of soil health are mainly dominated by various soil biota, their activities and influences or functions. Critical reviewing of various research papers and books has revealed and confirmed that the following soil management practices improves soil health especially through their influence on soil microflora and fauna: conservation tillage practices or conservation agriculture, crop rotations, intercropping with legumes, cover cropping, agro-forestry, use of organic manure and crop residues, soil liming and inoculation with effective microorganism. These practices have a positive influence on soil microbial and faunal activities and increase soil microbial populations, diversity and functions. Soil biota contribute to soil health and sustainable crop production in a number of ways including nutrient cycling, soil aggregation, soil aeration and bio-control or suppression of plant pathogens.
Key words: Biological indicators, soil management, soil health, soil microorganisms

2 INTRODUCTION

Soil is a dynamic living resource whose wellbeing is vital to both the production of food and fibre for global balance and ecosystem function and in that, it represents a unique balance between physical, chemical and biological factors (Doran *et al.*, 1996). This is well complemented by the concept of soil health. Soil health is defined as the continued capacity of the soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries to sustain biological activity, promote the quality of air and water environments and maintain plant, animal and human health (Pankhurst *et al.,* 1997; Doran and Zeiss, 2000). "A healthy soil should be capable of supporting life processes such as plant anchorage and nutrient supply, retain optimal water and soil properties, support soil food webs, recycle nutrients, maintain microbial diversity, remediate pollutants, sequester heavy metals, and contribute to disease suppression" (Wang and Hooks, 2010). Wang and Hooks (2010) note that soil health can be synthesized into six main characteristics:

i. High biological diversity
ii. High community stability that can provide resilience and self recovery to chemical and biological disturbance
iii. Ability to maintain the integrity of nutrient cycling and energy flow
iv. Suppression of multiple pests and pathogens
v. Ability to improve plant health
vi. Maintenance of water and air quality

Soil health is determined by physical, chemical, and biological indicators (Pankhurst *et al.,* 1997; Brady and Weil, 2008). This paper focuses on biological indicators. Pankhurst *et al.* (1997) and Martinez-Salgado *et al.* (2010) noted the following as some of the most important biological indicators of soil health:

i. Abundance of soil microflora (e. g. bacteria, fungi and actinomycetes)
ii. Soil fauna (e.g. earthworms, nematodes, protozoa)
iii. Soil biodiversity
iv. Soil biomass carbon
v. Soil biomass nitrogen (N)
vi. Mineralizable N
vii. Soil enzyme activity
viii. Soil food web structure
ix. Plant growth and diversity

Soil biological indicators highlight some activities and functions of microorganisms in the soil. Kennedy *et al.* (2004) and Russo *et al.* (2012) summarized the following as beneficial functions of soil microorganisms: release of plant nutrients from insoluble inorganic forms, decomposition of organic residues and release of nutrients, formation of beneficial soil humus by decomposing organic residues and through synthesis of new compounds, production of plant growth promoting compounds, improvement of plant nutrition through symbiotic relationships that lead to transformation of atmospheric nitrogen (N_2) into plant available N, increasing root surface area for phosphorus absorption, improvement of soil aggregation through production of binding agents such as glomalin (from mycorrhizal fungi) and polysaccharides (from bacteria), improvement of soil aeration and water infiltration, have antagonistic actions against insects, plant pathogens and weeds (biocontrol), help in pesticide degradation and rhizoremediation (bioremediation). Plate 1 illustrates contributions of soil microorganisms and their interactions with plants.

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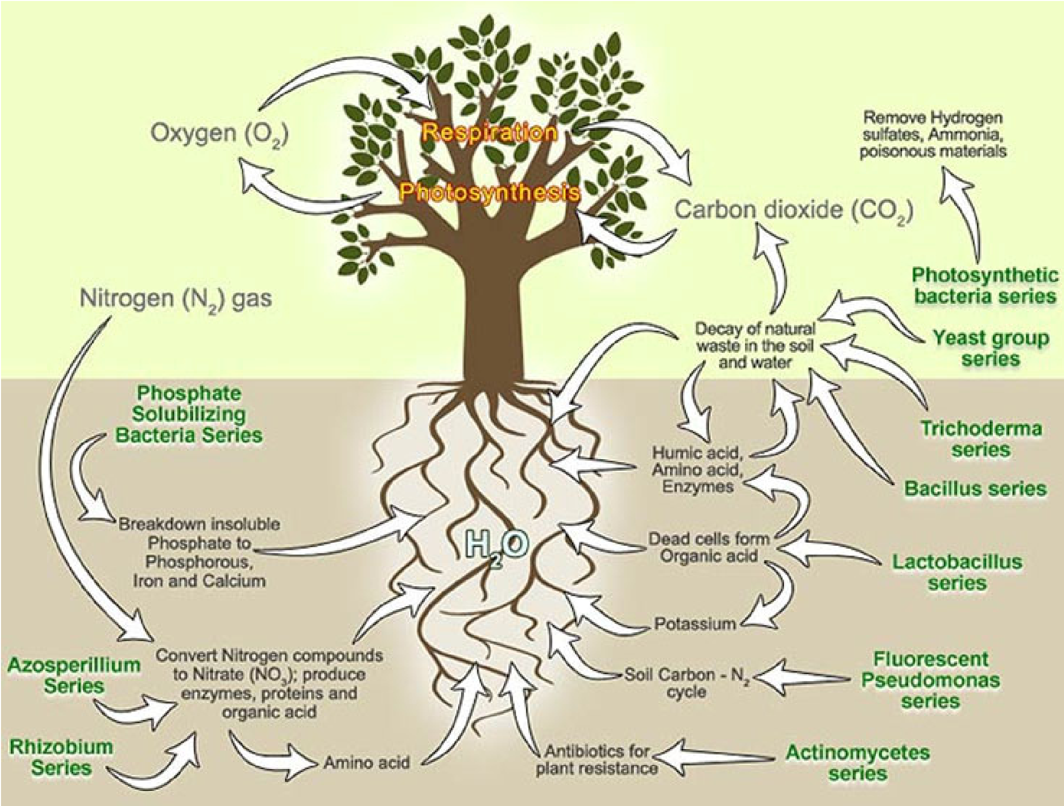

Plate 1: Illustration of beneficial functions of soil microorganisms and their interactions with plants (Adapted from Artemis and Angel Co., 2010)

The aim of this paper is to highlight the effects of various soil management practices or farming systems on maximizing soil microbial populations, diversity, and activities. Microbial activities are elucidated by soil enzymatic activities and functions such as N_2 fixation and phosphorus (P) acquisition. Important soil management practices and/or farming systems covered include conservation agriculture (CA), crop rotation, intercropping systems, cover cropping, residue and manure application, agroforestry systems, organic farming, inoculation with effective microorganisms and liming.

3 CONSERVATION AGRICULTURE

Conservation agriculture is one of the strategies that help to improve and sustain the fertility status of the soil. Conservation agriculture (CA) is an integrated system of farming that is aimed at managing agro-ecosystems to achieve sustained productivity, increased profits and food security by implementing and managing minimum soil disturbance through conservation tillage, permanent soil cover and diversified crop associations and rotations (FAO, 2010; Kassam and Friedrich, 2011). Conservation tillage is an agricultural practice that keeps at least 30% of the soil surface covered by plant residues (Brady and Weil, 2008). The three principles offer many advantages including: conservation of soil moisture, maintenance of good soil structure, improvement of the soil's fertility, promoting earthworms and other soil biota proliferation, and protect the soils from erosion (FAO, 2010; Kassam *et al,* 2010). There is huge evidence that conservation agriculture affect the abundance and the activities of microorganisms (Pankhurst *et al.* 1997; Hobbs and Gupta, 2004;

Plaster, 2009). Population and diversity of genomic patterns of the N_2 fixing *Bradyhizobium* increased with no-till compared to conventional tillage in Southern Brazil (Ferreira *et al.*, 2000). Nunez *et al.* (2012) reported bacterial diversity increase in zero tillage systems as compared to conventional tillage. WenQing *et al.* (2011) reported higher organic matter content, microbial biomass C, microbial biomass N and enzyme activities in more superficial layers of soils under CA than in soils under conventional tillage. The increase in microbial populations, diversity and other biological indicators of soil health under CA practices can be attributed to a number of factors that favour microbial proliferation and activities. These, include improvement in soil moisture retention and increase in soil organic matter (SOM) due to the effect of soil cover using mulch and cover crops and the increase in diversity of substrates for microorganisms due to diversified cropping systems and rotations. Mulch lowers the temperature of the soils to a certain extent and slows decompositions processes and eventually leading to accumulation of SOM (Brady and Weil, 2008). It also help in promoting more stable aggregates and biotic diversity as a result of increased microbial activity and better protection of the soil surface (Diekow *et al.,* 2005). Therefore, it provides a niche for different soil biota including earthworms that burrow the soil and improve its aeration (Plaster, 2009). All these in turn lead to increasing microbial activities and function. Kihara *et al.* (2011) reported higher soybean nitrogen fixation (% NDfA) in reduced tillage (55.6%) than in conventional tillage (46.6%) from a study done in Western Kenya. More positive effects of conservation tillage on biological indicators of soil health are summarized in Table 1.

Table 1: Improvements of biological indicators of soil health as affected by no-till system

Biological indicators	**References**
Microbial diversity; mineralizable N	Quadros *et al.,* 2012 ; Silva *et al.,* 2013
Microbial biomass carbon (MBC); total microbial abundance	Wang *et al.,* 2012
Enzyme activities (dehydrogenase, urease, protease, phosphatise, and β-glycosidase)	Roldan *et al*., 2004; Mohammadi, 2011
Earthworm and other faunal activities	Peigne *et al.,* 2007 ; Aquino *et al.,* 2008
Mycorrhizal activities	Schalamuk and Cabello, 2010

It should be noted that usually CA or conservation tillage practices depend on herbicides for weed control. The use of herbicides has always been a controversial issue with regard to their effects on the non-target community. It is therefore important in this paper to shed some light on effects of herbicides on the soil microbial community. From various studies reviewed, it is noted that herbicides pose both stimulating and suppressing effects on soil microorganisms depending on type of herbicide, concentration used and the composition of the soil microbial species. Ratcliff *et al.* (2006) reported higher increases in total bacteria population and culturable bacteria, and changed community composition by shifting from fungal dominance to an equal ratio of bacteria to fungi with glyphosate (the most highly used herbicide) application as compared to untreated soil. In a similar study, Busse *et al.* (2000) reported increased microbial activity, total and viable bacteria with *Pseudomonas*, *Arthrobacter, Xanthomonas* and *Bacillus spp* increasing in population at the highest rate of glyphosate addition while fungal population remained relatively unchanged regardless of its application. However, glyphosate applied to soil free media was lethal to both fungi and bacteria at a both recommended and high concentration. This difference was explained to be due to the chemistry and mobility of glyphosate (Busse *et al.,* 2000). Glyphosate is reported to be a polar phosphonate compound that binds rapidly with soil colloids such as aluminium and iron oxides, various clay types and organic matter, hence precluding uptake by microbial cells whereas in soil free media it remains unbound and active (Busse *et al.,* 2000; Borggaad, 2011). It is also a simple amino acid compound ($C_3H_8NO_5P$) capable of releasing carbon for energy and nitrogen and phosphorus as nutrients for soil microorganism when it is bound to soil particles (Busse *et al.,* 2000; Ratcliff *et al*., 2006). This factor makes glyphosate increasing proliferation of some microbial species as it provides their favourable substrates. However, the issue of herbicides is not yet conclusive as there are also studies that show high toxicity and suppressing effects of herbicides on soil microorganisms. Adeleye *et al.* (2004) reported decreasing populations of *Azotobacter vinelandii*, and *Rhizobium phaseoli* with increasing concentration of the three herbicides, Agroxone, Atranex 50Sc and 2, 4 – Damine. Therefore, there is need for more research on the effects on herbicides in particular on soil microbial community. However, in this review it is noted that conservation tillage as a soil management practice clearly shows positive influence on soil microbial community.

4 INTERCROPPING, CROP ROTATIONS AND COVER CROPS

Cropping practices such as intercropping, crop rotations and cover cropping are implemented both under CA and conventional systems and in both systems; they have shown evidence of promoting microbial proliferation and activities. Intercropping or polyculture is defined as the cultivation of two or more crops on the same piece of land to the extent that crops interact biologically (Lithourgidis *et al.,* 2011). Intercropping practices that include legumes promote Rhizobial-legume symbiotic relationships that lead to biological nitrogen fixation (FAO, 2001). Plate 2 illustrates an intercrop (pigeon pea, *Cajanus cajan* intercropped with groundnut, *Arachis hypogea*) that maximizes nitrogen fixation, (Njira, 2012). Biological nitrogen fixation improves the fertility of the soil and both the soil health and quality as the availability of nitrogen positively affects the C: N ratios by increasing the N value (Havlin *et al.,* 2005; Sylivia *et al.,* 2005; Brady and Weil, 2008). This in turn improves the general microbial ecology of the soil by allowing proliferation of diverse and increased numbers of soil biota. Quio *et al.* (2012) reported increased richness in soil bacterial diversity in mixed cropping systems of oat and common vetch as compared to their monocultures. Some new bacterial species were reported from the mixtures of oat and common vetch plots and not be observed from their monocultures (Quio *et al*., 2012). The different proportions of oat and common vetch releasing different qualities and quantities of root cell components and root exudates that enter the soil, which in turn modifies the soil community structure and activities, could explain this. Soil microbial biomass carbon (MBC) and N (MBN) increased by about 30 and 200 % respectively in Nigeria when maize was rotated with cowpea compared to monoculture maize (Yusuf *et al.,* 2009). Bagayoko *et al.* (2000) in Niger observed 27 % colonization of pearl millet roots and 45 % colonization when millet followed cowpea in rotation. Plaster (2009) also noted that involvement of crop rotations means changing of crops each year, which leads to different root systems, different rhizoshere, different residues and different effects on the soil. This in turn encourages a wider variety of organisms to inhabit the soil. Research shows that a cropping system that includes legumes encourages proliferation of mycorrhizal fungi (Plaster, 2009; Pagano *et al.,* 2010). Mycorrhizal relationships are beneficial to the soil through their effect on phosphorus absorption from deeper layers of soils in relatively P deficient levels, absorption of zinc, copper, and other nutrients, uptake of water and improvement in resistance to some pathogens (Plaster, 2009; Utobo *et al.,* 2011). Changing crops in rotation helps to break disease cycles. Larkin (2008) reported suppression of potato diseases (stem canker, black scurf and common scab) due to rotation. This is attributed to the breaking of the disease cycle due to sequential changes in host crop species.

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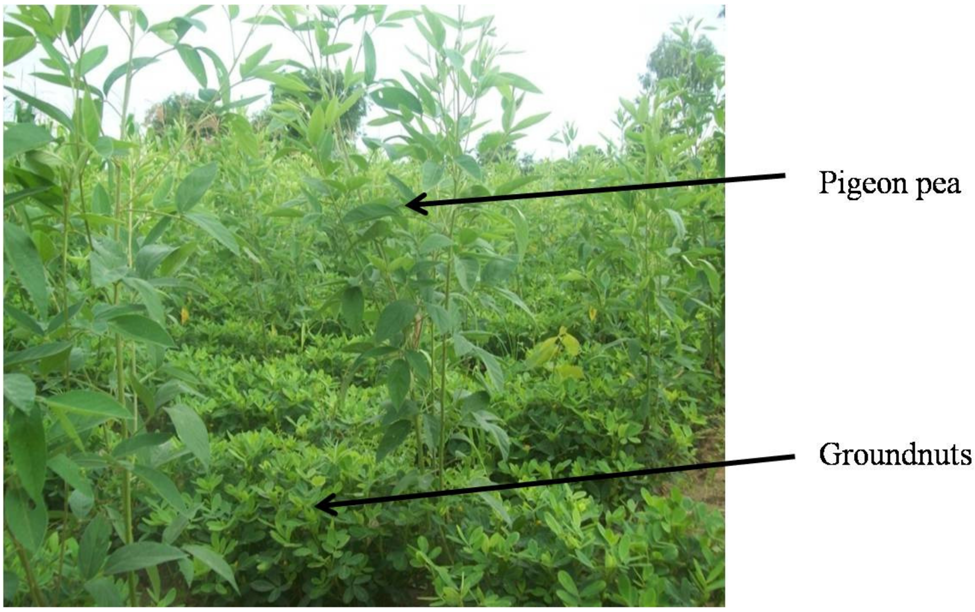

Plate 2: Pigeon pea (*Cajanus cajan*) and groundnut (A*rachis hypogea*) intercrop.
Source: Njira, 2012

Cover crops refer to closely grown crops for the purpose of protecting and improving soil properties and characteristics between periods of regular crop production. Some of the benefits of cover crops include; increased availability of nitrogen if the cover crop is a legume and addition of organic matter to the soil through the leaf litter and other crop residues. (Nandwa, 2003; Sanginga and Woomer, 2009). Cover crops also keep the soil moist, which is a good condition for microbial activity. Crop rotations and cover crops affected soil microbial biomass C and N of long term field experiments in Iowa, with the highest values found in longer rotations of four years compared to two years (Moore *et al.,* 2000). (Dupont et *al.* (2009) reported increased abundance of opportunistic nematodes, soil NH_4-N levels and inferred nitrogen mineralization in cover crop managements with low to mid C: N ratios. Griffins (1994) reported that soil fauna contribute significantly to N mineralization, liberating up to 30% of mineralized N.

5 AGROFORESTRY

Agroforestry is a technique of land use in which trees are combined with crops or pastures simultaneously or in phases with the objective of sustained optimization of total production per unit area. Salamon *et al.* (2008) reported that bacterial and fungal colonies in forest like systems are stimulated by arthropods such as collembola roles in micro-fragmentation of litter and nutrient cycling. Quantity and quality of litter, species diversity, deep and perennial root systems associated with agroforestry create a more suitable occasion of soil faunal (including earthworms) activities (Brown *et al.,* 2006). The activities of earthworms especially the burrowing provides good aeration and nutrient rich substrates respectively for microflora (Zirbes *et al.,* 2012). Agroforestry is also reported to enhance arbuscular mycorrhizal fungi abundance as compared to monocropped systems (Chifflot *et al.,* 2009). This in turn improves phoshorus availability to plants.

6 CROP RESIDUE AND MANURE APPLICATION

Crop residues and manure application have been associated with increased microbial abundance and activities. Bacterial diversity in terms of both richness and evenness was higher (in USA) in soils amended with poultry litter than those amended with inorganic fertilizers (Jangid *et al.,* 2008). Graham *et al.* (2010) noted that the increase in enzyme activities in response to farm yard manure is even higher than increases of microbial biomass and soil community structure, despite all these being affected positively. Wang *et al.* (2012) reported increased microbial biomass carbon with crop residue application in comparison to no crop residue application. These increases can be attributed to the substrates carbon for energy and various nutrient elements provided to the microorganisms from manure and crop residues as compared to inorganic fertilizers that does not contain C and usually contain specific nutrient types.

7 ORGANIC FARMING AS A SOIL MANAGEMENT PRACTICE

Organic farming is characterized by dependence on ecological friendly farming methods including crop rotations, manure and crop residue use, intercropping, cover crops, and non-use of synthetic products (e.g. chemical fertilizers and pesticides) (Lampkin, 1990). As observed in other sections, through its principles, it can be noted that it contributes to improvement of soil health. Stolze *et al.* (2000) reported higher values in organic than in conventional farming on the following; soil microbial activity, diversity and biomass, higher mycorrhizal colonization and higher saprophytic fungi proliferation.

8 SOIL LIMING

Soil reaction or pH is reported to influence different soil microorganisms and activities differently. Most bacteria species proliferation is usually associated with near neutral to slightly alkaline whereas fungi are known to adapt well in acidic environments. Although, fungi proliferate even in acidic environments, liming is done to raise the pH of the soil, usually to a range (near neutral) that is most favoured by most species of plants and microorganisms. Using the Shannon diversity index, Xue *et al.* (2010) reported increased soil microbial community diversity with lime level in raising pH from a range of 3.96-5.20 to 4.93-7.32 in orchards and forest soils in China. Fuetes *et al.* (2006) reported increased soil respiration rates, mineralization of organic matter and greater microbial soil microbial biomass carbon in lime treated than in non-lime treated acid soils of USA Pacific Northwest.

9 SOIL INOCULATION WITH EFFECTIVE MICROORGANISMS

Effective or beneficial microbes can be brought to a soil that has been proven to have ineffective species or strains for a specific function such as legume N_2 fixation in the case of rhizobia or improving phosphorus and other nutrients availability in the case of mycorrhizal fungi. Inoculants of phosphorus solubilising microorganisms have also been reported (Yadav and Tarafdar, 2007; Khan et al., 2009; Mardad *et al.,* 2013). Inoculation is done through application of the concerned microbes to the seed or bringing soil that is infected with the required microorganisms to the new environment. However, antagonistic interactions exist with indigenous strains. Several reports show increase in rhizobial numbers and increase in N_2 fixation leading to soybean yield increases of 50% (Sylvia *et al.,* 2005). Ike-Izundu (2007) summarized some studies on co-inoculation of legumes with rhizobia to fix nitrogen and arbuscular mycorrhizal (AM) fungi to enhance P uptake in which the co-inoculation increased plant growth more than inoculation with rhizobia alone. This was attributed to the effect of AM fungi in improving P uptake, thereby enhancing nitrogen activity in plant nodules and in turn promoting root and AM fungal development (Ike-Izundu, 2007). The introduction of new strains to the environment is still an area that needs further research as to establish how advantageous it is in the long term in terms of soil biodiversity with the consideration of antagonistic interactions between different soil organisms.

10 CONCLUSIONS

Soil microorganisms have an important contribution to soil productivity and therefore the relationship between soil microbial populations, diversity, functions and soil management practices needs thorough understanding. From this review it can be concluded that soil management practices such as conservation agriculture or tillage practices, intercropping, crop rotations, cover cropping, agroforestry, crop residue and manure applications, organic farming, liming and inoculation with effective microorganisms have a positive influence on soil microbial activities and generally increase soil microbial populations, diversity and functions. Diversified cropping systems such as intercropping, agroforestry and crop rotations lead to increased populations and diversity of microorganisms and changes in microbial community structure due to diverse types of cell components and root exudates released into the soil that in turn provide diverse substrates for the soil microbes. The type of crops and their crop residues also have an influence on type and numbers of microorganisms proliferating in an environment. This is mainly due to composition of the crop residues in terms of carbon to nitrogen and lignin to nitrogen ratios. Considering beneficial functions of soil biota, it is therefore noted that thorough exploitation of these soil management practices or farming systems will have a substantial contribution to improving low input ecological friendly farming methods and soil health in general.

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12 REFERENCES

Adeleye IA, Okolodudu E. and Lawal O: 2004. Effect of some herbicides used in Nigeria on Rhizobium phaseoli, Azotobacter vinelandii and Bacillus subtilis. Journal of Environmental Biology 25(2): 151-156.

Aquino AM, Silva RF, Mercante FM, Correia MEF, Guimaraes MF. and Lavelle P: 2008. Invertebrate soil macrofauna under different ground cover plants in the no till system in the cerado. European Journal of Soil Ecology 44: 191-197.

Artemis and Angels Co. Ltd: (2010). Functions of soil microorganisms http://www.artemisthai.com/description_info.php?descriptionid=22.

Bagayoko M, Buerkert A, Lung G, Bationo A. and Romheld V: 2000. Cereal/lume rotation effects on cereal growth in Sudano-Sahelian West Africa: Soil mineral nitrogen, mycorrhiza and nematodes. Plant and Soil 218: 103-116.

Brady NC. and Weil R: 2008. The Nature and Properties of Soils. Revised 14th Edition. Pearson Prentice Hall. New Jersey. 975pp.

Busse MD, Ratcliff AW, Shestak CJ. and Powers RF: 2000. Non-target effects of glyphosate on soil microbes. Proceedings of the California Weed Science Society, Vol 52. http:// www.fvmc.org/.../Busse%20et%20al_2000.Ca%20Weed%20Sci%20Soc.

Chifflot V, Rives D, Olivier A, Cogliastro A. and Khasa D: 2009. Molecular analysis of arbuscular mycorrhizal community structure and spores distribution in tree based intercropping and forest systems. Agriculture, Ecosystems and Environment 131: 32-39

Diekow J, Mielniczuk J, Kuicker H, Bayer C, Dick, DP and Kogel-Knabner I: 2005. Soil C and N stocks as affected by cropping systems and nitrogen fertilization in southern Brazil Acrisols managed under no tillage for 17 years. Soil and Tillage Research 81: 87-95.

Doran JW, Sarrantonio M. and Liebig M: 1996. Soil health and sustainability. In: Advances in Agronomy, Sparks, D. L. (Editor). Vol 56. Academic Press, New York.

Doran JW. and Zeiss MR: 2000. Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology 15: 3–11.

Dupont ST, Ferris H. and Van Horn M: 2009. Effects of cover crop quality and quantity on nematode based soil webs and nutrient cycling. Applied Soil Ecology 41: 157-167.

Food and Agricultural Organization of the United Nations (FAO): 2001. The economics of conservation agriculture. FAO corporate documents repository. www.fao.org/DOCREP/004/Y2781E/y2781e04.htm.

Food and Agricultural Organization of the United Nations (FAO): 2010. Farming for future in Southern Africa: An introduction to conservation agriculture. FAO Regional Emergency Office for Southern Africa Technical Brief 1. 4pp.

Friedrich T, Kassam AH. and Shaxson F: 2009. Conservation Agriculture. In: Agriculture for Developing Countries. Science and Technology Options Assessment (STOA) Project. European Parliament. European Technology Assessment Group, Karlsruhe, Germany. 11pp.

Fuentes JP, Bezdicek DE, Flury M, Albrecht S. and Smith JL: 2006. Microbial activity affected by lime in a long term no till soil. Soil and Tillage 88: 123-131

Graham E, Grandy SS. and Thelen M: 2010. Manure effects on soil organic matter and soil quality. Michigan State University Extension. Emerging Issues in Animal Agriculture. Michigan. USA. 6pp.

Griffiths BS: 1994. Microbial-feeding nematodes and protozoa in soil-their effects on microbial activity and nitrogen mineralization in decomposition hotspots and the rhizosphere. *Plant and Soil* 164, 25–33.

Hobbs PR. and Gupta RK: 2004. Problems and challenges of no-till farming for the rice-wheat systems of the Indo-Gangetic Plains in South Asia. In: Sustainable Agriculture and the Rice-Wheat System, Lal R, Hobbs P, Uphoff N. and Hansen DO (Editors) Columbus, Ohio, and New York, USA: Ohio State University and Marcel Dekker, Inc. pp 101-19.

Ike-izundu NE: 2007. Interaction between arbuscular mycorrhizal fungi and soil microbial populations in the rhizosphere. MSc Thesis. Rhodes University. Republic of South Africa, pp. 25-32.

Jangid K, Williams MA, Franzluebbers AJ, Sanderlin, JS, Reeves JH, Jenkins MB, Endale DM, Coleman DC and Whitman WB: 2008. Relative impacts of land-use, management intensity and fertilization upon soil microbial community structure in agricultural systems. Soil Biology and Biochemistry 40: 2843-2853.

Kassam A. and Friedrich T: 2011. Principles, Sustainable Land Management and Ecosystem Services. *Società Italiana de Agronomia XL Convegno Nazionale*, Università degli Studi Teramo. 4pp.

Kennedy AC, Stubbs TL. and Schillinger, WF: 2004. Soil and crop management effects on soil microbiology. In: Soil Organic Matter in Sustainable Agriculture, Magdoff F and Weil RR (Editors). CRC Press. 398pp.

Khan AA, Jilani G, Akhtar MS, Naqvi SMS. and Rasheed M: 2009. Phosphorus solubilization: Occurrence, mechanisms and their role in crop production. Journal of Agriculture and Biological Sciences 1(1): 48-58.

Kihara J, Christopher M, Bationo A. and Vlek PLG: 2011. Effects of tillage and crop residue application on soybean nitrogen fixation in a Tropical Ferrasol. Agriculture 1: 22-37.

Larkin RP: 2008. Relative effects of soil biological amendments and crop rotations on soil microbial communities and soil borne diseases of potato. Soil Biology and Biochemistry 40(6): 1341-1351.

Lithourgidis AS, Dordas CA, Damalas CA. and Vlachostergios DN: 2011. Annual Intercrops: an alternative pathway for sustainable agriculture. Australian Journal of Crop Science 5(4): 396-410.

Mardad I, Serano A. and Soukri A: 2013. Solubilization of inorganic phosphate and production of organic acids by bacteria isolated from Moroccan mineral phosphate deposit. African Journal of Microbiology Research 7(8): 626-635.

Martinez-Salgado MM, Gutiérrez-Romero V, Jannsens M, Ortega-Blu R: 2010. Biological soil quality indicators: A review. In: Current Research, Technology and Microbiology and Microbial Biotechnology, Mendez-Vilas A (Editor.), Formatex. www.formatex.info/microbiology2/319-328.pdf.

Mohammadi K: 2011. Soil microbial community and biomass as influenced by tillage and fertilization in wheat production. American Eurasian Journal of Agriculture and Environmental Science 10(3):330-337.

Nandwa SM. (2003). Perspectives on soil fertility in Africa. In: Soil fertility management in Africa. A regional perspective, Gichuru MP (Editor). ASP-TSPF-CIAT Publication, 306pp.

Njira KOW: 2012. Biological nitrogen fixation and crop yields under sole cropped and doubled-up legume technologies. MSc Thesis. University of Malawi. Malawi. 96pp.

Nunez EV, Bens F, Valenzuela-Encinas C, Alcantara-Hernandez RJ, Serna FJZ, Govaerts B, Marsch R, Luna-Guido M, Castro-Silva C, Ruiz-Valdiviezo VM, Verhulst N. and Dendooven L: 2012. Bacterial diversity as affected by tillage practice in raised bed-planting system. African Journal of Microbiology Research 6(43):7048-7058.

Pankhurst CE, Doube BM. and Gupta VVSR (Editors.): 1997. Biological Indicators of Soil Health. CAB International Wallingford, UK, 451pp.

Peigne J, Ball BC, Roger-Estrade J. and David C: 2007. Is conservation agriculture suitable for organic farming? A review. Soil Use and Management. http:// www.isara.fr/en/layout/set/print/content /.../1/.../Article+SCAB-4.pdf.

Plaster EJ, 2009. Soil Science and Management. 5th Edition. Delmar Cengage Learning. New York. 495pp.

Quadros PD, Zhalnina K, Davis-Richardson A, Fagen JR, Drew J, Bayer C, Camargo FAO. and Triplett EW: 2012. The effect of tillage system and crop rotation on soil microbial diversity and composition in subtropical Acrisol. Diversity 4: 375-395.

Quio YJ, Li ZZ, Wang X, Zhu B, Hu YG. and Zeng ZH: 2012. Effect of legume-cereal mixtures on the diversity of bacteria communities in the rhizosphere. Plant, Soil and Environment 58: 174-180.

Ratcliff AW, Busse MD. and Shestak CJ: 2006. Changes in microbial community structure following herbicide (glyphosate) additions to forest soils. Applied Soil Ecology 34: 114-124.

Roldan A, Salinas-Garcia JR, Alguacil MM, Diaz G. and Caravaca F: 2004. Changes in soil microbial activity following conservation tillage practices in a sorghum field under subtropical conditions. ISCO 13th International Soil Conservation Organization Conference, July 2004, Brisbane, Australia, 4pp.

Russo A, Carrozza GP, Vettori L, Felici C, Cinelli F. and Toffanin A: 2012. Plant beneficial microbes and their application in plant biotechnology. In: Innovations in Biotechnology, Agbo EC (Editor). http://www.intechopen.com/books/innovations-in-biotechnology/plant-beneficial-microbes-and- their application-in-plant-biotechnology.

Salamon JA, Scheu S. and Schaefer M: 2008. The collembola community of pure and mixed stands of beech (*Fagus sylvatica*) and spruce (Picea abies) of different ages. Pedologia 51: 385-396.

Schalamuk S. and Cabello M: 2010. Arbscular mycorrhizal fungal propagules from tillage and no-tillage systems: possible effects on Glomeromycota diversity. Mycologia 102(2): 261-268.

Silva AP, Banjula LC, Matsumoto LS, Guinaraes MF. and Hungria M: 2013. Bacterial diversity under Oxisol of Southern Brazil. The Open Agricultural Journal 7: 40-47.

Sylvia DM, Furhmann JJ, Hartel PG. and Zuberer DA: 2005. Principles and application of soil microbiology. 2nd Edition. Pearson Prentice Hall. New Jersey. 640pp.

Utobo EB, Ogbodo EN. and Nwogbaga AC: 2011. Techniques for extraction and qantification of arbuscular mycorrhizal Fungi. Libyan Agriculture Research Center Journal International 2 (2): 68-78.

Wang JJ, Li XY, Zhu AN, Zhang XK, Zhang HW. and Liang WJ: 2012. Effect of tillage and residue management on soil microbial communities in North China. Plant, Soil and Environment 58: 28-33.

WenQing H, EnKe L, ChangRong Y., Govaerts B, XuRong M, CaiXia Z, Qin L, Shuang L. and Castellanos A: 2011. Effect of conservation agriculture on the soil biochemical characters in semi-arid area of north China. Soil and Tillage Research *(in press).*

Xue D, Huang X, Yao H. and Huang C: 2010. Effect of lime application on microbial community in acid tea orchard soils comparison with those in wasteland and forest soils. Journal of Environmental Sciences 22(8): 12-1260.

Yadav BK. And Tarafdar JC: 2007. Ability of *Emericella rugulosa* to mobilize unavailable P compounds during pearl millet (*Pennisetum glaucum* L.) crop under arid condition. Indian Journal of Microbiology 41(1): 57-63.

Yusuf AA, Abaido RC, Iwuafor ENO, Ohafajo, OO. and Sanginga N: 2009. Rotation effects of grain legumes and fallow on maize yield, microbial biomass and chemical properties of an Alfisol in the Nigerian Savanna. Agriculture, Ecosystem and Environment 129: 325-331

Zirbes L, Thornat P. and Haubrauge E, 2012. Microscale interactions between earthworms and microorganisms. Biotechnology, Agronomy, Society and Environment 16: 125-131.