Asian Journal of Plant Sciences

ISSN 1682-3974

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2017.109.131

Review Article

Impact of Crop Production Inputs on Soil Health: A Review

Yayeh Bitew and Melkamu Alemayehu

Department of Plant Science, College of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 5501, Bahir Dar, Ethiopia

Abstract

External crop production inputs such as mineral fertilizers, organic amendments, microbial inoculants and pesticides are applied with the ultimate goal of maximizing productivity and economic returns, while side effects on soil health are often neglected. This study summarized the current understanding of how crop production inputs affect soil health (soil physical, chemical and biological properties). Mineral fertilizers have limited direct (such as soil physical property) effects but their application can enhance soil biological activity via increases in system productivity, crop residue return and soil organic matter. Another important indirect effect such as N fertilization is soil acidification, with considerable negative effects on soil health such as on amount, activity and diversity of organisms. Organic amendments such as manure, compost, biosolids and humic substances provide a direct source of C for soil organisms as well as an indirect C source via increased plant growth and plant residue returns. Non-target effects of microbial inoculants appear to be small and transient. Among the pesticides, herbicides have few significant effects on soil health, whereas negative effects of insecticides and fungicides are more common and their application warrants strict regulation. The sound management of crop production inputs must attempt to ensure both an enhanced and safeguarded environment; therefore, an Integrated Pest and Nutrient Management (IPNM) strategy that combines the use of chemical, organic crop production inputs together with cultural practices must be developed and evaluated as suggested by Integrated Pest and Nutrient Management Protocols (IPNMP).

Key words: Soil health, input, pest, fertilizer, pesticide, crop, production, biosolids

Received: January 09, 2017 Accepted: May 05, 2017 Published: June 15, 2017

Citation: Yayeh Bitew and Melkamu Alemayehu, 2017. Impact of crop production inputs on soil health-a review. Asian J. Plant Sci., 16: 109-131.

Corresponding Author: Yayeh Bitew, Department of Plant Science, College of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 5501, Bahir Dar, Ethiopia Tel: +251922608234

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Currently, increase in food production is the one of the primary objective of all countries as world population is expected to grow to nearly 9-10 billion by 2050[1]. In developing countries the population growth rate is 3% $year^{-1}$. Demand for food increases[1] by 3.8% $year^{-1}$. However, food production is increasing by only 1.2% $year^{-1}$. World food production needs to increase by 70%, in order to keep pace with the demand of growing population[2]. However, increase in food production is faced with the ever-growing challenges especially the new area that can be increased for cultivation purposes is very limited[3]. Moreover, the soil fertility of developing countries has become deteriorated[4] and occurrence of various pest infestations increased[5]. The increasing world population coupled with other challenges has therefore put a tremendous amount of pressure on the existing agricultural system so that food needs can be met from the same current resources like land, water etc.[6]. In the process of increasing crop production, crop production inputs (fertilizers and pesticides) are now being used in higher quantities than in the past with proper or improper application system[4,7].

Crop production inputs to crop production systems include mineral fertilizers such as urea, ammonium nitrate, sulfates and phosphates[8]; organic fertilizers such as animal manures, composts and biosolids; various other organic products such as humic acids and microbial inoculants[6,9] and pesticides including herbicides, insecticides, nematicides, fungicides and soil fumigants[8]. All these products are applied with the ultimate goal of maximizing crop productivity and economic returns[9].

Mineral fertilizers are a major physical input into world agricultural production. The global total nutrient capacity ($N+P_2O_5+K_2O$) was 284 million tons in 2014, out of which the total supply was 240 million tons[10]. During 2015, the total capacity was increase by 2.9% and supplies were grown by 1.6%. Based on the production process, it can be roughly categorized into three types: chemical, organic and bio fertilizer. Each type of fertilizer has its advantages and disadvantages. Common types of mineral fertilizers as used in this review are ammonium nitrate, ammonium sulfate, calcium nitrate, diammonium phosphate, elemental sulfur, phosphate rock, sodium dihydrogen phosphate, superphosphate, triple superphosphate and urea. Though, there is lack of information on organic fertilizer consumption globally, Organic agriculture using organic fertilizer is now practiced in more than 130 countries with a total area of 30.4 million ha in 0.7 million number of organic farms[11,12]. It is clear that early many long-term studies have shown that combinations of both organic and inorganic nutrient sources lead to enhanced nutrient availability and synchronization of nutrient release and uptake by crops and positive effects on soil properties[6].

Pesticides are a diverse group of inorganic and organic chemicals[13]. Now it become an integral part of our modern life and are used to protect agricultural land, stored grain, flower gardens as well as to eradicate the pests transmitting dangerous infectious diseases mainly in developing countries[14]. It has been estimated that globally nearly $38 billion are spent on pesticides each year[15]. Manufacturers and researchers are designing new formulations of pesticides to meet the global demand. Ideally, the applied pesticides should only be toxic to the target organisms and unwanted plants, should be biodegradable and eco-friendly to some extent to the soil health. Unfortunately, this is rarely the case as most of the pesticides are non-specific and may kill the organisms that are harmless or useful to the ecosystem. In general, it has been estimated that only about 0.1% of the pesticides reach the target organisms and the remaining contaminates the surrounding environment[16]. On account of this behavior then, they can best be described as biocides (capable of killing all forms of life)[17]. Researches showed that pesticides have not only entered into the food chain and have bio-accumulated in the higher tropic level but also more recently causing several human acute and chronic illnesses[7,18]. The repeated uses of persistent and non-biodegradable pesticides and herbicides have polluted various components of water, air and soil ecosystem[17]. Pesticides and herbicides affect various properties of soil such as, soil physical and chemical properties and mainly soil microorganisms[7,19].

This study summarized the current understanding of the effects of crop production inputs on soil health. The underlying concept is that these inputs can affect soil health through direct or indirect effects. Schreck *et al.*[6] and Bunemann *et al.*[8] summarized this effect in to two categories: (1) Direct effects (example: Increased amount and/or activity after removal of nutrient limitations and decreased activity due to high nutrient availability and decreased amount and/or activity due to toxicity) and (2) Indirect effects [Example: change in pH, change in soil physical properties (aggregation, porosity), change in productivity, residue inputs and soil organic matter levels]. Due to difficulty to distinguished the above classification, existing data are presented for the different amendments separately but the effects are discussed together. Note that, this study did not focused on the direct uptake of nutrients and its effect on crop productivity rather mainly focused on what happen on some soil chemical properties and the amount, activity and diversity of soil microorganisms when the crop production inputs are applied for crop production systems. The evidence from Ethiopia is rather almost none and therefore this study includes literature from overseas, in an attempt to establish the main effects and to draw some conclusions applicable to all users in the world.

SOIL HEALTH

There is increasing recognition of soil as an important non-renewable asset that needs to be managed well and looked after[19]. Soil health is defined as the capacity of a soil to function, within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health[20]. It considers the chemical, physical, biological and ecological properties of soils and the disturbance and ameliorative responses by land managers. Soil health also describes the capacity of soil to meet performance standards relating to nutrient and water storage and supply, biological diversity and function, structural integrity and resistance to degradation[6]. Nonetheless, it should be emphasized that these functions operate by complex interaction with the abiotic physical and chemical environment of soil. Both natural and agricultural soils are the habitat for many different organisms which collectively contribute to a variety of soil-based goods and services[21]. However, these soil-based biological processes may become disturbed or improved by different factors such as addition of agricultural inputs, improper land cultivation, climatic conditions etc.[22]. More specifically, Under-use, over-use and adequate use of crop production inputs determine the soil health of an environment as discussed previously[6]. For instance Fig. 1 shows differences in nutrient inputs and outputs at three locations representing under-use, over-use and adequate use of fertilizers. Western Kenya is characterized by low inputs of N and P in marked contrast to the situation in China and the USA. The N outputs at the Kenyan site are much larger than the inputs, leading to substantial nutrient depletion or "soil mining" and consequent long-term degradation of soil health. On the other hand, high fertilizer nutrient inputs in China greatly exceed nutrient outputs and point towards substantial risks of nutrient losses to the environment. With almost similar inputs and outputs of both N and P, soil health in the Midwest USA is better than in either the Kenyan or Chinese sites[23].

In Ethiopia and worldwide productions and consumption of crop production inputs: Pesticides include chemically synthesized compounds, devices or organisms that are regularly utilized in agriculture to manage, destroy, attack or repel pests, pathogens and parasites. Pesticides include both organic and inorganic moieties and may be classified into different groups based on their chemical composition[24]. Over 1990s, the global pesticide sale remained relatively constant, between 270 to 300 billion dollars, of which 47% were herbicides, the remaining were insecticides, fungicides /bactericides and the others. Over the period 2007-2008 herbicides ranked the first in three major categories of pesticides (insecticides, fungicides/bactericides, herbicides). Fungicides/bactericides increased rapidly and ranked the second[7,17] . Europe is now the largest pesticide consumer in the world followed by Asia. Countries like China, United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world. Although, most of the pesticides worldwide are used to fruit and vegetable crops, developing countries like Ethiopia used to mainly cereal crops[25]. In the developed countries pesticides, mainly herbicides are mostly used[7].

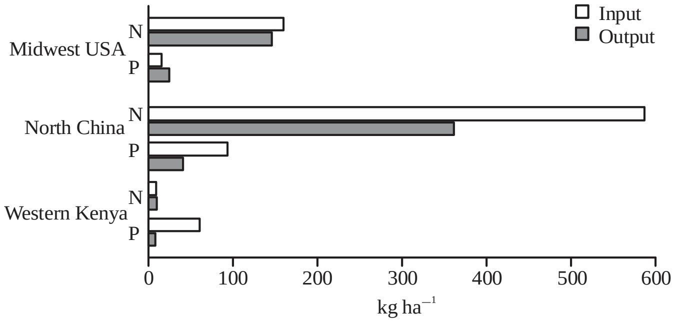

Fig. 1: Total agronomic inputs and outputs of N and P in agricultural soils at Western Kenya, North China and Midwest USA[23]

Although chemical pesticide usage in Ethiopia was historically low, recent developments in increased food production and expansion in floriculture industry have resulted in higher consumption of chemical pesticides. Recently, Ethiopia has been considered as the largest accumulator of obsolete pesticides in the whole of Africa[25]. According to the Ethiopian Federal Environmental Protection Authority (EFEPA)[26] pesticides are mainly imported for agricultural purposes while some amounts of pesticides are imported for health care and industrial purposes. Both public and private enterprises are engaged in pesticide importation business. In contrary, there is one factory that formulates pesticides within the country[25,26]. Large quantities of pesticides are imported annually to Ethiopia. In this regard, currently, about 20 organizations are actively involved in importation and sale of pesticides and over 3000 tons of various types of pesticides that are worth more than USD 20 million are imported annually[26].

In the medium term, global fertilizer consumption would grow moderately at an annual rate of 1.7%, to reach 199.4 Mt nutrients in 2019[27]. Increases are projected for all three major nutrients, with average annual growth rates of 1.3% for N, 2.1% for P and 2.4% for K. Total sales in the fertilizer and industrial sectors in 2019 are forecast at 264 Mt nutrients, representing a 10% increase over 2014. In Ethiopia, over the last 10 years, total fertilizer imports have increased by more than 50%, from less than 370,000 Mt in 2002 to almost 570,000 Mt in 2011, with a spike of 627,000 Mt in 2009. Fertilizer carryover stocks averaged 33% of imports between 2002 and 2011, with a high of 61% in 2002 and a low of 12% in 2007. Fertilizer sales and consumption have increased by more than 100% between 2002 and 2011, with an average rate of 6% year^{-1}, more so for urea than for diammonium phosphate[28]. The information on world consumption of organic fertilizer is very fragmented and difficult to present a comprehensive review in this study. However, organic agriculture using organic fertilizer is now practiced in more than 130 countries with a total area of 30.4 million ha in 0.7 million number of organic farm[11,12]. This constitutes about 0.65% of the total agriculture land of the world[12].

IMPACT OF FERTILIZERS ON SOIL HEALTH

For optimum plant growth, nutrients must be available in sufficient and balanced quantities. Soils contain natural reserves of plant nutrients but these reserves are largely in forms unavailable to plants and only a minor portion is released each year through biological activity or chemical processes. This release is too slow to compensate for the removal of nutrients by agricultural production and to meet crop requirements[29]. Therefore, fertilizers are designed to supplement the nutrients already present in the soil. The use of chemical fertilizer, organic fertilizer or biofertilizer has its advantages and disadvantages in the context of nutrient supply, crop growth and environmental quality. The advantages need to be integrated in order to make optimum use of each type of fertilizer and achieve balanced nutrient management for crop growth[8,30,31].

Impact of inorganic fertilizers on soil health: Most inorganic fertilizers in the world are applied to systems with regular and significant nutrient exports in harvested products, such as lands under arable cropping[8,30]. Various studies conducted at laboratory, pot and filed level revealed that mineral fertilizers had different effects on soil health. The application of chemical fertilizers causing accumulation of acid soils such as hydrochloric and sulfuric acids creates a damaging effect on soil referred to as soil friability. The different acids in the soil dissolve the soil crumbs which help to hold together the rock particles. Soil crumbs result from the combination of humus or decomposed natural material such as dead leaves, with clay. These mineral rich soil crumbs are essential to soil drainage and greatly improve air circulation in the soil. As the chemicals in the chemical fertilizers destroy soil crumbs, the result is a highly compacted soil with reduced drainage and air circulation[32,33].

Addition of Organic fertilizer increased Effective Cation Exchange Capacity (ECEC) by 16% while it reduced in inorganic fertilizer plots[34]. Bulk Density (BD) and soil pH decreased while total porosity, Water Holding Capacity (WHC) improved with the application of increased level of N fertilizers[34,35]. Gypsum amendment was superior in reducing the chemically available heavy metals (Fe, Mn, Zn, Cu, Ni and Cd) in the heavy clay salt-affected soil[35]. The experiment at laboratory inoculation pointed out that the addition of 200 mg N kg^{-1} soil as ammonium sulfate to 2 pasture soils of varying P status resulted in a decrease in microbial P, no change in the turnover of added C and an increase in N mineralization during 168 days of incubation[36]. Long term experiment on chemical fertilizers usage showed that soil physical characteristics such as bulk density were changed in long-term and it was increased compared to control soil. The heavy metals accumulations in soil were highly affected and the concentration of some metals such as cadmium has reached a limit beyond the standard for agricultural purposes. The results also showed that fortunately the concentration of other metals is not beyond the standard[36].

In contrary, an increase in soil respiration and microbial P but no effect on microbial N and a decrease in various enzyme activities upon addition of 500 mg P kg^{-1} soil as calcium diphosphate were reported by Bunemann *et al.*[8]. The addition of N, P, K and S at 100, 20, 100 and 20 mg kg^{-1} soil, respectively, to a range of soils followed by incubation for 20 days, resulted in minor changes (increase or decrease) of soil respiration and microbial C, N and P that remained within 20% difference from the non-amended controls[8]. Ammonium addition did not change the composition of the microbial community during 28 days of incubation but led to community shifts after 16 weeks of incubation[37]. Using molecular techniques in a range of pot experiments, soil pH and N and P fertilization can affect the microbial community composition but that substrate availability, e.g. in the form of root exudates in the rhizosphere, appears to be the main factor determining the community composition in the rhizosphere[38]. It is thus, important to consider the potential feedback from improved plant nutrition when examining fertilizer effects on soil health[8]. Moreover, the addition of mineral N did not affect Arbuscular Mycorrhizal Fungi (AMF) while increasing additions of inorganic P decreased the rate of root length colonization[39]. A decrease in AMF root colonization was also observed in pastures after 15-17 years of mineral P and N fertilization[40] (Table 1).

Many field experiments have shown a lack of response of the microbial biomass and earthworms to inorganic fertilizers (Table 2, 3). Where a decrease in microbial C was observed, it was usually accompanied by a decrease in soil pH after application of N or S fertilizers[41]. Other methods such as microbial enumeration by plate counts, enzyme activities[42] and nematode counts[43], which are possibly more sensitive than measurements of microbial biomass, show variable changes due to mineral fertilization (Table 1). For instance, although the total number of nematodes was not affected by N fertilization and a concomitant decrease in pH, some nematode species increased, whereas others were decreased[41].

There was absence of changes in microbial C in response to N fertilization and a related decrease in pH in the 2 long-term field experiments[44]. This study is interesting, because in the same study microbial C was found to be correlated to levels of organic C as induced by different crop rotations. Several long-term field experiments in which inorganic and organic fertilizer inputs have been compared are indicated in Table 3 and 4. Several studies showed that there was a good correlations between the microbial biomass and soil organic C. Although soil organic C levels are often increased by inorganic fertilization compared with the non-fertilized control, even greater increases in soil organic C are usually achieved in treatments receiving organic amendments[8]. This is also reflected in the fact that whereas inorganic fertilizers show variable effects on soil organisms and soil pH, organic amendments have only been reported to have insignificant or positive long-term effects (Table 2).

The amounts of microbial C and N under sugarcane after 59 years of differential crop residue management and NPK fertilization and showed that the microbial biomass was directly influenced by residue management and indirectly by NPK fertilization through increased residue inputs[42]. Another study in the same trial revealed the interaction of soil acidification with negative effects and organic matter accumulation with positive effects on soil organisms and enzyme activities[42]. The long term field experiment exemplifies that agro-ecosystems can be relatively slow to respond to changes in management and thus illustrates the value of long-term field experiments[8]. The excellent correlation between microbial C and soil organic C found after 100 years of constant management practices remained disturbed 2 years after a change in crop rotation and crop residue management. The time required to reach a new equilibrium is a factor that may confound the results from many short-term studies.

The comparison of various long term experiment on N, P and K fertilizers, liming and manure treatments revealed that ammonium fertilizers decreased pH and CEC, causing a degradation of hydraulic properties, whereas basic amendments increased pH and CEC[45,46]. Aggregate stability was lowest in acid plots, intermediate in basic plots and highest in plots treated with manure. A short term study suggested that ammonium nitrate enhanced soil porosity by 18%, compared with 46% increase in a manure treatment[30]. Since soil respiration almost doubled in the mineral fertilizer treatment compared with the unfertilized control, the authors discussed a potential priming effect of N addition on the decomposition of soil organic matter (Table 1). A decreased amount or activity of soil organisms after mineral fertilization could be due to the toxicity of metal contaminants contained in mineral fertilizers[8,36,41]. In general, N and K fertilizers contain very low levels of contaminants, whereas P fertilizers often contain significant amounts of cadmium, mercury and lead[8]. Metal contaminants are, however, most prevalent in waste products from urban and industrial areas[8,47]. Long term chronic toxicity due to gradually accumulating metals appears to be far more common than immediate, acute toxicity. Quality control of fertilizer products is therefore required. This applies in particular to any new products. For example, the application of rare earth elements such as lanthanum, which is increasing in China, was shown to decrease soil respiration and dehydrogenase activity at high application rates[8,48]. Such observations warrant more detailed investigation into

Table 1: Summery of effects of inorganic fertilizers on soil health

Test plants	Time frame	Fertilizers (kg ha^{-1})	Effect on soil health (Amount (%) and activity of control)	References
Pot experiments with white clover and ryegrass	5 weeks	200 P [#](Sodium dihydrogen phosphate)	Negative effect: Clover root length colonized by AMF (20-30%) No change on ryegrass root length colonized (%)	Ryan and Ash[60]
Pot experiments with wheat	6 month	17-86 P (Triple super phosphate, phosphate rock)	Negative effect: Root colonization (60-90%); Positive effect: Fungi (480%), Gram-ve bacteria (140%); no change on microbial P, earthworms	Rubio *et al.*[39]
Posture	2 weeks	0-120 P (Super phosphate, phosphate rock	Positive effect on fungi (480%), Gram-ve bacteria (140%); No change on microbial P, earthworms; pasture production increase	Sarathchandra *et al.*[41]
Pasture	10 weeks	40 N (Ammonium nitrate)	Positive effect: Nitrification, ammonification; no change on microbial, earthworms; Microbial C and N	Lovell and Hatch[64]
Wheat-canola	1-2 seasons	20 S (Elemental sulfur or ammonium sulfate)	Negative: Diversity (Biology); no change on microbial C;	Ladha *et al.*[65]
Pasture	Pasture	61 P (Super Phosphate)	No change on Microbial P and S; increases herbage	Adeoye *et al.*[14]
Pasture	4 years	400 N (Urea)	Negative effect: Microbial C (80%), diversity (Biology), *Meloidogyne* (10%), plant-associated (68%) and fungal-feeding (82%) nematodes; No change on total nematodes; Negative effect on paratylenchus (1677%)	Sarathchandra *et al.*[41]
Canola-fallow	2 years	50-100 S (Elemental sulfer)	Negative: Fungal CFUs (38%), protozoa (4-25%), microbial C (49-98%), respiration (67-86%); positive effect: Microbial S (136-168%), acid phosphatase (106-130%)	Gupta and Germida[66]
Pasture	5 years	44 S (Elemental sulfer)	Negative effect on microbial C (60%), respiration (54%), hyphal length (24%), fungal CFUs (23%), protozoa (29-71%); no effect on Bacterial and actinomycetes CFUs; positive effect on Microbial S (178%), acid phosphatase (141%); pH increased by 1.0 units, OC decreased	Gupta and Germida[66]
Wheat rotations	9-13 years	0-80 N (Ammonium nitrate)	Negative effect: Microbial C (68-86%), pH decreased by by 0.4-1.0 units; no change on C and N mineralization	Martikainen *et al.*[67]
Pasture	7-23 years	12-37 P, 12-26 S	No change on earthworms; positive effect on microbial P (168-300%), microbial N (106-163%), total nematodes (123-223%)	Chan[68]
Pasture	15-17 years	27 P (Superphosphate, Diammonium phosphate) 17 N (Urea)	Negative effect on: Clover and grass root length colonized by AMF (67-79%); pH reduced by 0.1-0.9 units; microbial C related to OC; no change on microbial C	Ryan[69]
Sugarcane	59-60 years	140 N, 20 P, 140 K	Negative effect on: Dehydrogenase, arylsulfatase, alkaline phosphatase; positive effect: e microbial C (119-136%), FDA hydrolysis rate, acid phosphatase; no change; OC increased, pH decreased by 0.7 units; no change protease, respiration	Graham and Haynes[42]

[#]mg kg^{-1} soil

Table 2: Comparative effects of inorganic and organic fertilizers on soil organisms as concluded from field experiments (FYM, farmyard manure)

Test plants	Time frame	Fertilizers (kg ha^{-1})	Effect on soil health (amount (%) and activity of control)	References
Maize-pasture rotation	5	18 N (Ammonium nitrate) FYM (252 N)	Negative effect on Gram -ve bacteria (85%); no change on total PLFAs Gram +ve bacteria; positive effect on Gram +ve bacteria (120%), total PLFAs (170%), Gram -ve bacteria (115%); pH reduced by 0.6 units, OC increased	Peacock *et al.*[83]
Cover crop	12	100 N (Ammonium nitrate), 75 P (Superphosphate), 150 K (Superphosphate); Compost (500-1500 N); FYM (500)	No change on microbial C, microbial C correlated to OC; positive effect on microbial C (200-350%) and microbial C (243%)	Leita *et al.*[84]
Arable crops	34-36	80 N (CaN); 80N (Ammonium sulfatc); FYM (4 t ha^{-1} year); Sewage sludge	No negative effect, positive effect on microbial C (142%); Negative effect on Microbial C(13%); negative effect on microbial C(69%), positive effect on microbial C (209%); in general pH reduced with AS and sewage sludge; microbial C and respiration related to OC	Witter *et al.*[85]
Wheat-fallow rotation	55	90 N	Negative effect on amidase, urease; no change on acid and alk.phosphatase, arylsulfatase, glucosidase; pH reduced by 0.6 units	Bunemann *et al.*[8]
Wheat	69	67 N, 15 P, 28 K	Negative effect on Fast-growing Bacteria; no change on: Bacterial and fungal CFU, alk. phosphatase, phosphodiesterase, pyrophosphatase; positive effect on: Microbial C, acid phosphatase, slow-growing bacteria; pH reduced by ~0.5 units	Parham *et al.*[86]
Pasture	100	35 N (Ammonium sulfate)	Negative effect on microbial P, C	Colvan *et al.*[87]
		60 P	Positive effect on microbial P	
		67 K	Positive effect on phosphatase	
		35 N, 60 P, 67 K	Positive effect on microbial P, phosphatase	
		FYM (20 t ha^{-1} year)	Positive effect on microbial P, pH increased by 0.6 units	
Wheat-sugar beet	112	87 N, 40 P, 75 K	Positive effect on microbial C; Microbial C related to OC	Houot and Chaussod[88]
		FYM (1 tons ha^{-1} year)	Positive effect on microbial C	
cucumber (*Cucumis Sativa*)		compost of plant residues and animal and mixed composts	Mature compost of plant residues was higher in saturation percent and lower in C/N ratio, pH, electrical conductivity and bulk density than the animal and mixed composts Nitrogen and phosphorus content of the soil significantly increased, as did the soil organic matter, with the increase of organic nitrogen applied Combination of organic and inorganic fertilizers could increase soil fertility It also confirmed that composted organic wastes can be used to substitute for around 25% of chemical nitrogen fertilizers	Mahmoud *et al.*[29]

Table 3: Comparative effects of inorganic and organic fertilizers on soil health as concluded from field experiments (FYM, farmyard manure)

Test plants	Time frame	Fertilizer (kg ha^{-1})	Effect on soil health (amount (%) and activity of control)	References
Tea (*Camellia sinensis* L.)	2 year	Cocoa husk, cow dung	About 3.0-4.6, 0.08-0.21, 0.69-1.79, 0.36-0.76, 0.17-0.24 and 31.5-5.45 kg N, P, K, Ca, Mg and C ha^{-1}, respectively could be recycled to the soil through pruned materials from tea seedlings treated with enriched manures compared to 1.17, 0.05, 0.25, 0.69, 0.18 and 40.84 kg ha^{-1} for similar elements for NPK treated plants	Ipinmoroti *et al.*[30]
Rice-soybean-rice	4 years	Paddy straw and inoculants +30 N-60 P205- 30 K20	The soil fertility viz., soil organic carbon content, soil available nitrogen, phosphorous and potassium built up significantly under application inorganic fertilizer combined with composted paddy straw or inoculants or both composted paddy straw and inoculants as compared to the treatments those applied only inorganic fertilizers	Son *et al.*[97]
Brinjal	2 years	60% organic +40% inorganic	The organic matter content and availability of N, P, K and S in soil were increased by organic matter application. On the other hand soil pH was increased with chemical application than organic.	Ullah *et al.*[98]
Maranth	3 years	0 kg ha^{-1} manure, 2 tons ha^{-1} organic compost and 200 kg ha^{-1} NPK 15-15-15	The organic matter increased by 23.3 and 0.6% in the second and third year respectively in the plot treated with organic compost, while there was no such increase trend in the plot treated with 200 kg NPK ha^{-1}. The organic matter content correlated positively with the yield and vitamin C content of amaranth.	Adekayode and Ogunkoya[99]
Sugarcane	3 years	farm yard manure (25 tons ha^{-1}), compost (2.5 tons ha^{-1}) and NADEP compost (5.0 tons ha^{-1})	The plots which received FYM at 25 tons ha^{-1}+RDF recorded highest organic carbon (0.55%) and available N (226 kg ha^{-1}) maximum available P2O5 and K2O (38.89 and 254 kg ha^{-1}) was observed in plots which received press mud cake at 12 tons ha^{-1}+RDF as press mud cake is a rich source of phosphorus (2.76%). Decrease in pH in manured plots was attributed to increase in partial pressure of CO_2 and organic acids due to organic matter decomposition	Bunemann *et al.*[8]
Maize	15 years	No fertilizer application (control), application of farmyard manure application of FYM, Mavuno Fertilizer and top dressing	The Aggregate stability was significantly higher on application of farmyard manure (FYM) alone. OC was significantly higher on combined application of FYM, Mavuno fertilizer and top dressing. Mineral fertilizers contribute more to the increase of OC than organic fertilizers	Gomez *et al.*[100]
Maize	4 years	(Calliandra calothyrsus, Leucaena trichandra, Tithonia diversifolia, Mucuna pruriens, Crotalaria ochroleuca and cattle manure) = chemical fertilizer	Cattle manure proved to be the most effective and improved soil fertility by increasing pH, cations (Ca, K and Mg) and C. Calliandra, Leucaena, Tithonia and herbaceous legumes generally reduced soil pH, C and N but increased Ca, K and Mg. Cattle manure is therefore an important resource for maintaining Soil Organic Matter (SOM) in the area and in other similar areas with arable-livestock systems. Reduction of soil C and N by the high quality organic materials suggests that their role in maintaining SOM in the long-term is limited in this area. A sound nutrient management system should strive to make a balance between maximizing crop production and sustaining soil quality	Mugwe *et al.*[101]

Table 4: Effects of animal manures, biosolids and composts on soil health

Compared treatments	Effects	References
Poultry manure, gypsum+dolomite, others	Manured treatment had highest microbial C	Sharpley *et al.*[102]
Long-term annual application of farmyard manure, control	Manure addition enhanced microbial biomass and xylanase and invertase activity	Poll *et al.*[103]
3 years poultry manure, FYM, sesbania and gliricidia residues, control	Organic manures increased microbial biomass, activity, diversity and C turnover	Dinesh *et al.*[104]
Manure, mineral fertilizer, combined manure and fertilizer	Manure±N and P fertilizer treatments restored OC and microbial C to the level of the native sod	Dinesh *et al.*[104]
Lab. incubation of soil amended with sheep manure at various soil matric potentials and clay contents	Manure increased soil respiration in all combinations of soils and matric potentials. Microbial biomass increased most with the addition of manure to the sandiest soil	Thomsen *et al.*[105]
Surface mulches of grass clippings, Lucerne stems, composted manure, eucalyptus, oleander or pine chip waste, chipped construction waste	Only grass clippings stimulated dehydrogenase activity in the soil measured after 1 year. Eucalyptus yard waste and grass clippings caused shifts in bacterial populations and increased bacterial diversity but only at the soil surface	Young *et al.*[96]
Single application of poultry manure, NPK fertilizer to soil after wildfire	Poultry manure application increased microbial biomass C, particularly at high dose. Little or no changes as a consequence of inorganic fertilization	Villar *et al.*[106]
Biosolids (30-120 tons ha^{-1})	Increase in earthworm abundance	Baker *et al.*[107]
Single application of biosolids from 5 treatment plants applied to one soil. Biosolids from 1 plant applied to 6 soils	Symbiotic effectiveness of rhizobium dependent on soil type and level and source of biosolids, not on basis of heavy metal concentrations	Munn *et al.*[108]
Long-term FYM, metal-contaminated sewage sludge, NPK mineral fertilizer	FYM-treated soil than in NPK and sludge-amended soils. Relatively small heavy-metal concentrations decreased microbial C and bacterial numbers, increased metabolic quotient and changed microbial community 40 years after metal inputs ceased	Abaye *et al.*[109]
Several combinations of sludge and coal ash, control, NPK fertilizer	Microbial C and soil enzyme activities increased with all amendments; highest at equal proportions of coal ash and sludge. Mobile fractions of Cd and Ni correlated with microbial C	Chaudhuri *et al.*[110]
Short-term incubation, sewage sludge, composted turf and plant residues	Compared with compost, sewage sludge caused greater increases in soil respiration, microbial C,and metabolic quotient, especially with increasing application rate	Yang *et al.*[111]
2 years of sewage sludge applied to de-surfaced soils	Microbial biomass not affected by sludge, but metabolic activity and organic matter mineralization enhanced. Increased soil respiration from sludge-amended soil represented 21% of C applied that year and 15% of C applied the year before	Alvarez *et al.*[112]
Single application of biosolids	6years after application, amended plots had increased microbial respiration, nitrogen mineralization, root colonization by AM, microbial biomass. No change in metabolic quotient	Barbarick *et al.*[113]

processes of accumulation, bioavailability and threshold levels of elements contained in fertilizers that can be toxic to soil health.

Soil health is also influenced by increased rate of decomposition of low quality or high C:N ratio organic inputs and SOM when fertilizers are applied to the soil. Fertilizer application leads to enhancement of microbial decomposer activity, which has been previously limited by low nutrient concentrations in the organic materials, although in a few studies added inorganic N has had either a neutral or even an inhibitory effect on the decomposition of low-N plant materials[49]. Long-term use of fertilizers in crop production, however, leads to soil organic matter accumulation[6] and soil health improvement through addition of increasing amount of litter and root biomass to the soil. It suggests that the application of N fertilizer can have complex interactive effects on C transformations in the soil.

Some of the commonly used chemical fertilizers such as ammonium sulfate [$(NH_4)_2SO_4$], ammonium nitrate (NH_4NO_3), urea (NH_2CONH_2), triple super phosphate [$Ca\ (H_2PO_4)_2$] and potassium chloride (KCl) affects soil health (Table 3-4). Ammonium sulfate ($NH_4)_2SO_4$) is one of the synthetic N fertilizer and contains 21N-0P-0K + 24% S. In the soil, it reacts with water to produce sulfuric acid (H_2SO_4). Sulfuric acid has a pH of less than 1. It is extremely toxic and kills organisms. Hydrogen ions released from the acid replace alkaline elements on the cation exchange sites, depleting the soil of nutrients. The free oxygen created in this reaction oxidizes the organic matter of the soil causes a low level "combustion" (burning) of the organic matter. This is a purely chemical reaction which depletes the organic matter. In calcareous soils (soil with excess calcium) the sulfuric acid reacts with calcium carbonate ($CaCO_3$) to form gypsum ($CaSO_4$ = Calcium sulfate)[50]. Gypsum is a salt and attracts water to it and away from soil organisms and plant roots. In anaerobic conditions gypsum and water form hydrogen sulfide (H_2S), which is a toxic gas. Gypsum is banned from landfills. Sulfuric acid is a major component of acid rain[50].

Ammonium nitrate (NH_4NO_3) contains 34N-0P-0K. In the soil, it breaks down into ammonium (NH_4^+) and nitrate (NO_3^-). The ammonium is consumed by plants and fungi or by denitrifying bacteria which eventually convert it to nitrate[51]. The nitrates are consumed by soil organisms, leached or converted to nitrogen gas and volatilized. The free oxygen created through these processes oxidizes the organic matter of the soil and causes a low level "combustion" (burning) of the organic matter. This is a chemical reaction which depletes the organic matter. Some biological soil scientists advocate the use of small amounts of ammonium nitrate under specific circumstances even though it is prohibited for use under organic standards[51,52]. Urea (NH_2CONH_2) contains 46N-0P-0K. The urea is consumed by bacteria which convert it to (excrete) anhydrous ammonia (which is a gas) and carbon dioxide (= $2(NH_3)+CO_2$)[52]. Anhydrous ammonia is highly toxic and kills soil organisms. If urea is applied to the soil surface, the gases quickly dissipate. However, in the presence of high air humidity anhydrous ammonia gas vapours form. These are heavier than air and can accumulate in low lying areas. If urea is incorporated into the soil, the ammonia gas reacts with water (H_2O) to produce ammonium hydroxide (NH_4OH), which has a pH of 11.6[53]. It is highly caustic and causes severe burns. This creates a toxic zone in the immediate vicinity of the applied urea that kills seeds, seedlings and soil dwelling organisms. Within a few days further chemical reactions in the soil release the ammonium ion NH_4^+, which then follows the same path as naturally occurring ammonium, with any excess nitrate created in this way leached into the environment, etc.

Triple super phosphate [$Ca\ (H_2PO_4)_2$] contains 0N-46P-0K. This is produced by treating phosphate rock (apatite) with either sulfuric acid or phosphoric acid, making it extremely acidifying[52]. When applied to the soil it reacts with calcium to form tri-calcium phosphate, which is water insoluble, i.e., requiring microbial action for breakdown. Even in a soil with healthy microbial activity only about 15-20% of this phosphorous is easily available to plants, considerably less in soil which does not have good microbial diversity[53]. The production of each ton of phosphoric acid is accompanied by the production of 4 ½ tons of calcium sulfate, also known as phosphogypsum. This is a highly radioactive product and also contains heavy metals and other impurities. Depending on the production process, radioactive substances and heavy metals can be extracted into the fertilizer. The high concentration of radioactive polonium-210 in tobacco is thought to be associated with the use of acid-extracted phosphate fertilizers[54].

Potassium chloride (KCl) contains 0N-0P-60K.This product contains about 50% potassium and 50% chloride. In the soil the chloride combines with nitrates to form chlorine gas. This kills microbes. Applying 1 pound of potassium chloride to the soil is equivalent to applying 1 gallon of clorox bleach. Or in other words: 2 ppm chlorine are generally thought to be sufficient to sterilize drinking water potassium chloride application typically results in chloride levels as high as 50-200 ppm[53]. Potassium chloride contains very high amounts of potassium, which can result in an unbalanced phosphate:potash ratio. This ratio ideally ranges from 2:1 (most soils) to 4:1 (grasses). Excess potassium in the soil can lead to a calcium deficiency in plants, since plants absorb calcium, magnesium and potassium largely in the ratio in which they are present in the soil. In the soil excess potassium causes a loss of soil structure[53]. Reduced soil air levels result in reduced root respiration and the production of toxic compounds in plants. Reduced soil air and insufficient calcium each also result in the reduction of soil microbes and the corresponding reduced breakdown of organic matter/nutrient availability to plants. In drilling potassium is used to "close" the soil, because it disintegrates the clay particles ("ages" the clay) and effectively seals the soil[55].

Effects of Organic fertilizers on soil health: Since most organic fertilizers are waste products; their application rate is often determined by availability rather than demand[7,8]. Most amendments are applied primarily to benefit plant growth. In contrast to inorganic fertilizers, however, effects on the soil's physical, chemical and biological properties are intended as well in the following section. Besides, in the following sections, we try to establish some links between the properties of various organic inputs and their effects on soil health (Table 2, 3).

Compostable organics: Compostable and composted materials vary widely in characteristics such as dry matter content, pH, salinity, carbon content, plant nutrient concentrations, non-nutrient elements and microbial types, numbers and activity[6]. Onwudiwe *et al.*[56] reported that application of municipal solid waste did not cause significant improvement in some soil physical properties such as soil aggregate stability, saturated hydraulic conductivity, bulk density and porosity. Although studies of amendments vary widely in nature of materials, application rates and experimental conditions, amendment with raw and composted organics generally results in increased microbial proliferation in the soil (Table 3). The duration of observed increases in soil organisms depends on the amount and proportions of readily decomposable carbon substrates added and the availability of nutrients, particularly nitrogen[57]. However, soil chemical, physical and microbial characteristics of amended soils often return to their baseline within a few years[58]. Sustained changes in microbial biomass, diversity and function are more likely where organic amendments are ongoing as is the case in organic and biodynamic farms[59]. However, an increase in microbial populations may not be seen when system productivity is limited by nutrient input or water supply[60].

Manures and sewage sludge generally have higher salinity than municipal garden wastes and salts can build up in soil with repeated heavy applications[61,62]. Sewage sludge (biosolids) often contains heavy metals such as copper, zinc or cadmium, especially where industries contribute to the waste stream. Heavy metals can affect microbial processes more than they affect soil animals or plants growing on the same soils. For example, nitrogen-fixing rhizobia were far more sensitive to metal toxicity than their host plant clover. This resulted in N deficiency of clover due to ineffective rhizobia in sludge-amended soils. Sewage sludge and livestock manure may also contain active residues of therapeutic agents used to treat or cure diseases in humans and animals[63]. Green wastes from farms and gardens are typically lower in nutrient concentrations than manures or sewage sludge's but may contain residues of synthetic compounds such as herbicides, insecticides, fungicides and plant growth regulators. Composting degrades some but not all such compounds, depending on the nature of the pesticide and the specific composting conditions.

In general terms compost will modify Soil Organic Matter (SOM) levels depending on compost quality and when/where applied. This often leads to increases in organic carbon and total nitrogen in topsoil. Equilibrium is achieved after long periods of time and this is affected by soil type, climate, by the means of exploitation and the quality/quantity of the compost. Soil pH is generally increased or stabilized this can save lime inputs in some circumstances. The Cation Exchange Capacity (CEC) of SOM is higher than that of clay minerals so raising SOM will lift overall soil CEC. In terms of the effects on physical properties compost use can lead to larger and more stable aggregates. Mature compost is better than young compost in this respect. Over the longer term (>3 years) soil density decreases-increased aeration has been seen but there has only been a small number of studies. The majority of studies showed increased water-holding capacity and infiltration though this was in the longer term studies. It was noted that many field studies did not provide a consistent picture of the details of the composts used e.g. ingredients, management of the composting process and quality parameters. If mineral fertilizers were added this was often not stated (Table 1).

Humic substances: Humus in soil has traditionally been separated into humin, humic acid and fulvic acid based on extraction with an alkaline solution and subsequent precipitation after addition of an acid[8]. The fractions typically rank in their resistance to microbial decomposition in the order humic acid> fulvic acid>humin[70]. Concentrated sources of organic material such as peat, composts and brown coal (oxidized coal, lignite, leonardite) also contain humic substances and are often marketed on the basis of their humic and fulvic acid contents as determined by similar procedures. Contents of humic acids vary, however. Some of the chemically extracted humic and fulvic acid separates are themselves sold as soil amendments. In discussion of organic amendments, a clear distinction must be made between products containing humic substances and those products that are humic (or fulvic) acids extracted from the primary sources listed above. Humic substances can stimulate microbial activity directly through provision of carbon substrate, supplementation of nutrients and enhanced nutrient uptake across cell walls. Valdrighi *et al.*[71] reported that increasing amounts of compost or brown coal-derived humic acid stimulated aerobic bacterial growth but had only slight effects on actinomycetes and no effect on filamentous fungi.

Differences in microbial response were related to the molecular weight of the humic acids, with the lower weight fractions, typical of composts, causing greater microbial stimulation than the higher molecular weight fractions extracted from brown coal[71]. Application of humic substances may induce changes in metabolism, allowing organisms to proliferate on substrates which they could not previously use. Both heterotrophic and autotrophic bacteria can be stimulated by humic acid addition, mostly through the enhanced surfactant-like absorption of mineral nutrients, although heterotrophs also benefit from the direct uptake of organic compounds[70,71]. Nitrifiers (chemotrophs) cannot use humic acids as an alternative carbon and energy source[71].

The principal indirect effects of humic substances on soil organisms are through increased plant productivity by mechanisms as listed below but excessive applications can negatively affect plant growth[71,72], possibly through reduced availability of chelated nutrients[73]. Field studies vary widely in the applied amounts of humic substances and in outcomes[8,73] found no effect of commercial humate applied at 8.2 t ha^{-1} on microbial activity or microbial functional groups (total fungi, actinomycetes, total Gram-negative bacteria, fluorescent pseudomonas and *P. capsici*) in a sandy soil used to grow bell peppers. Similarly, after 5 years of annual applications of 100 L ha^{-1} liquid humic acid to a horticultural soil[74], found no effect on microbial biomass or enzyme activity. They ascribed the lack of effect to the low rates recommended by the manufacturer because of high product costs. Municipal solid waste compost and sewage sludge were more affordable and led to significant increases in microbial biomass in the same study[73]. Calculated from laboratory studies that 67.5 kg ha^{-1} of humic substances were needed for effective application to a sandy soil but thought beneficial effects to plants may only occur in semi-arid or arid areas when applied in combination with irrigation and mineral nutrients.

Combined use of chemical and organic fertilizers: There is increased emphasis on the impact on environmental quality due to continuous use of chemical fertilizers[75]. The integrated nutrient management system is an alternative and is characterized by reduced input of chemical fertilizers and combined use of chemical fertilizers with organic materials such as animal manures, crop residues, green manure and composts. Management systems that rely on organic inputs as plant nutrient sources have different dynamics of nutrient availability from those involving the use of chemical fertilizers. For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer[29,31,75]. A field experiment was conducted for 7 years continuously to evaluate the influence of combined applications and organic and chemical fertility buildup and nutrient uptake in a mint (*Mentha arvensis*) and mustard (*Brassica juncea*) cropping sequence[76]. Results indicated that integrated supply of plant nutrients through FYM (farmyard manure) and fertilizer NPK, along with *Sesbania* green manuring, played a significant role in sustaining soil fertility and crop productivity. Based on the evaluation of soil quality indicators, the use of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health[77]. Application of organic manure in combination with chemical fertilizer has been reported to increase absorption of N, P and K in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone (Table 2-5)[78].

The comparison of the change of chemical and biological properties in soils receiving FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for 7 years under a cropping sequence of pearl millet and wheat results showed that all treatments except chemical fertilizer application improved the soil organic C, total N, P and K status. Increase in microbial biomass C and N was observed in soils receiving organic manures only or with the combined application of organic manures and chemical fertilizers compared to soils receiving chemical fertilizers[79]. This study showed that balanced fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter content and long-term soil productivity in the tropics where soil organic matter content is low. The effects of organic fertilization and combined use of chemical and organic fertilizer on crop growth and soil fertility depend on the application rates and the nature of fertilizers used. Application of 15 tons FYM ha^{-1} significantly increased soil organic matter and available water holding capacity but decreased the soil bulk density, creating a good soil condition for enhanced growth of the rice crop[80]. Positive balances of soil N and P resulted from combined application of FYM and inorganic N and P sources. Application of 15 tons ha^{-1} FYM and 120 kg N ha^{-1} resulted in 214.8 kg ha^{-1} N positive balance while application of 15 tons ha^{-1} FYM and 100 kg P_2O_5 ha^{-1} resulted in a positive balance of 69.3 kg P_2O_5 ha^{-1} available P. The compost manure and compost manure+NPK showed a greater potential for increasing plant macronutrients (N, P, K, Ca and Mg) contents[81]. The result showed that combined application of Municipal solid waste with NPK performed better than sole application of either Municipal solid waste or NPK fertilizer[82] (Table 2, 5).

Microbial inoculants: Inoculation with natural or genetically engineered microbial formulations can be broadly categorized according to whether they are intended to (a) exist on their own in the bulk soil, (b) populate the rhizosphere, (c) form symbiotic associations with plants or (d) promote microbial activity on leaf or straw surfaces. To achieve the desired effect in the field, the inoculant organism must not only survive but establish itself and dominate in the soil or rhizosphere[8]. Survival depends firstly on the quality of the inoculant itself, i.e., purity, strain trueness, viable numbers, the degree of infectivity and level of contaminants[89]. Secondly, the establishment and proliferation of inoculant in the soil environment are determined by many edaphic and climatic factors, the presence of host organisms (for symbionts and endophytes) and, most importantly, by competitive interactions with other microorganisms and soil fauna[90]. Effects of inoculation on indigenous soil organisms can therefore either result from direct addition effects and interactions with indigenous soil organisms or from indirect effects via increases in plant growth by one or several of the mechanisms.

Positive effects of inoculants on the soil microbial biomass may be short-lived and increases in biomass or activity can even be due to the indigenous population feeding on the newly added microorganism[89,90]. The most successful and widely studied inoculants are the diazotroph bacteria (*Rhizobium*, *Bradyrhizobium*, *Sinorhizobium* and *Frankia*) used for symbiotic fixation of N_2 from air. Provided soil conditions are favorable for rhizobia survival[90,91] inoculation can increase microbial C and N in the rhizosphere compared with uninoculated soils[91]. Population changes can be limited to the season of inoculation if the newly added organism is not as well adapted to the soil conditions as the indigenous population[90]. Inoculant application research is increasingly focusing on co-inoculation with several strains or mixed cultures enabling combined niche exploitation, cross-feeding, complementary effects and enhancement of one organism's colonization ability when co-inoculated with a rhizosphere-competent strain.

An example is the use of phosphorus-solubilizing bacteria to increase available phosphorus along with mycorrhizae that enhance phosphorus uptake into the plant. Saini *et al.*[92] achieved maximum yields of sorghum and chickpea at half the recommended rates of inorganic fertilizer when a combination of mycorrhizae, N_2-fixing bacteria and phosphorus-solubilizing bacteria was added. Increases in microbial biomass C, N and P in soils of inoculated treatments were strongly correlated with N and P uptake of the plants. Specific 'helper' bacteria may improve the receptivity of the root to the fungus to enhance mycorrhizal colonization and symbiotic development with plant roots. Similarly, legume root nodulation can be enhanced by co-inoculation with *Azospirillum*, which increases root production and susceptibility for rhizobium infection and may also increase secretion of flavonoids from roots that activate nodulation genes in *Rhizobium*. A significant reduction in indigenous actinobacterial endophytes upon inoculation of soil with a commercial multi-organism product, compared with no change in diversity after inoculation with a single species[93]. Trial with 'Effective Microorganisms' (EM), a proprietary combination of photosynthetic bacteria, lactic acid bacteria and yeasts used as a soil and compost inoculant, showed enhanced soil microbial biomass, plant growth and produce quality[94]. The interactions of microbial inoculants with indigenous soil organisms are likely to be complex and a better mechanistic understanding is necessary to predict short- and long-term effects.

Combined use of bio fertilizers with chemical or organic fertilizers: The activity of soil organisms is very important for ensuring sufficient nutrient supply to the plant. If the microorganisms find suitable conditions for their growth, they can be very efficient in dissolving nutrients and making them available to plants. The application of PSB, *Bacillus megatherium* var. *phosphaticum*, increased the PSB population in the rhizosphere and P availability in the soil. It also enhanced sugarcane growth, yield and quality[95]. When used in conjunction with P fertilizers, PSB reduced the required P dosage by 25%. In addition, 50% of costly superphosphate could be replaced by a cheap rock phosphate, when applied in combination with PSB. The effects of a combined treatment of multifunctional biofertilizer (mixture of Bacillus sp. *B. subtilis*, *B. erythropolis*, *B. pumilus* and *P. rubiacearum*) plus 50% chemical fertilizer (½ CF+biofertilizer) on a treatment of with chemical fertilizer (CF) and biofertilizer on the growth of lettuce were compared by Young *et al.*[96]. Results showed there was a 25% increase of lettuce yield for the treatment of ½ CF+biofertilizer compared to that of the CF treatment, indicating that at least 50% of chemical fertilizer can be saved as multifunctional biofertilizer was used along with chemical fertilizer. The effects of multifunctional biofertilizer (mixture of *Bacillus* sp. *B. subtilis*, *B. erythropolis*, *B. pumilus* and *P. rubiacearum*) on rhizosphere microbial activity and the growth of water celery in a field experiment[96]. Results showed that the dry weight of water celery in the treatment with 50% organic compound fertilizer with multifunctional biofertilizer (MC+½ OCF) was increased by 34% compared to the treatment with 100% Organic Compound Fertilizer (OCF) added. In addition, the beneficial bacterial counts including mineral PSB, cellulolytic bacteria and N_2-fixing bacteria in the rhizosphere of water celery in the MC +½ (OCF) treatments were increased 102-104 CFU/gin (Table 4-5).

Integrated use of chemical, organic and bio fertilizers: Increased attention is now being paid to developing an Integrated Plant Nutrition System (IPNS) that maintains or enhances soil productivity through balanced use of all sources of nutrients, including chemical fertilizers, organic fertilizers and bio fertilizers. The basic concept underlying the IPNS is the adjustment of soil fertility and plant nutrient supply to an optimum level for sustaining desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner[75]. The experiment conducted in a field to evaluate the effects of Chemical Fertilization (CF), organic fertilization (compost-n and compost-p), combined use of chemical and organic fertilizer (compost-p + urea) and integrated use of chemical and organic fertilizer along with biofertilizer [½ (compost-p+urea) +biofertilizer] on the growth of cabbage and maize (residual effect) and soil fertility. The contents of mineral N (NH_4^+ $+NO_3^-$) and Bray-1 P in all treatments, except CK, were higher than those of the CF treatment, showing the benefits of biofertilizer and compost by supplying and enhancing the release of N and P. Excess inputs and excess accumulation of P in soil usually increase their potential to contribute soluble and particulate P to surface waters and result in P-driven eutrophication. The content of Bray-1 P in the test soil was 69 mg kg^{-1}, rated as "high" in terms of P availability. There are many suggestions in the literature that significant rising of Bray-1 P content is not good for a soil with a high level of P availability, from the economic and environmental standpoint. The Bray-1 P content of the soil was approximately twice as high in the Compost-N treatment compared to the CF treatment, showing significant P accumulation in the soil. This indicated that reducing half the amount of compost and urea combined with inoculants of mixed strains of beneficial microorganisms has considerable potential to lessen P accumulation in the soil and saves the input of chemical and organic fertilizers[75].

PESTICIDES

The results from literature on the effects of selected pesticides on soil health are shown in Table 4 (herbicides), Table 5 (insecticides and nematicides) and Table 6 (fungicides). There is clearly a paucity of data (particularly on physical and chemical property of the soil) in international literature on the effects of a large number of pesticides on soil health. Most of this review has focused on soil microorganisms. Pesticides that reach the soil can alter the soil microbial diversity and microbial biomass. Any alteration in the activities of soil microorganisms due to applied pesticides eventually leads to the disturbance in soil ecosystem and loss of soil fertility[120]. Numerous studies have been undertaken which highlight these adverse impacts of pesticides on soil microorganisms and soil respiration[77,121]. In addition to this, exogenous applications of pesticides could also influence the function of beneficial root-colonizing microbes such as bacteria and arbuscular mycorrhiza, fungi and algae in soil by influencing their growth, colonization and metabolic activities[122]. The pesticides that reach the soil can interact with soil microorganisms in several ways:

- It can adversely affect the growth, microbial diversity or microbial biomass of the soil microflora. For example, sulfonylurea herbicides (metsulfuron methyl, chlorsulfuron and thifensulfuron methyl) were reported to reduce the growth of the fluorescent bacteria Pseudomonas strains that were isolated from an agricultural soil[123]. The *Pseudomonas* spp. is known to play an important ecological role in the soil habitat and hence its reduction can adversely affect soil fertility
- Pesticide application may also inhibit or kill certain group of microorganisms and outnumber other groups by releasing them from the competition[124]. For example, increase in bacterial biomass by 76% was reported in response to endosulfan application and that reduced the fungal biomass by 47%[125]

Table 5: Effect of animal manures, biosolids and composts on soil organisms

Compared treatments	Effects	References
Compost of biosolids, wood waste and green waste	Soil basal respiration, microbial C and anaerobically mineral sable N were significantly increased in the amended plots. No effects on rhizobial numbers or microbial biosensors (Rhizotox C and lux-marked *Escherichia coli*)	Speir *et al.*[114] and Canali *et al.*[115]
Composts of distillery waste and livestock manure, poultry manure, mineral fertilizer control	Parameters related to potentially mineral sable C showed significant differences among the treatments. No differences were observed in biodiversity indexes	Wells *et al.*[116]
Composts of woody material with either manure (poultry and horse) or sewage sludge, several mineral fertilizer treatments	Both composted treatments higher in microbial C than mineral fertilizer treatments, but trial was of systems so there were also other differing factors	Zhang *et al.*[117]
9-year study of traditionally composted FYM, 2 types of biodynamically composted manure	FYM increased microbial biomass, dehydrogenase activity, decomposition (cotton strips), but not saccharase activity, microbial basal respiration, or metabolic quotient. Biodynamic manure preparation decreased soil microbial basal respiration and metabolic quotient compared to non-biodynamic manure. After 100 days, decomposition was faster in plots which received biodynamic FYM than in plots which received no or non-biodynamic FYM	Miyittah and Inubushi[118]
Composts of soymilk residues, cow manure, poultry manure and sewage sludge	Soil respiration increased rapidly initially, but patterns differed among the composts. Composted soymilk treatment gave higher CO_2-evolution and lower metabolic quotient than the other composts	Franco *et al.*[119]
Glucose, maize stalks, or maize stalk compost added to soils contaminated with crude oil	The addition of organic substrates (glucose, maize stalks and maize stalk compost) to contaminated soils had no synergistic effect on the decomposition of crude oil but produced a marked increase in microbial biomass, although the increase was smaller than in uncontaminated soils. Compost decreased the stress conditions caused by oil contamination as measured by a reduction in metabolic quotient	Handa *et al.*[120]

Table 6: Impact of herbicides on non-target soil organisms

Active chemicals	Effects	References
Atrazine	Significant activation of soil urease activity (up to 100-fold increase) and suppression of invertase enzyme	Panda and Sahu[134]
Butachlor	Very toxic, suppressing growth, sexual maturation and cocoon production of the earthworm Drawida willsi following single dose at recommended rate	Busse *et al.*[135]
Glyphosate	Glyphosate Bacteria reduced. Fungi and actinomycetes increased. Microbial activity increase by 9-19%. Increased glyphosate degradation with repeated application	Araujo *et al.*[136]
Glyphosate	Short term changes to community structure. Increased microbial activity and no long-term changes to community structure	Delgado *et al.*[137]
Glyphosate, parquet	Activation of urease and invertase soil enzymes, but glyphosate suppressed phosphatase activity (up to 98%)	Panda and Sahu[134]
Glyphosate and 2,4-DB	No effect of single dose to soil on growth or survival of the earthworms *Aporrectodea trapezoides*, *A. caliginosa*, *A. longa* or *A. rosea*	Singh and Ryan[138]
Oxyfluorfen, oxadiazon	Both herbicides stimulated microbial populations and increased availability of phosphorus in rhizosphere soil of rice	Filip and Tesarova[139]
Pendimethalin	Soil nematodes and other invertebrates reduced, plant-rhizobium symbiosis reduced at herbicide rates as low as 0.5-1.0 kg ha^{-1}	Kinney *et al.*[140]
Prosulfuron	Significant reduction in production of N_2O and NO following N-based fertilizer application: Significant reduction in nitrification	Chen[141]

- Applied pesticide may also act as a source of energy to some of the microbial group which may lead to increase in their growth and disturbances in the soil ecosystem. For example, bacterial isolates collected from wastewater irrigated agricultural soil showed the capability to utilize chlorpyrifos as a carbon source for their growth[126]
- Pesticides can alter and/or reduce the functional structure and functional diversity of microorganisms but increase the microbial biomass[127]. In contrast, application of pesticides can also reduce the microbial biomass while increasing the functional diversity of microbial community. For example, methamidophos and urea decreased the microbial biomass and increased the functional diversity of soil as determined by microbial biomass and community level physiological profiles[128]

Herbicides: The herbicides (Table 6) generally had no major effects on soil health, with the exception of butachlor, which was shown to be very toxic to earthworms at agricultural rates. The authors showed, however, that butachlor had little effect on acetylcholinesterase activity. Phenmedipham induced avoidance behavior in earthworms and collembola. These effects are expected to be relatively short lived as phenmedipham is broken down moderately rapidly (25-day half-life) in soil. Other effects of herbicides on soil organisms were mainly isolated changes in enzyme activities. Glyphosate, for example, was shown to suppress the phosphatase activity by up to 98% in a laboratory study; however, urease activity was stimulated by glyphosate as well as atrazine.

Insecticides: Insecticides (Table 7) were generally shown to have a greater direct effect on soil health than herbicides[8]. Organophosphate insecticides (chlorpyrifos, quinalphos, dimethoate, diazinon and malathion) had a range of effects including changes in bacterial and fungal numbers in soil, varied effects on soil enzymes as well as reductions in collembolan density and earthworm reproduction. Carbamate insecticides (carbaryl, carbofuran and methiocarb) had a range of effects on soil organisms, including a significant reduction of acetylcholinesterase activity in earthworms, mixed effects on soil enzymes and inhibition of nitrogenase in *Azospirillum* species.

Persistent compounds including arsenic and lindane caused long-term effects, including reduced microbial activity[129], reduced microbial biomass and significant decreases in soil enzyme activities. Azoxystrobin, have recently been shown to effect on a biocontrol agent used for the control of *Fusarium* wilt[130], illustrating potential incompatibilities of chemical and biological pesticides. The insecticides methyl parathion and especially pentachlorophenol have been shown to interfere with legume-rhizobium chemical signaling. Reduction of these symbiotic chemical signaling results in reduced nitrogen fixation and thus reduced crop yields[131]. Root nodule formation in these plants saves the world economy $10 billion in synthetic nitrogen fertilizer every year[132]. When the natural nutrient cycling in the ecosystem is interfered in any way by pesticides or other sources of pollution, it will lead to decline in soil fertility and soil productivity. Long term experiment on insecticides usage showed that soil physical characteristics such as bulk density were changed in long-term and it was increased compared to control soil[133]. The heavy metals accumulations in soil were highly affected and the concentration of some metals such as cadmium has reached a limit beyond the standard for agricultural purposes. The results also showed that fortunately the concentration of other metals is not beyond the standard[36].

Soil fumigants: Soil fumigants are designed to eliminate harmful soil organisms and any competition for soil resources between soil organisms and the crop[8]. In spite of this, soil fumigants have not always been found to have significant effects on soil health (Table 8). Soil fumigants had long-term effects on various soil functions[141]. The long-term effects of fumigants were shown to be reduced by the addition of composted steer manure, with normal biological activity being observed 8-12 weeks following high application rates of the fumigant[142]. In the absence of the organic amendment, little recuperation (resilience) of soil function was detected even after 12 weeks.

Pesticide formulation: The formulation is the chemical and physical form in which the pesticide is sold for use. The active ingredient (a.i.) is the chemical in the formulation that has the specific effect on the target organism. In addition to the active ingredient, the formulation of a pesticide may also influence soil health. This is, however, an aspect that is rarely investigated. Little is known about the environmental fate of adjuvants after application on agricultural land. Adjuvants constitute a broad range of substances, of which solvents and surfactants are the major types[8]. Non-ionic surfactants such as Alcohol Ethoxylates (AEOs) and alkylamine ethoxylates (ANEOs) are typical examples of pesticide adjuvants[8]. The surfactant in the Roundup formulation polyoxyethylene amine (POEA) was significantly more toxic to Microtox bacterium than glyphosate acid or the IPA salt of glyphosate. Even Roundup was found to be less toxic[143]. The toxicity of glyphosate acid was concluded to be a result of its inherent

Table 7: Impact of insecticides and nematicides on soil health

Active chemicals	Effects	References
Diazinon	Significant increase in dehydrogenase activity and decrease in alkaline phosphomonoesterase for up to 30 days following treatment	Loureiro *et al.*[146]
Dimethoate	Short-term reduction in microarthropod numbers (Collembola), but recovery in numbers after time. Community structure remained differentiated. Slight reduction in soil microbial biomass (measured by ATP)	Loureiro *et al.*[146]
Imidacloprid	Significant increases in dehydrogenase and phosphomonoesterase activities when used as seed dressing, effect lasting p to 60 days	Loureiro *et al.*[146]
Lindane, dimethoate	Collembola avoid soil with lindane (10-20 mg kg^{-1}) and dimethoate (5-20 mg kg^{-1}), while earthworms avoided dimethoate at 2.5 mg kg^{-1}	Amorim *et al.*[147]
Arsenic	Arsenic co-contamination was shown to inhibit the breakdown of DDT and a concomitant reduction in microbial activity was found	Van Zwieten *et al.*[129]
Benomyl	Enchytraeid worms avoids benomyl in standard avoidance test procedures	Saggar *et al.*[148]
Carbaryl	Activation of urease and invertase soil enzymes, but suppression of phosphatase enzyme	Panda and Sahu *et al.*[149]
Carbofuran, malathion	Significant reduction in acetylcholinesterase activity in earthworms (D. willsi) for up to 45 days (carbofuran) and 75 days (malathion)	Menon *et al.*[150]
Chlorpyrifos, quinalphos	Reduced oxidative capability of the soils as measured by reduced dehydrogenase activity and inhibited iron reduction	Dick [151]
Malathion	Short-term impacts of standard application rates of malathion on earthworm reproduction lasting for 105 days	Menon *et al.*[150]

Table 8: Impact of fungicides on soil health

Active chemicals	Effects	References
Benomyl	Suppression of respiration, stimulation of dehydrogenase activity, effects were less noticeable with organic matter addition	Merrington *et al.*[152]
	Significant long-term effects on mycorrhizal colonization (80% reduction), reduction in fungal to bacterial ratios and nematode numbers	Bunemann *et al.*[8]
	Earthworms avoid benomyl at 1 mg kg^{-1} soil	Amorim *et al.*[147]
Captan	Suppression of respiration and dehydrogenase activity; increases in ammonium N	Merrington *et al.*[152]
	Fungal length and density, and microbial C and N significantly reduced	Bunemann *et al.*[8]
Copper	Earthworm populations avoid soils with concentrations as low as 34 mg kg^{-1}. Lack of breakdown of organic carbon suggest potential long-term implications	Van Zwieten *et al.*[129]
	Increased metabolic quotient indicating microbial stress at 280-340 mg Cu kg^{-1}. Significantly reduced microbial biomass and ratio of microbial biomass to OC	Gaw *et al.*[153]
	Reduced performance of soil functions resulting in reduction of DDT degradation	Monkiedje *et al.*[154]
Chlorothalonil	Suppression of respiration, stimulation of dehydrogenase activity	Merrington *et al.*[152]
Mancozeb, chlorothalonil	Significant reduction in production of N2O and NO following N-based fertilizer application: Significant reduction in nitrification	Kinney *et al.*[140]
Chlorothalonil, azoxystrobin	Both fungicides toxic to the biocontrol agent Fusarium oxysporum strain CS-20 which has been used to reduce incidence of *Fusarium* wilt	Fravel *et al.*[130]
Metalaxyl, mefenoxam	Reduced enzyme activity, in particular dehydrogenase activity, for up to 90 days. Increased bacterial numbers with increasing doses, but toxic to N fixers at 1 mg kg^{-1} (mefenoxam) and 2 mg kg^{-1} (metalaxyl)	Monkiedje *et al.*[154]

acidity. In another study, demonstrated that the presence of ethylamine in a glyphosate formulation had major effects on *Bradyrhizobium*[144,145], whereas the active ingredient (glyphosate) had little if any effect. In formulation, effects included reduced nodulation in a soybean crop[8].

CONCLUSION

Organic amendments such as manure, compost, biosolids and humic substances provide a direct source of C for soil organisms as well as an indirect C source via increased plant growth and plant residue returns. Herbicides showed less significant effects on soil health, whereas negative effects of insecticides and fungicides were more common. The sound management of crop production inputs must attempt to ensure both an enhanced and safeguarded environment.

REFERENCES

1. FAO., 2014. Ethiopia: El Nino-Southern Oscillation (ENSO) and the main Kiremt rainy season an assessment using FAO's Agricultural Stress Index System (ASIS). http://www.fao.org/es/GIEWS/english/shortnews/enso27062014.htm.
2. FAO., 2011. FAOSTAT. http://www.fao.org/faostat/en/#home.
3. Saravi, S.S.S. and M. Shokrzadeh, 2011. Role of Pesticides in Human Life in the Modern Age: A Review. In: Pesticides in the Modern World-Risks and Benefits, Stoytcheva, M. (Ed.). In Tech, USA., pp: 4-11.
4. IFA., 2015. IFADATA. International Fertilizer Association. http://ifadata.fertilizer.org/ucSearch.aspx.
5. Bale, J.S., J.C. van Lenteren and F. Bigler, 2008. Biological control and sustainable food production. Philos. Trans. R. Soc. London B: Biol. Sci., 363: 761-776.
6. Schreck, E., F. Geret, L. Gontier and M. Treilhou, 2008. Neurotoxic effect and metabolic responses induced by a mixture of six pesticides on the earthworm *Aporrectodea caliginosa nocturna*. Chemosphere, 71: 1832-1839.
7. Zhang, W., F. Jiang and J. Ou, 2011. Global pesticide consumption and pollution: With China as a focus. Proc. Int. Acad. Ecol. Environ. Sci., 1: 125-144.
8. Bunemann, E.K., G.D. Schwenke and L. Van Zwieten, 2006. Impact of agricultural inputs on soil organisms. A review. Aust. J. Soil Res., 44: 379-406.
9. Haynes, R.J. and R. Naidu, 1988. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. Nutr. Cycling Agroecosyst., 51: 123-127.
10. FAO., 2016. World fertilizer trends and outlook to 2019. Food and Agriculture Organization of the United Nations, Rome.
11. Malik, S.S., R.C. Chauhan, J.S. Laura, T. Kapoor, R. Abhilashi and N. Sharma, 2014. Influence of organic and synthetic fertilizers on soil physical properties. Int. J. Curr. Microbiol. Applied Sci., 3: 802-810.
12. Willer, H., M. Yussefi-Menzler and N. Sorensen, 2008. The World of Organic Agriculture: Statistics and Emerging Trends 2008. Earthscan Publications, USA., ISBN: 9781844075928, pp: 23-46.
13. Mugendi, D.N., P.K. Nair, J.N. Mugwe, M.K. O'neill and P. Woomer, 1999. Alley cropping of maize with calliandra and leucaena in the subhumid highlands of Kenya: Part 2. Soil-fertility changes and maize yield. Agroforest. Syst., 46: 39-50.
14. Adeoye, P.A., S.K. Abubakar and A.R. Adeolu, 2013. Effect of agrochemicals on groundwater quality: A review. Sci. Agric., 1: 1-7.
15. Pan-Germany, 2012. Pesticide and health hazards. Facts and Figures, pp: 1-16.
16. Carriger, J.F., G.M. Rand, P.R. Gardinali, W.B. Perry, M.S. Tompkins and A.M. Fernandez, 2006. Pesticides of potential ecological concern in sediment from South Florida canals: An ecological risk prioritization for aquatic arthropods. Soil Sediment Contam., 15: 21-45.
17. Aktar, M.W., D. Sengupta and A. Chowdhury, 2009. Impact of pesticides use in agriculture: Their benefits and hazards. Interdisciplin. Toxicol., 2: 1-12.
18. WHO., 2008. Children's health and the environment. WHO Training Package for the Health Sector, World Health Organization (WHO), July 2008. http://www.who.int/ceh/capacity/Lead.pdf.
19. Ibekwe, A.M., S.K. Papiernik, J. Gan, S.R. Yates, C.H. Yang and D.E. Crowley, 2001. Impact of fumigants on soil microbial communities. Applied Environ. Microbiol., 67: 3245-3257.
20. Kibblewhite, M.G., K. Ritz and M.J. Swift, 2008. Soil health in agricultural systems. Philos. Trans. R. Soc. B: Biol. Sci., 363: 685-701.
21. Heffer, P. and M. Prud'homme, 2015. Fertilizer outlook 2015-2019. Proceedings of the 83rd IFA Annual Conference, May 25-27, 2015, Istanbul, Turkey, pp: 1-6.
22. Sanginga, N. and P.L Woomer, 2009. Integrated Soil Fertility Management in Africa: Principles, Practices and Development Process. CIAT, Nairobi, ISBN: 978929059261, Pages: 263.
23. Vitousek, P.M., R. Naylor, T. Crews, M.B. David and L.E. Drinkwater *et al*., 1996. The Water Balance of Mixed Tree-Crop Systems. In: Tree-Crop Interaction, a Physiological Approach, Ong, C.K. and P. Huxley (Eds.). AB International, Wallingford, UK., pp: 189-234.
24. Kalia, A. and S.K. Gosal, 2011. Effect of pesticide application on soil microorganisms. Arch. Agron. Soil Sci., 57: 569-596.
25. Amera, T. and A. Abate, 2008. An assessment of the pesticide use, practice and hazards in the Ethiopian rift valley. Africa Stockpiles Program, February 2008, pp: 1-145.

26. EFEPA., 2004. Environmental Impact Assessment Guideline on Pesticides. Environmental Protection Authority, Addis Ababa, Ethiopia, Pages: 38.
27. Cebula, P., 2013. Long-term effects of organic and mineral fertilizer application on physical soil properties and maize yield in western Kenya. Master's Thesis, Saint Louis University, Swedish, Missouri. Master's Thesis, Saint Louis University, Swedish, Missouri.
28. IFDC., 2012. Ethiopia fertilizer assessment. The African Fertilizer and Agribusiness Partnership, Muscle Shoals, Alabama, USA., pp: 1-35. https://ifdcorg.files.wordpress.com/2015/04/ethiopia-fertilizer-assessment.pdf.
29. Mahmoud, E., N.A. El-Kader, P. Robin, N. Akkal-Corfini and L.A. El-Rahman, 2009. Effects of different organic and inorganic fertilizers on cucumber yield and some soil properties. World J. Agric. Sci., 5: 408-414.
30. Ipinmoroti, R.R., G.O. Adeoye and E.A. Makinde, 2008. Effects of urea-enriched organic manures on soil fertility, tea seedling growth and pruned yield nutrient uptake in Ibadan, Nigeria. Bulgarian J. Agric. Sci., 14: 592-597.
31. Diallo-Diagne, N.H., K. Assigbetse, S. Sall, D. Masse, M. Bonzi, I. Ndoye and J.L. Chotte, 2016. Response of soil microbial properties to long-term application of organic and inorganic amendments in a tropical soil (Saria, Burkina Faso). Open J. Soil Sci., 6: 21-33.
32. Tien, C.J. and C.S. Chen, 2012. Assessing the toxicity of organophosphorus pesticides to indigenous algae with implication for their ecotoxicological impact to aquatic ecosystems. J. Environ. Sci. Health, Part B, 47: 901-912.
33. Venkateswarlu, K., 1993. Pesticide interaction with cyanobacteria in soil and pure culture. Soil Biochem., 8: 137-139.
34. Ayoola, O.T., 2006. Effects of fertilizer treatments on soil chemical properties and crop yields in a cassava-based cropping system. J. Applied Sci. Res., 2: 1112-1116.
35. Avrahami, S., W. Liesack and R. Conrad, 2003. Effects of temperature and fertilizer on activity and community structure of soil ammonia oxidizers. Environ. Microbiol., 5: 691-705.
36. Yargholi, B. and S. Azarneshan, 2014. Long-term effects of pesticides and chemical fertilizers usage on some soil properties and accumulation of heavy metals in the soil (case study of Moghan plain's (Iran) irrigation and drainage network). Int. J. Agric. Crop Sci., 7: 518-523.
37. Arinze, A.E. and A.G. Yubedee, 2000. Effect of fungicides on fusarium grain rot and enzyme production in maize (*Zea mays* L.). Global J. Pure Applied Sci., 6: 629-634.
38. Marschner, P., D.E. Crowley and C.H. Yang, 2004. Development of specific rhizosphere bacterial communities in relation to plant species, nutrition and soil type. Plant Soil, 261: 199-208.
39. Rubio, R., F. Borie, C. Schalchli, C. Castillo and R. Azcon, 2003. Occurrence and effect of arbuscular mycorrhizal propagules in wheat as affected by the source and amount of phosphorus fertilizer and fungal inoculation. Applied Soil Ecol., 23: 245-255.
40. Ryan, M.H., D.R. Small and J.E. Ash, 2000. Phosphorus controls the level of colonisation by arbuscular mycorrhizal fungi in conventional and biodynamic irrigated dairy pastures. Anim. Prod. Sci., 40: 663-670.
41. Sarathchandra, S.U., A. Ghani, G.W. Yeates, G. Burch and N.R. Cox, 2001. Effect of nitrogen and phosphate fertilisers on microbial and nematode diversity in pasture soils. Soil Biol. Biochem., 33: 953-964.
42. Graham, M.H. and R.J. Haynes, 2005. Organic matter accumulation and fertilizer-induced acidification interact to affect soil microbial and enzyme activity on a long-term sugarcane management experiment. Biol. Fertil. Soils, 41: 249-256.
43. Parfitt, R.L., G.W. Yeates, D.J. Ross, A.D. Mackay and P.J. Budding, 2005. Relationships between soil biota, nitrogen and phosphorus availability and pasture growth under organic and conventional management. Applied Soil Ecol., 28: 1-13.
44. Moore, J.M., S. Klose and M.A. Tabatabai, 2000. Soil microbial biomass carbon and nitrogen as affected by cropping systems. Biol. Fertil. Soils, 31: 200-210.
45. Pernes-Debuyser, A. and D. Tessier, 2004. Soil physical properties affected by long term fertilization. Eur. J. Soil Sci., 55: 505-512.
46. Ribera, D., J.F. Narbonne, C. Arnaud and M. Saint-Denis, 2001. Biochemical responses of the earthworm *Eisenia fetida andrei* exposed to contaminated artificial soil, effects of carbaryl. Soil Biol. Biochem., 33: 1123-1130.
47. Rosell, G., C. Quero, J. Coll and A. Guerrero, 2008. Biorational insecticides in pest management. J. Pestic. Sci., 33: 103-121.
48. Chu, H.Y., J.G. Zhu, Z.B. Xie, H.Y. Zhang, Z.H. Cao and Z.G. Li, 2003. Effects of lanthanum on dehydrogenase activity and carbon dioxide evolution in a Haplic Acrisol. Aust. J. Soil Res., 41: 731-739.
49. Ge, Y., J.B. Zhang, L.M. Zhang, M. Yang and J.Z. He, 2008. Long-term fertilization regimes and diversity of an agricultural affect bacterial community structure soil in northern China; Long-term fertilization regimes and diversity of an agricultural affect bacterial community structure soil in Northern China. J. Soils Sediments, 8: 43-50.
50. Casiday, R. and R. Frey, 1998. Natural acidity of rainwater. Washington University, St. Louis, Missouri.
51. Heenan, D.P., W.J. McGhie and M.K. Conyers, 1998. Soil pH change over time in relation to rotation, N fertiliser, stubble management and tillage. Australian Society of Agronomy. http://www.regional.org.au/au/asa/1998/8/263heenan.htm.

52. Wheeler, P.A. and R.B. Ward, 1998. The Non-Toxic Farming Handbook. Acres U.S.A., Metairie, LA., ISBN-13: 978-0911311563, Pages: 238.
53. Anderson, A.B., 2004. The Anatomy of Life and Energy in Agriculture. Acres U.S.A., Metairie, LA., Pages: 114.
54. Martin, R., 2000. Radioactive polonium-210 found in tobacco! American Computer Scientists Association Inc. http://www.acsa 2000.net/HealthAlert/lungcancer.html
55. Pevear, D.R., 1999. Illite and hydrocarbon exploration. Proc. Natl. Acad. Sci. USA., 96: 3440-3446.
56. Onwudiwe, N., O.U. Benedict, P.E. Ogbonna and E.E. Ejiofor, 2014. Municipal solid waste and NPK fertilizer effects on soil physical properties and maize performance in Nsukka, Southeast Nigeria. Afr. J. Biotechnol., 13: 68-75.
57. Adediran, J.A., N. de Baets, P.N.S. Mnkeni, L. Kiekens, N.Y.O. Muyima and A. Thys, 2003. Organic waste materials for soil fertility improvement in the border region of the Eastern Cape, South Africa. Biol. Agric. Hortic.: An Int. J. Sustainable Prod. Syst., 20: 283-300.
58. Garcia, C., T. Hernandez, F. Costa and A. Polot, 1991. Humic substances in composted sewage sludge. Waste Manage. Res., 9: 189-194.
59. Zaller, J.G. and U. Kopke, 2004. Effects of traditional and biodynamic farmyard manure amendment on yields, soil chemical, biochemical and biological properties in a long-term field experiment. Biol. Fertil. Soils, 40: 222-229.
60. Ryan, M. and J. Ash, 1999. Effects of phosphorus and nitrogen on growth of pasture plants and VAM fungi in SE Australian soils with contrasting fertiliser histories (conventional and biodynamic). Agric. Ecosyst. Environ., 73: 51-62.
61. Usman, A.R.A., Y. Kuzyakov and K. Stahr, 2004. Dynamics of organic C mineralization and the mobile fraction of heavy metals in a calcareous soil incubated with organic wastes. Water Air Soil Pollut., 158: 401-418.
62. Hao, X. and C. Chang, 2003. Does long-term heavy cattle manure application increase salinity of a clay loam soil in semi-arid southern Alberta? Agric. Ecosyst. Environ., 94: 89-103.
63. Hunt, J., 2016. Fertilizer facts. Montana State University Extension Service, Montana State University, Bozeman, MT., USA.
64. Lovell, R.D. and D.J. Hatch, 1997. Stimulation of microbial activity following spring applications of nitrogen. Biol. Fertil. Soils, 26: 28-30.
65. Ladha, J.K., C.K. Reddy, A.T. Padre and C. van Kessel, 2011. Role of nitrogen fertilization in sustaining organic matter in cultivated soils. J. Environ. Qual., 40: 1756-1766.
66. Gupta, V.V.S.R. and J.J. Germida, 1988. Populations of predatory protozoa in field soils after 5 years of elemental S fertilizer application. Soil Biol. Biochem., 20: 787-791.
67. Martikainen, E., J. Haimi and J. Ahtiainen, 1998. Effects of dimethoate and benomyl on soil organisms and soil processes-a microcosm study. Applied Soil Ecol., 9: 381-387.
68. Chan, K.Y., 2001. Soil particulate organic carbon under different land use and management. Soil Use Manage., 17: 217-221.
69. Ryan, M., 1999. Is an enhanced soil biological community, relative to conventional neighbours, a consistent feature of alternative (organic and biodynamic) agricultural systems? Biol. Agric. Hortic., 17: 131-144.
70. Qualls, R.G., 2004. Biodegradability of humic substances and other fractions of decomposing leaf litter. Soil Sci. Soc. Am. J., 68: 1705-1712.
71. Valdrighi, M.M., A. Pera, S. Scatena, M. Agnolucci and G. Vallini, 1995. Effects of humic acids extracted from mined lignite or composted vegetable residues on plant growth and soil microbial populations. Compost Sci. Utiliz., 3: 30-38.
72. Atiyeh, R.M., S. Lee, C.A. Edwards, N.Q. Arancon and J.D. Metzger, 2002. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Bioresour. Technol., 84: 7-14.
73. Chen, Y., M. De-Nobili and T. Aviad, 2004. Stimulatory Effect of Humic Substances on Plant Growth. In: Soil Organic Matter in Sustainable Agriculture, Magdoft, F. and R. Ray (Eds.). CRC Press, Washington, DC., ISBN: 0849312949, pp: 103-130.
74. Albiach, R., R. Canet, F. Pomares and F. Ingelmo, 2000. Microbial biomass content and enzymatic activities after the application of organic amendments to a horticultural soil. Bioresour. Technol., 75: 43-48.
75. Laharia, G.S., D.U. Patil and P.R. Damre, 2013. Effect of organic sources on soil fertility, nutrient uptake and yield of soybean. Crop Res., 45: 155-159.
76. Chand, S., M. Anwar and D.D. Patra, 2006. Influence of long term application of organic and inorganic fertilizer to build up soil fertility and nutrient uptake in mint mustard cropping sequence. Commun. Soil Sci. Plant, 37: 63-76.
77. Dutta, S., R. Pal, A. Chakeraborty and K. Chakrabarti, 2003. Influence of integrated plant nutrient phosphorus and sugarcane and sugar yields. Field Crop Res., 77: 43-49.
78. Bokhtiar, S.M. and K. Sakurai, 2005. Effects of organic manure and chemical fertilizer on soil fertility and productivity of plant and ratoon crops of sugarcane. Arch. Agron. Soil Sci., 51: 325-334.
79. Kaur, K., K.K. Kapoor and A.P. Gupta, 2005. Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. J. Plant Nutr. Soil Sci., 168: 117-122.
80. Tadesse, T., N. Dechassa, W. Bayu and S. Gebeyehu, 2013. Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain-fed lowland rice ecosystem. Am. J. Plant Sci., 4: 309-316.

81. Law-Ogbomo, K.E., 2013. Nutrient uptake by *Abelmoschus esculentus* and its effects on changes in soil chemical properties as influenced by residual application of fertilizer. J. Soil Sci. Environ. Manage., 4: 132-138.
82. Berard, A., F. Rimet, Y. Capowiez and C. Leboulanger, 2004. Procedures for determining the pesticide sensitivity of indigenous soil algae: A possible bioindicator of soil contamination?. Arch. Environ. Contam. Toxicol., 46: 24-31.
83. Peacock, A.D., M.D. Mullen, D.B. Ringelberg, D.D. Tyler, D.B. Hedrick, P.M. Gale and D.C. White, 2001. Soil microbial community responses to dairy manure or ammonium nitrate applications. Soil Biol. Biochem., 33: 1011-1019.
84. Leita, L., M.D. Nobili and C. Mondini, 1999. Influence of inorganic and organic fertilization on soil microbial biomass, metabolic quotient and heavy metal bioavailability. Biol. Fertil. Soils, 28: 371-376.
85. Witter, E., A.M. Martensson and F.V. Garcia, 1993. Size of the soil microbial biomass in a long-term field experiment as affected by different nitrogen fertilizers and organic. Soil Bol. Biochem., 25: 659-669.
86. Parham, J.A., S.P. Deng, H.N. Da, H.Y. Sun and W.R. Raun, 2003. Long-term cattle manure application in soil. II. Effect on soil microbial populations and community structure. Biol. Fertil. Soils, 38: 209-215.
87. Colvan, S., J. Syers and A. O'Donnell, 2001. Effect of long-term fertiliser use on acid and alkaline phosphomonoesterase and phosphodiesterase activities in managed grassland. Biol. Fertil. Soils, 34: 258-263.
88. Houot, S. and R. Chaussod, 1995. Impact of agricultural practices on the size and activity of the microbial biomass in a long-term field experiment. Biol. Fertil. Soils, 19: 309-316.
89. Kennedy, I.R., A.T.M.A. Choudhury and M.L. Kecskes, 2004. Non-symbiotic bacterial diazotrophs in crop-farming systems: Can their potential for plant growth promotion be better exploited? Soil Biol. Biochem., 36: 1229-1244.
90. McInnes, A. and K. Haq, 2003. Contributions of Rhizobia to Soil Nitrogen Fertility. In: Soil Biological Fertility: A Key to Sustainable Land Use in Agriculture, Abbott, L.K. and D.V. Murphy (Eds.). Kluwer Academic Publishers, The Netherlands, ISBN-13: 9781402017568, pp: 99-128.
91. Muharram, T.M., M.A. El-Muhandes and M.A. Badawi, 1999. Effect of inoculation and organic manure application on symbiotic N_2-fixation, microbial biomass and nutrients availability in sandy soils cultivated with soybean and peanut. Ann. Agric. Sci., 44: 27-40.
92. Saini, V.K., S.C. Bhandari and J.C. Tarafdar, 2004. Comparison of crop yield, soil microbial C, N and P, N-fixation, nodulation and mycorrhizal infection in inoculated and non-inoculated sorghum and chickpea crops. Field Crop Res., 89: 39-47.
93. Conn, V.M. and C.M.M. Franco, 2004. Effect of microbial inoculants on the indigenous actinobacterial endophytes population in the roots of wheat as determined by terminal restriction fragment length polymorphism. Applied Environ. Microbiol., 70: 6407-6413.
94. Cao, Z., W. Li, Q. Sun, Y. Ma and Q. Xu, 2001. Effect of microbial inoculation on soil microorganisms and earthworm communities: A preliminary study. J. Crop Prod., 3: 275-283.
95. Slattery, J.F., D.R. Coventry and W.J. Slattery, 2001. Rhizobial ecology as affected by the soil environment. Aust. J. Exp. Agric., 41: 289-298.
96. Young, C.C., W.A. Lai, F.T. Shen, M.H. Hung, W.S. Hung and A.B. Arun, 2003. Exploring the microbial potentially to augment soil fertility in Taiwan. Proceedings of the 6th ESAFS International Conference: Soil Management Technology on Low Productivity and Degraded Soils, November 24-29, 2003, Taipei, Taiwan, pp: 25-27.
97. Son, T.T. N., V. van Thu, L.H. Man, H. Kobayashi and R. Yamada, 2004. Effect of long-term application of organic and biofertilizer on soil fertility under rice-soybean-rice cropping system. Omonrice, 12: 45-51.
98. Ullah, M.S., M.S. Islam, M.A. Islam and T. Haque, 2008. Effects of organic manures and chemical fertilizers on the yield of brinjal and soil properties. J. Bangladesh Agric. Univ., 6: 271-276.
99. Adekayode, F.O. and M.O. Ogunkoya, 2011. Comparative effects of organic compost and NPK fertilizer on soil fertility, yield and quality of amaranth in Southwest Nigeria. Int. J. Biol. Chem. Sci., 5: 490-499.
100. Gomez, E., L. Ferreras and S. Toresani, 2006. Soil bacterial functional diversity as influenced by organic amendment application. Bioresour. Technol., 97: 1484-1489.
101. Mugwe, J., D. Mugendi, M. Mucheru Muna, D. Odee and F. Mairura, 2009. Effect of selected organic materials and inorganic fertilizer on the soil fertility of a humic nitisol in the central highlands of Kenya. Soil Use Manage., 25: 434-440.
102. Sharpley, A.N., S.J. Smith and W.R. Bain, 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. Soil Sci. Soc. Am. J., 57: 1131-1137.
103. Poll, C., A. Thiede, N. Wermbter, A. Sessitsch and E. Kandeler, 2003. Micro scale distribution of microorganisms and microbial enzyme activities in a soil with long term organic amendment. Eur. J. Soil Sci., 54: 715-724.
104. Dinesh, R., R.P. Dubey and G.S. Prasad, 2000. Organic manuring in rice-based cropping system: Effects on soil. Curr. Sci., 79: 1716-1720.
105. Thomsen, I.K., P. Schjonning and B.T. Christensen, 2003. Mineralisation of ^{15}N-labelled sheep manure in soils of different texture and water contents. Biol. Fertil. Soils, 37: 295-301.
106. Villar, M.C., V. Petrikova, M. Diaz-Ravina and T. Carballas, 2004. Changes in soil microbial biomass and aggregate stability following burning and soil rehabilitation. Geoderma, 122: 73-82.

107. Baker, G., D. Michalk, W. Whitby and S. O'Grady, 2002. Influence of sewage waste on the abundance of earthworms in pastures in South-Eastern Australia. Eur. J. Soil Biol., 38: 233-237.

108. Munn, K.J., J. Evans and P.M. Chalk, 2001. Nitrogen fixation characteristics of *Rhizobium surviving* in soils equilibrated with sewage biosolids. Crop Pasture Sci., 52: 963-972.

109. Abaye, D.A., K. Lawlor, P.R. Hirsch and P.C. Brookes, 2005. Changes in the microbial community of an arable soil caused by long term metal contamination. Eur. J. Soil Sci., 56: 93-102.

110. Chaudhuri, D., S. Tripathy, H. Veeresh, M.A. Powell and B.R. Hart, 2003. Relationship of chemical fractions of heavy metals with microbial and enzyme activities in sludge and ash-amended acid lateritic soil from India. Environ. Geol., 45: 115-123.

111. Yang, X.M., C.F. Drury, W.D. Reynolds, D.J. McKenney, C.S. Tan, T.Q. Zhang and R.J. Fleming, 2002. Influence of composts and liquid pig manure on CO_2 and N_2O emissions from a clay loam soil. Can. J. Soil Sci., 82: 395-401.

112. Alvarez, R., M. Alconada and R. Lavado, 1999. Sewage sludge effects on carbon dioxide carbon production from a desurfaced soil. Commun. Soil Sci. Plant Anal., 30: 1861-1866.

113. Barbarick, K.A., K.G. Doxtader, E.F. Redente and R.B. Brobst, 2004. Biosolids effects on microbial activity in shrubland and grassland soils. Soil Sci., 169: 176-187.

114. Speir, T.W., A.P. Van Schaik, A.R. Lloyd-Jones and H.A. Kettles, 2003. Temporal response of soil biochemical properties in a pastoral soil after cultivation following high application rates of undigested sewage sludge. Biol. Fertil. Soils, 38: 377-385.

115. Canali, S., A. Trinchera, F. Intrigliolo, L. Pompili, L. Nisini, S. Mocali and B. Torrisi, 2004. Effect of long term addition of composts and poultry manure on soil quality of citrus orchards in Southern Italy. Biol. Fertil. Soils, 40: 206-210.

116. Wells, A.T., K.Y. Chan and P.S. Cornish, 2000. Comparison of conventional and alternative vegetable farming systems on the properties of a yellow earth in New South Wales. Agric. Ecosyst. Environ., 80: 47-60.

117. Zhang, H., M. Xu and F. Zhang, 2009. Long-term effects of manure application on grain yield under different cropping systems and ecological conditions in China. J. Agric. Sci., 147: 31-42.

118. Miyittah, M. and K. Inubushi, 2003. Decomposition and CO_2-C evolution of Okara, sewage sludge, cow and poultry manure composts in soils. Soil Sci. Plant Nutr., 49: 61-68.

119. Franco, I., M. Contin, G. Bragato and M. De Nobili, 2004. Microbiological resilience of soils contaminated with crude oil. Geoderma, 121: 17-30.

120. Handa, S.K., N.P. Agnihotri and G. Kulshrestha, 1999. Effect of Pesticide on Soil Fertility. In: Pesticide Residues: Significance, Management and Analysis, Handa, S.K., N.P. Agnihotri and G. Kulshrestha (Eds.). Research Periodicals & Book Publishing House, India, ISBN-13: 9780965603836, pp: 184-198.

121. Sofo, A., A. Scopa, S. Dumontet, A. Mazzatura and V. Pasquale, 2012. Toxic effects of four sulphonylureas herbicides on soil microbial biomass. J. Environ. Sci. Health Part B: Pestic. Food Contam. Agric. Wastes, 47: 653-659.

122. Menendez, A., A. Martinez, V. Chiocchio, N. Venedikian, J.A. Ocampo and A. Godeas, 2010. Influence of the insecticide dimethoate on arbuscular mycorrhizal colonization and growth in soybean plants. Int. Microbiol., 2: 43-45.

123. Boldt, T.S. and C.S. Jacobsen, 1998. Different toxic effects of the sulfonylurea herbicides metsulfuron methyl, chlorsulfuron and thifensulfuron methyl on fluorescent pseudomonas isolated from an agricultural soil. FEMS Microbiol. Lett., 161: 29-35.

124. Hussain, S., T. Siddique, M. Saleem, M. Arshad and A. Khalid, 2009. Impact of pesticides on soil microbial diversity, enzymes and biochemical reactions. Adv. Agron., 102: 159-200.

125. Xie, H., F. Gao, W. Tan and S.G. Wang, 2011. A short-term study on the interaction of bacteria, fungi and endosulfan in soil microcosm. Sci. Total Environ., 412: 375-379.

126. Bhagobaty, R.K. and A. Malik, 2008. Utilization of chlorpyrifos as a sole source of carbon by bacteria isolated from wastewater irrigated agricultural soils in an industrial area of Western Uttar Pradesh, India. Res. J. Microbiol., 3: 293-307.

127. Lupwayi, N.Z., M.A. Monreal, G.W. Clayton, C.A. Grant, A.M. Johnston and W.A. Rice, 2001. Soil microbial biomass and diversity respond to tillage and sulphur fertilizers. Can. J. Soil Sci., 81: 577-589.

128. Wang, M.C., M. Gong, H.B. Zang, X.M. Hua, J. Yao, Y.J. Pang and Y.H. Yang, 2006. Effect of methamidophos and urea application on microbial communities in soils as determined by microbial biomass and community level physiological profiles. J. Environ. Sci. Health Part B: Pesticides Food Contam. Agric. Wastes, 41: 399-413.

129. Van Zwieten, L., M.R. Ayres and S.G. Morris, 2003. Influence of arsenic co-contamination on DDT breakdown and microbial activity. Environ. Pollut., 124: 331-339.

130. Fravel, D.R., K.L. Deahl and J.R. Stommel, 2005. Compatibility of the biocontrol fungus *Fusarium oxysporum* strain CS-20 with selected fungicides. Biol. Control, 34: 165-169.

131. Rockets, R., 2007. Down On the Farm, Yields, Nutrients and Soil Quality. In: Pesticides Reduce Symbiotic Efficiency of Nitrogen-Fixing Rhizobia and Host Plants, Proceedings of the National Academy of Sciences, USA., Fox, J.E., J. Gulledge, E. Engelhaupt, M.E. Burow and J.A. McLachlan (Eds.). National Academy of Sciences, USA.

132. Fox, J.E., J. Gulledge, E. Engelhaupt, M.E. Burow and J.A. McLachlan, 2007. Pesticides reduce symbiotic efficiency of nitrogen-fixing rhizobia and host plants. Proc. Nat. Acad. Sci. USA., 104: 10282-10287.
133. Sannino, F. and L. Gianfreda, 2001. Pesticide influence on soil enzymatic activities. Chemosphere, 45: 417-425.
134. Panda, S. and S.K. Sahu, 1999. Effects of malathion on the growth and reproduction of *Drawida willsi* (Oligochaeta) under laboratory conditions. Soil Biol. Biochem., 31: 363-366.
135. Busse, M.D., A.W. Ratcliff, C.J. Shestak and R.F. Powers, 2001. Glyphosate toxicity and the effects of long-term vegetation control on soil microbial communities. Soil Biol. Biochem., 33: 1777-1789.
136. Araujo, A.S.F., R.T.R. Monteiro and R.B. Abarkeli, 2003. Effect of glyphosate on the microbial activity of two Brazilian soils. Chemosphere, 52: 799-804.
137. Delgado, A., A. Madrid, S. Kassem, L. Andreu and M.C. del Campillo, 2002. Phosphorus fertilizer recovery from calcareous soils amended with humic and fulvic acids. Plant Soil, 245: 277-286.
138. Singh, B. and J. Ryan, 2015. Managing Fertilizers to Enhance Soil Health. International Fertilizer Industry Association (IFA), Paris, France.
139. Filip, Z. and M. Tesarova, 2004. Microbial degradation and transformation of humic acids from permanent meadow and forest soils. Int. Biodeterior. Biodegrad., 54: 225-231.
140. Kinney, C.A., K.W. Mandernack and A.R. Mosier, 2005. Laboratory investigations into the effects of the pesticides mancozeb, chlorothalonil and prosulfuron on nitrous oxide and nitric oxide production in fertilized soil. Soil Biol. Biochem., 37: 837-850.
141. Chen, J.H., 2006. The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. Proceedings of the International Workshop on Management of the Soil-Rhizosphere System for Efficient Crop Production and Fertilizer Use, October 16-20, 2006, Bangkok, Thailand, pp: 1-11.
142. Dungan, R.S., A.M. Ibekwe and S.R. Yates, 2003. Effect of propargyl bromide and 1, 3-dichloropropene on microbial communities in an organically amended soil. FEMS Microbiol. Ecol., 43: 75-87.
143. Tisdall, J.M. and J.M. Oades, 1982. Organic matter and Water-stable aggregates in soils. Eur. J. Soil Sci., 33: 141-163.
144. Solaimalai, A., R.T. Ramesh and M. Baskar, 2004. Pesticides and Environment. In: Environmental Contamination and Bioreclamation, Kumar, A. (Ed.)., APH Publishing, New Delhi, pp: 345-382.
145. Singh, J. and D.K. Singh, 2005. Dehydrogenase and phosphomonoesterase activities in groundnut (*Arachis hypogaea* L.) field after diazinon, imidacloprid and lindane treatments. Chemosphere, 60: 32-42.
146. Loureiro, S., A.M. Soares and A.J. Nogueira, 2005. Terrestrial avoidance behaviour tests as screening tool to assess soil contamination. Environ. Pollut., 138: 121-131.
147. Amorim, M.J.B., J. Rombke and A.M.V.M. Soares, 2005. Avoidance behaviour of *Enchytraeus albidus*: Effects of benomyl, carbendazim, phenmedipham and different soil types. Chemosphere, 59: 501-510.
148. Saggar, S., C.B. Hedley, K.M. Giddens and G.J. Salt, 2000. Influence of soil phosphorus status and nitrogen addition on carbon mineralization from 14C-labelled glucose in pasture soils. Biol. Fertil. Soils, 32: 209-216.
149. Panda, S. and S.K. Sahu, 2004. Recovery of acetylcholine esterase activity of *Drawida willsi* (Oligochaeta) following application of three pesticides to soil. Chemosphere, 55: 283-290.
150. Menon, P., M. Gopal and R. Parsad, 2005. Effects of chlorpyrifos and quinalphos on dehydrogenase activities and reduction of Fe^{3+} in the soils of two semi-arid fields of tropical India. Agric. Ecosyst. Environ., 108: 73-83.
151. Dick, R.P., 1994. Soil Enzyme Activities as Indicators of Soil Quality. In: Soil Enzymes, Doran, J.W., D.C. Coleman, D.F. Bezdicek and B.A. Stewart (Eds.). Soil Science Society of America, Madison, WI., pp: 107-124.
152. Merrington, G., S.L. Rogers and L. Van Zwieten, 2002. The potential impact of long-term copper fungicide usage on soil microbial biomass and microbial activity in an avocado orchard. Aust. J. Soil Res., 40: 749-759.
153. Gaw, S.K., A.L. Wilkins, N.D. Kim, G.T. Palmer and P. Robinson, 2006. Trace element and σDDT concentrations in horticultural soils from the Tasman, Waikato and Auckland regions of New Zealand. Sci. Total Environ., 355: 31-47.
154. Monkiedje, A., M.O. Ilori and M. Spiteller, 2002. Soil quality changes resulting from the application of the fungicides mefenoxam and metalaxyl to a sandy loam soil. Soil Biol. Biochem., 34: 1939-1948.