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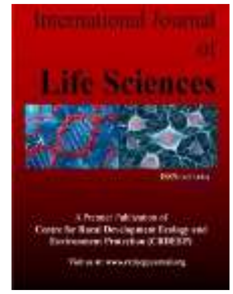

Full Length Research Paper

A Comparative Account of Improvising Degraded Soil Health: From Organic Agriculture Perspective

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ABSTRACT

The basic theme of the Sustainable agriculture is to treat soil as living biological ecosystem, not just as abiotic factor. The Crop productivity is sustained by the manipulation of this living ecosystem is based on the concept that organic farming seeks to provide nutrition to the crops by efficient recycling of nutrients. Organic farming really better than conventional one from economic and environmental point of view. In terms of soil health, the quantitative and quantitative profile of soil microbes and then relate them to physical and chemical properties of the soil studies are required. The present review attempts to substantiate the superiority of organic over conventional farming by considering the soil health and its microbial aspect. It also tries to relate biological activity with physical and chemical properties of the soil

Introduction

Agriculture is one of the ancient and noblest professions. About 65% of the total world population is dependent on agriculture and occupations related with it. During past years large-scale forest areas, grazing lands and even waste lands are switched into croplands to fulfill the greed and need of rising population. Repercussions of these activities are ecological imbalance and atmospheric pollution. As there is no further scope for expansion of agricultural land, the main focus have been made to enhance the production of food grains using high-yielding variety of seeds, fertilizers and irrigation along with advanced farm equipment's. Soil health is measured by the presence and interaction among microorganisms, availability of nutrient to plant, protecting them from disease and maintaining the health and structure of the soil. The ability of soil to support and sustain plant life is in direct proportion to the abundance and vigor of the microorganisms. Soil microbial health is reflected by population of fungi, yeasts, protozoa and algae, eubacteria, actinomycetes and archaea organisms residing in the soil. Majority of soil microorganisms are heterotrophic and require organic materials as both carbon and energy sources (Shannon *et. al.*, 2002). Many micro-organisms possess urease enzymes which play a role in soil enrichment through the degradation or hydrolysis of organic nitrogen (Hasan, 2000). Soil microbial biomass is governed by a variety of soil and environmental parameters including soil texture and structure, pH, air/moisture content, and soil temperature (Campbell *et al.*, 1999). One of the prime factors that determine soil microbial status is the type and amount of organic material that enters the soil ecosystem.

Biological activity is the life of the soil. Microorganisms are like an army of workers in the soil- feeding the plant, protecting it from disease and maintaining the health and structure of the soil. The ability of soil to support and sustain plant life is in direct proportion to the abundance and vigor of the microorganisms. Over 170 years ago, Justus Von Liebig, the architect of chemical fertilizers, used inorganic fertilizers to supplement the soil's basic organic matter. However, with the advent of high-output farming in the 1950s, agriculturists have overlooked the importance of the organic matter and soil health. As a result, millions of acres of farmland are dangerously low in organic matter and microbial activities. Today's high production farming practices can rapidly deplete the soil of essential biological activity. A most noticeable result is soil compaction. When the soil is compacted, water, oxygen and nutrient intake into the soil is reduced. The soil 'freezes-up' and normal plant production is greatly inhibited.

Historically, producers and agricultural professionals have described the soil's capacity to meet the requisites for successful production—nutrients, moisture, aeration, workability, and stability—as soil quality. With growing understanding that only a living, biodiverse soil with sufficient soil organic matter (SOM) can sustain crop and livestock production over the long run, farmers and professionals have adopted the term soil health. Over the past 30 years, extensive research has begun to elucidate the many trophic levels and functional groups of the soil food web, and how an optimally functioning soil biota feeds and protects crops, reduces risks, and strengthens farm economic viability (Ingham et al., 2000). Table 1 summarizes the roles of different soil organisms in key soil functions and ecosystem services.

Table 1. Soil Life and Soil Functions

	Soil Functions	**Some Key Organisms**
CROP PRODUCTION NEEDS		
Plant nutrition	Retains and recycles nutrients from organic residues	Decomposer bacteria and fungi, earthworms, arthropods*
	Delivers nutrients to plants	Protozoa, nematodes, N fixing bacteria, mycorrhizal fungi
Plant-available moisture Drainage and aeration	Maintains SOM, aggregation (tilth), network of small and large pores, deep channels	Bacteria (glues), fungi (mycelia), earthworms, arthropods, plant roots, (pores, channels, exudates)
Crop protection	Deters plant pathogens, nematode and other pests	Pathogen antagonists, predators and parasites of pests
	Enhances plant disease and pest resilience	Microbial symbionts that induce systemic resistance (ISR)
ECOSYSTEM SERVICES		
Water quality	Minimizes leaching and runoff Retains nutrients.	.. Plant roots and cover, microbes that immobilize nutrients s. Binds or destroys toxins.
Detoxification	Attenuates plant, animal, and human pathogen	Dung beetles, microbes that degrade organic wastes and pesticides, or bind heavy metals
Carbon sequestration	Builds stable soil organic matter (SOM).	Plant roots, fungi, bacteria, deep burrowing earthworms
SOIL SELF-MAINTENANCE		
Stability against erosion	Protects soil surface, maintains soil aggregation.	Plant cover and roots, fungi (hyphae), bacteria (glues)
Resilience and tilth	Restores structure after tillage, grazing, traffic, or downpour.	Plant roots, earthworms, arthropods, fungi
Active and stable SOM	Digests manure and plant residues into SOM.	Decomposer bacteria and fungi, earthworms, arthropods
Food and habitat for soil life.	Builds active SOM, maintains large and small pore spaces	Plant roots (exudates), fungi, bacteria, earthworms, arthropods

. * *Mites, springtails, ants, termites, ground beetles, dung beetles, centipedes, millipedes, etc*

Soil degradation

Soil degradation is a 21st century global problem that is especially severe in the tropics and sub-tropics. Some estimates indicate degradation decreased soil ecosystem services by 60% between 1950 and 2010. Accelerated soil degradation has reportedly affected as much as 500 million hectare (Mha) in the tropic and globally 33% of earth's land surface is affected by some type of soil degradation. The major cause of the degradation is due to salinity. Soil salinity results from an excess of salts in the soil that reduces plant growth and crop productivity and affects soil biological activity. Salinized soils impose an osmotic stress on plants, reducing water uptake and concentrating toxic level of sodium and chloride. Salinity intersects with major global concerns, including food security, desertification, and biodiversity protection. Approaches include prevention, stabilization, active management, or land retirement or abandonment. (Harper *et.al.*2020)

Type of soil degradation

Soil degradation and unhealthy agro-ecosystems are major threats as they would deprive future generations of food security. Healthy natural soil is an incredible mixture of rock-derived minerals, organic matter, dissolved nutrients, and most importantly it contains a plethora of microbes. Natural soil is booming with various microbes, i.e., bacteria, fungus, and other organisms. These microscopic organisms interact with each other and perform important tasks such as breaking down complex organic matter (dead plants and animals), nitrogen fixation, phosphate solubilization, production of siderophores, etc. These microbial activities in turn make the soil extremely fertile whereby the agricultural practice thrives without any external use of chemical fertilizers .Conceptually, there are four types of soil degradation:

Soil physical degradation generally results in a reduction in structural attributes including pore geometry and continuity, thus aggravating a soil's susceptibility to crusting, compaction, reduced water infiltration, increased surface runoff, wind and water erosion, greater soil temperature fluctuations, and an increased propensity for desertification.

Soil chemical degradation is characterized by acidification, salinization, nutrient depletion, reduced cation exchange capacity (CEC), increased Al or Mn toxicities, Ca or Mg deficiencies, leaching of NO_3-N or other essential plant nutrients, or contamination by industrial wastes or by-products.

Soil biological degradation reflects depletion of the soil organic carbon (SOC) pool, loss in soil biodiversity, a reduction in soil C sink capacity, and increased greenhouse gas (GHG) emissions from soil into the atmosphere. One of the most severe consequences of soil biological degradation is that soil becomes a net source of GHG emissions (*i.e*., CO_2 and CH_4) rather than a sink.

*Ecological degrada***tion** reflects a combination of other three and leads to disruption in ecosystem functions such as elemental cycling, water infiltration and purification, perturbations of the hydrological cycle, and a decline in net biome productivity. The overall decline in soil quality, both by natural and anthropogenic factors, has strong positive feedbacks leading to a decline in ecosystem services and reduction in nature conservancy.

Chemical farming Vis-a vis Organic farming:

In the 1980s, Wes Jackson began using the term sustainable agriculture to describe an alternative system of agriculture based upon resource conservation and quality of the rural life. Modern organic farming evolved as an alternative to chemical agriculture in the 1940s. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manure, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth to supply plant nutrients, and to control insects, weeds and other pests (Alvares, 1996 and 1996a).

In organic farming, compost and other natural materials are applied in soil. They are, in turn, worked upon by the soil microbes (plant additives) slowly for a consistent release of nutrients in the soil. The soil and plant additives include (i) microbial fertilizers and soil inoculants which are purported to contain unique and beneficial strains of soil microorganisms, (ii) microbial activators that supposedly contain special chemical formulations for increasing the number and activity of beneficial microorganisms in soil, (iii) soil conditions that claim to create favorable soil physical and chemical conditions which result in increased growth and yield of crops, and (iv) vermin-compost which helps in improving soil health and fertility (Dhama, 2001).

Is organic farming really better than conventional one from economic and environmental point of view? In terms of soil health, one should look into the quantitative and quantitative profile of soil microbes and then relate them to physical and chemical properties of the soil studies are required to answer such query. The present review attempts to substantiate the superiority of organic over conventional farming by considering the microbial aspect. It also tries to relate biological activity with physical and chemical properties of the soil.

Organic farming considers soil not as an inert medium but as a living biological system or ecosystem. It is through the manipulation of this system that organic farming seeks to provide nutrition to the crops, thus, relying on the efficient cycling of nutrients to sustain the crop productivity. This implies that soil fertility is an inseparable component of organic farming.

How organic farming improve the degraded soil health

Amending soil with organic matter of the soil produces an alteration of soil properties, including soil salinity electrical conductivity (EC), organic matter and elements that are important determinants of the agricultural quality of a soil. Besides improving the general edaphic condition in cultivated soils, organic matter has ecological role in maintaining and enhancing the soil microbial community, which actively participate in nutrient cycling (Lampkin 1992). Thus, amending soils with organic materials results not only in the enhanced fertility of soils but also enrichment of the soil with microflora that are involved in the various nutrient cycles. It is the soil biological processes that play a major role in organically managed soil since the release of nutrients from organic matter is dependent on the decomposition process brought about by a wide range of soil organisms (Beare *et al*. 1995): bacteria, fungi, micro fauna (e.g. protozoa, nematodes), mesofauna (e.g. mites, springtails) and macro fauna (e.g. millipedes, termites and earthworms).

Organic matter when incorporated into the soil forms the fraction referred to as soil organic matter (SOM). The SOM comprises of organic material stabilized to varying degree by molecular recalcitrance, physical separation from the microbial biomass and /or direct association with organic ions and clay surfaces. Many workers have separated SOM into categories relating to the characteristics of the constituents. Carter (1996) has presented the most recent categories of SOM viz., organo-miniral (SOM associated with soil, silt and clay fraction, constitute upto 80% of SOM); intra-aggregate (SOM associated with mico and macro aggregates) and free-organic matter. Several long-term studies (10 years or more) have shown that there is a steady increase of SOM in soils that are managed organically / biodynamically than the conventional ones (Reanold 1988, Niederbudde 1989, Bachinger *et al*., 1992, Scow *et al*. 1994, Fliessbach *et al* 1997). Thus organic system generally have a greater return of organic matter (as manures) so that SOM levels inevitably be larger than their conventionally fertilized (and /less frequently manured) conventional counterparts.

The role of tillage is more important in organic farming because it is a type and frequency of cultivation practices that influence the soil health. Therefore, choice of cultivation should be considered the main objective particularly in organically managed systems, although the same holds true for conventional systems too. The effects of the extent of tillage (i.e. cultivation) on the soil properties have been recently reviewed by Silgram & Shepherd (1999).

On the biological front, the soil microbial population which are involved in the nutrient cycling processes by being (i) a labile source of C, N, P and S; (ii) an immediate sink of C, P and S and (iii) an agent for nutrient transformation and pesticide degradation. Apart from these crucial functions, the soil microorganisms also form symbiotic associations with plant roots (e.g. mycorrhiza), act as biological agents against plant pathogens (e.g. *Tricoderma sp., Pseudomonas sp*), contribute towards soil aggregation and participate in soil formation.

Organically managed systems have been reported to have higher microbial diversity than their conventional counterparts. Moreover, conventional systems rely heavily upon pesticides and herbicide that have a negative impact on the non- target microorganisms. Soil receiving chemicals such as 2,4-D, 2,4,5-T, atrazine, picloram, 4-chlorobanzeneamine; petachlorophenol, hexachlorobenzene, DDT, trichloroetene, benzene, phenol; lindane, captan, metam sodium etc, where found to be toxic for soil microbes and reduced their activity (Welp and Brummer 1999), reduced the bacterivorous nematode population (Yardim & Edwards 1998), adversely affected the bacterial, fungal and actinomycetes population as a function of time of incubation (Banerjee & Banerjee 1991), adversely affect the vesicular mycorrhizal population (Johnston & Pfleger 1992, Ascullion *et al*. 1998), reduced the activity of azotobactor (Van Schreven *et al*. 1970).

As the organically managed systems avoid the use of such chemicals, it is clear that such adverse effects on the soil microflora would not likely to be found. Positive effect of organic fertilization on the soil microbial activity has been reported by many workers (Bachinger *et al*. 1992, Raupp 1995, Bossio *et al*. 1998, Gunapala *et al*. 1998). The soil microbial activity was measured in terms of microbial biomass, enzyme activities, soil respiration etc. These factors were found to vary with the type and quality of applied organic manure, agronomic techniques (crop rotation, soil tillage etc). Further, a noteworthy study of Gunapala *et al*., 1998 in a long term Sustainable Agriculture Farming Systems (SAFS) showed that soils managed under organic farming practices had greater soil microbial abundance and activity and higher number if bacterial feeding nematodes during crop growth, than those managed under conventional farming practices

Soil microbial biomass can be regarded as a sink and a source of plant nutrients. Organic systems supported a higher microbial biomass level than conventional and unmanured systems. Accordingly, soil enzyme activities (dehydrogenase, protease, phosphatase) were distinctly higher in the organic systems. The amount of carbon dioxide required per unit microbial biomass indicates the efficiency of resource utilization. Soil microbes from organic farming system utilize available resources more efficiently in terms of microbial growth rather than for maintenance.

The role of microorganisms in P–turnover and P availability was found to be more important in the organic system. Additionally, mycorrhizal colonization of roots of wheat and grass clover was higher in organic than in conventional systems. Earthworm biomass, which indicates soil fertility, as well as the diversity and activity of carbides, was enhanced in the organic systems. In conclusion, soil quality as indicated by the abundance and diversity of soil organisms as well as by their activity tends to be improved under organic agriculture (Mäder *et.al.* 1995; Mäder *et.al.* 1996, Oberson *et al* 1996, Fileβbash and Mäder 1998).

Need to improvise the organic techniques

Compost prepared by traditional method is usually low in nutrients and there is need to improve its quality. Enrichment of compost using low cost N fixing and phosphate solubilizing microbes is one of the possible ways to improving nutrient status of the product. It could be achieved by introducing microbial inoculants, which are more efficient than the native strains associated with substrate materials. Both the nitrogen fixing and phosphate solubilizing microbes are more exactly in their physiological and ecological requirements under natural conditions. The only alternative is to enhance their inoculum potential in the composting mass. Studies conducted at Indian Agricultural Research Institute (IARI), New Delhi, showed that inoculation with Azotobacter/ Azospirillum and phosphate-solubilizing culture in the presence of 1per cent rock phosphate is a beneficial input to obtain good quality compost rich in nitrogen (1.8%). The humus content was also higher in materials treated with microbial inoculants (Sharma, 2001). Soil management affects the distribution and types of microbial populations. After tilling soil, there is an increase in microbial activity in all depths probably due to the disruption of aggregates, better aeration and additional organic matter that is plowed into the soil. No tillage is a soil management practice used to control erosion.

In general, microbial population and activity in no-tillage soils are greater than in conventional tillage soils. This may be because no-tillage soils are generally moister than conventional tillage soil and have more organic C. As one proceeds through soil profile, however, the situation reverses. You can see this phenomenon by comparing the ration of microbial numbers from no-tillage and tilled soil as soil depth increases (Table-2. Microorganisms that don't require organic C for growth are less influenced by tillage practice.

Table 2. Effect of tillage on microbial population s in Alfisol after 23 years of continuous corn

Microbial group	Ratio of microorganisms in No-tillage vs. Tilled soil	
	0 to 7.5cm	7.5 to 15 cm
Total aerobic bacteria	5.6	0.4
Actinomycetes	5.5	1.1
Fungi	1.2	0.7

(From Handayani 1996)

Compacting soil has adverse effects on soil microorganisms, as there is decrease in organic C, total N, microbial population and microbial biomass, enzyme activity. It exerts its adverse effects partly by reducing soil porosity and aeration.

Conclusion

These differences in the biology between the organic and conventional farming systems vanished when the soils were amended with organic maintained under the similar conditions. The variety of substrates utilized by soil microorganisms serves as an indicator of microbial functions diversity, which was higher in bio-dynamic than in conventional soils. Concomitantly, microbes in the biodynamic soil decomposed added plant material to a higher extent than in conventional soil with a higher proportion of the plant materials being used for microbial biomass build up. Scientists of research Institute of Organic agriculture led by Paul Madder after a 21-year study conclude that although organic yield averaged 20per cent less than those from conventional plots, the inputs of fertilizer was reduced by between 34 per cent and 53 per cent and pesticide use by 97 per cent. They also found that the organic soils housed a larger and more diverse community of organisms. They included soil microbes, which govern the nutrient cycling reactions in soils and mycorrhiza root colonizing fungi, which help plant to absorb nutrients (Organic farming 'a realistic choice' by Alex Kerby BBC News Science/nature, 30 May 2002).

Lary M. Zibilske from Integrated Farming and Natural Resources Research Unit of Texas, USA has revealed that soil microbes have convincingly contributed to increase uptake of the nutrient from organic based fertilizers during the peak requirement period of the crop. In another study from USA, a cost effective technology was devised for retention of nutrients in manure.

References

Azcon-Aguilar, C., and Barea, J.M., 1996. Arbuscular mycorrhizas and biological control of soil-borne plant pathogens – anoverview of the mechanisms involved. Mycorrhiza, 6, 457-464.

Bachinger J., Arrens S and Mahnke K. (1992). Influence of different fertilizer types and rates of an eleven –year field investigation on various n-fractions and soil microbiological parameters as well as root growth and yield. Kongressband 1992 Gottingen . Vortrage Zum Generalthema Des 104. VDLUFA-Kongress Vom in Gottingen: Okologische Aspekte Extensiver landbewirtschaftung .1992, 571-574: 9.

Baker, B., D. Jerkins, J. Ory, and V. Lowell. 2016. Soil microbial interactions and organic farming. Organic Farming Research Foundation. 8pp. https://ofrf.org/sites/ofrf.org/files/staff/OFRF.Soil_.brochure.4.16. v4.Web_.pdf.

Battacharya P. and Bihari, K (2003). Scope of organic farming in India. Yojna (November issue) 27-30.

Baysal-Tustas, F., M. Benitez, A. Camp, M.D. Kleinhenz, J. Cardina, S.A. Miller, and B.B. McSpadden Gardener. 2006. Effects of different organic field management strategies on soil quality and soilborne diseases of vegetable crops. Phytopathology 96:S11a.

Beare M.H.,Coleman D.C., Crossley D.A., Hendrix P.F. and Odum E.P.(1995). A hierarchical approach to evaluation the significance of soil biodiversity to biogeochemical cycling. IN: The significance and regulation of soil biodiversity (Eds. Collins H.Pobertson G.P. and Klung M.J.), Kluwer Academic Publishers. Pp.5-22.

Bossio D.A., Scow K.M., Gunapala N. and Graham K.J.(1998). Determinants of soil microbial communities : Effect of agricultural management , season and soil type on phospholipid fatty acid profiles. Microbial Ecology 36,1-12.

Carter, M.R., 1996. Characterization of soil physical properties and organic matter under long term primary tillage in humid climates. Soil Tillage research 38, 251-263.

Fliebaach A., Wolewinski K., Oberson A, Mader P. and Niggli U. (1997). Carbon and nitrogen content of the density fractions of particulate organic substance from the soil under long –term ecological or conventional farming systems.(Kohlenstoff und Sticksoffgehalt von Dichtefractionen der partikularen organischen substanz aus Bodon unter lanngjahrig okologischer orer konventioneller Bewirtscaftung) Schriftenreihe-Institut fur Organischen Landbau 4 , 571-577.

Gunapala N., Venete R.C. Ferris H. and Scow K.M.(1998). Effects of soil management history on the rate of organic matter decomposition. Soil Biology and biochemistry 30,1917-1927.

Hallema, M., C. Pekrun, H. Lambers, and E. Kandeler. 2019. Hidden miners – the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. Plant and Soil 434:7–45. Hamel, C. 2004. Impact of arbuscular mycorrhizal fungi on N and P cycling in the root zone. Can J Soil Sci. 84(4):383-395.

Handayani, I.1996. Soil carbon and nitrogen pools and transformations after 23 years of no tillage and conventional tillage . Ph.D. diss., university of Kentucy, Lexington.

Johnson N.C. and Pfleger F.L. (1992). Vesicular- arbuscular mycorrhizae and cultural stress. In./ Mycorrhizae in sustainable Agriculture (Eds, Bethlenfalvay G.J. and Linderman R.G.) ASA Special Publication No.54 American society of Agronomy, Madison, Wisconsin, 71-99.

Lampkin N (1992). Organic Farming Press, UK.
Lori, M., S. Symnaczik, P. MaEder, G. De Deyn, A. Gattinger. 2017. Organic farming enhances soil microbial abundance and activity – A meta-analysis and meta-regression. PLOS ONE July 12, 2017, 25 pp. https://doi.org/10.1371/journal.pone.0180442
Mark Schonbeck, Diana Jerkins, Vicki Lowell2019. Soil Health and organic farming. https://ofrf.org/wp-content/uploads/2019/09/Soil_Biology_Guide.pdf
McDaniel, M. D., L. K., Tiemann, and S. Grandy. 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecol Appl. 24(3):560-70
Montgomery, D. R., 2017. Growing a Revolution: bringing our soil back to life. W. W. Norton & Co., New York. 316 pp.
Niederbudde E.A., Kaubrugger H and Flessa H. (1989. Changes in clay soils under organic and conventional farming. (Veranderungen von Tonboden bei alternativokologischen und konvetionellen Anbauverfahren). Journal of Agronomy and crop Science 162, 217-224.
Raupp J. (1995). Main effects of various organic and mineral fertilization on soil organic matter turnover and plant growth. Proceedings Ist Meeting Action Fertilization Systems in Organic Farming, Darmstadt.
Reganold J.P. (1988). Comparison of soil properties as influenced by organic and conventional farming systems . American Journal of Alternative Agriculture 3, 144-155.
Scow K.M. ,Smasco O. ,Gunapala N., lau S., Venette R., Ferris h., Miller R. and Shennan C. (1994). Transition from conventional to low input agriculture changes soil fertility and biology. California Agriculture 48,20-26.
Silgram M and Shepherd M.A.(1999). The effect of cultivation in soil nitrogen mineralization . Advances in Agronomy 65, 267-311.
Tian, X., C. Wang, X. Bao, P. Wang, X. Li, S. Yang, G. Ding, P. Christie, and L. Li. 2019. Crop diversity facilitates soil aggregation in relation to soil microbial community composition driven by intercropping. Plant and Soil 436 (1-2): 173-192.
Tiemann, L.K., A.S. Grandy, E.E. Atkinson, E. Marin-Spiotta, and M.D. McDaniel. 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecol. Lett. 18(8): 761–771.
Wander, M. 2015. Measures of Soil Biology and Biological Activity. https://articles.extension.org/pages/18626/measures-of-soil-biology-and-biological-activity.
Welp G. and Brummer G.W.(1999). Effects of organic pollutant on soil microbial activity. The influence of sorption , solubility and speciation . Ecotoxicology and Environmental Safety 43, 83-90.
Wolfe, D. W. 1996. Management Strategies for Improved Soil Quality with Emphasis on Soil Compaction. Final Report, Northeast SARE project LNE94-044.
Yardim E.N. and Edwards C.A.(1998). The effects of chemical pest, diseases and weed management practices on the trophic structure of nematode populations in tomato agroecosystems. Applied soil Ecology 7,137-147.