DYNAMIC PROPERTIES OF ORGANIC AMENDMENTS AS AGENTS OF SOIL QUALITY AND DISEASE SUPPRESSION.

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Abstract
There is an increasing interest, intensified by environmental health concern, in the replacement of synthetic agrochemicals with organic amendments. This substitution with organic amendments is causing resurgence in popularity as efficient and environmentally benign alternatives to chemical fertilizers and pesticides. Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, support human health and habitation. Soil quality can be assessed using a Minimum Data Set (MDS) that comprised soil attributes such as texture, organic matter, pH, bulk density and rooting depth. Soil organic matter has particular significance to soil quality, as it can influence many different soil properties including other attributes of the MDS. It has been reported as a very reliable and important soil quality parameter. Organic agriculture increase soil microbial community, reduce severity of early root rot of tomato caused by *Pythium* and *Phytopthora* spp and reduce incidence of *Verticilliumdahlia* in potato. Studies have shown a reduction in diseases, associated with increases in general levels of soil-borne fungi and bacteria following the addition of organic matter. Majority of compost manures have been reported to suppress diseases caused by *Pythium* and *Phytopthora* spp. Higher mean root rot disease suppression of French bean caused by *R.solani* by poultry manure (42.0%) and plant-based composts (lantana compost (46.6%) and urtica compost (34.5%)) treatments when compared to farm yard manure (18.6%), vermin compost (12.6%) and spent mushroom compost (23.0%) has been documented.

Keywords: Disease suppression, organic amendment, soil health, soil quality.

Introduction

The practice of adding organic amendments to crop soils is undergoing resurgence as an efficient way to restore soil organic matter content and improve soil quality. The quantity and quality of the organic amendment can improve soil quality by affecting many parameters, such as soil aeration, structure, moisture, nutrient availability and microbial ecology (Bailey and Lazarovits 2003; Doran and Zeiss 2000). Organic amendments, such as animal manures and composts, were commonly used in the past for agricultural production due to their value as fertilizers and for their ability to improve plant health. The widespread availability of chemical fertilizers and pesticides led to the replacement of those organic materials by these highly effective and inexpensive synthetic agrochemicals (Lazarovits, 2001). At present, however, there is an increasing interest, intensified by environmental/health concern, in the replacement of synthetic agrochemicals with organic amendments, which are experiencing resurgence in popularity as efficient and environmentally benign alternatives to chemical fertilizers and pesticides (Lazarovits, 2001). Once a land manager begins working towards enhancing soil organic matter, a series of soil changes and environmental benefits follow. The rate and degree of these changes and the best suite of practices needed to achieve results vary with soil and climate. Soil organic matter holds 10 to 1000 times more water and nutrients than same amount of mineral soils. In soils managed for organic matter, beneficial soil organisms become more numerous and active with diverse crop rotations and higher organic matter levels. Organic matter may bind pesticides, making them less active. Soils managed for organic matter may suppress disease organisms, which could reduce pesticide needs. Crop health and vigour increase, with increase in soil biological activity and diversity. Crops are able to withstand drought when infiltration and water holding capacity of the soil increase with increase in soil organic matter.

Soil Quality and Soil Health

Soil quality, according to Doran and Parkin (2001) is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, support human health and habitation. It refers to the *inherent quality* of soil – those properties (texture and mineralogy) that are determined by factors of soil formation, and the *dynamic quality* of soil – those properties that are affected by management. More recently, soil quality has come to emphasis only the *dynamic quality* of soils, defined as the changing nature of soil properties resulting from human use and management. In this paper, soil quality refers to the dynamic quality of soil – those properties that are affected by management. There is a broad agreement in the literature that soil quality is measured by a combination of physical, chemical and biological soil characteristics. However, the exact combination of the parameters best used to describe soil quality varies. The proposed Minimum Data Set (MDS) of Seybold *et al.* (1996) as shown in Table 1highlights the principal place of organic amendments in improving the physical, chemical and biological properties of a quality and healthysoil. Onweremadu (2008) evaluated soil quality of Otamiri River floodplain in Owerri, southeast Nigeria using Soil Quality Morphological Index in relation to soil organic matter, which is an indicator of soil health in tropical soils. Results obtained showed that soil quality had a good positive relationship with organic matter (r = 0.92; r^2 = 0.84; 1-r^2 = 0.16; P = 0.05 at n = 9). Gregorich*et al.* (1994) had reported that soil organic matter is a very reliable and important soil quality parameter. Soil health, on the other hand, is a newer, less defined term and does generallyrefer to the expansion of the biological aspect of soil quality. The term "soil health" is preferred bysome authors because it portrays soil as a living, dynamic system whose functions are mediated by adiversity of living organisms that require management and conservation (Doran and Zeiss, 2000). A modern consensus definition of soilhealth is "the

Table1. Proposed Minimum Data Set for screening the quality and health of soil (Seybold *et al*., 1996).

Indicators of soil condition	Relationship to soil function/Rationale as a priority measurement
Physical indicators	
Texture	Retention and transport of water and chemicals. Modeling use, soil erosion and variability estimate.
Depth of soil, topsoil and rooting	Estimate of productivity potential and erosion. Normalizes landscape and geographic variability.
Infiltration and bulk density	Potential for leaching, productivity and erosivity. Soil bulk density needed to adjust analyses to volumetric basis.
Water holding capacity	Relation to water retention, transport and erosivity. Available water, calculate from SBD, texture and OM.
Chemical indicators	
Soil organic matter (SOM)	Defines soil fertility, stability and erosion extent. Use in processes, models and for site normalization
pH	Defines biological and chemical activity thresholds
Electrical conductivity	Defines plants and microbial activity thresholds. Presently lacking in most process models.
Exchangeable N,P and K	Plant available nutrients and potential for N loss. Productivity and environmental quality indicators.
Biological indicators	
Microbial biomass C and N	Microbial catalytic potential and respiratory for C and N. Modeling; early warning of management effects on OM.
Potentially mineralizable N	Soil productivity and N supplying potential; process modeling (surrogate indicator of biomass).
Soil respiration, water content and temperature	Microbial activity measure. Process modeling, estimate of biomass activity

continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans"(Natural Resources Conservation Service – USDA-NRCS, 2012; Soil Renaissance,2014).However, "soil quality" and "soil health" are often used interchangeably in practice and they will be used synonymously throughout this paper.

Soil quality influences both yield and quality of root and tuber crops (Snapp *et al*., 2016). This is not surprising because the harvested portion of these crops is directly connected with the soil environment. Root and tuber producers are among those who should invest heavily in soil management. However, absence of such investment is making the soils that grow these crops to be more degraded. This has caused a "chemical drip" which has worsened with little organic matter input into the soil system. Soils in organic production systems loose less nitrogen into nearby water systems than in conventional production systems (Liebhardt*etal*., 1989). Gunapala and Scow (1998) reported that the amount of soil nitrogen in field under conventional production systems has been negatively correlated with soil microbial components, whereas soil nitrogen in fields under organic production was positively correlated with soil microbial component. Natural pathogens control is not only conserved but is also promoted in organic farming conditions. Van Bruggen and Termorshuizen (2003) had posited that most soil-borne plant pathogens causing root rots in older plants are usually less prevalent in organic than in conventional farms.Table 2 lists some examples of field comparisons between organic and conventional agriculture in different crops andlocation according to Van Bruggen and Termorshuizen (2003).Whereas, no application of fertilizers and pesticides in organic agriculture increased microbial communities in cereals (Teviotdale and Hendrics, 1994), organic farming in the absence of fungicides or copper fungicides reduced *Verticilliumdahliae* (Lazarovits, 2001) in potato production. The use of biological insecticides, living mulch cover crops and composted manure, lower severity of early root rot, *Pythium* and *Phytopthora* root rot of tomato (Clark *et al.*, 1998). The mechanisms involved in disease suppression are varied and complex and may differ depending upon the pathogen involved.

Table 2. Comparison of disease levelsof some important crops under organic versus conventional management (Van Bruggen and Termorshuizen, (2003)).

Crop	Management practice in organic crops	Consequences as compared to conventional	References
Cereals	Organic practices (no fertilizers & pesticides)	Increased microbial communities	Teviotdale and Hendrics (1994)
Potato	Absence of fungicides or only copper fungicides	Reduced Venticilium dahlia	Lazarovits (2001)
Tomato	Biological insecticides and living mulch cover crops and composted manure	Lower severity of curly root rot, Pythium and Phytopthora root rot	Clark *et al.* (1998)

Soil organic matter (SOM) enhances soil aggregation and improves structure in contrasting soil textures such as sandy and clay-textured soils (Snapp and Grandy, 2011). The primary means of building SOM are additions of high-quality organic material from amendments or crop residues and judicious tillage to prevent organic matter degradation. Organic matter helps form micro-aggregates that hold water and support good drainage. They are also stable and resistant to breakdown during routine cultivation. One of the challenges to maintaining and building soil physical structure in root and tuber production systems is the neglect of organic amendments and soil-restorative crops. Root and tuber crops are also frequently tilled, sometimes during less than ideal soil moisture conditions, when aggregates are susceptible to degradation. The adoption of long, diverse crop rotation sequences can help address these issues. Some crops can be grown with minimum tillage, others produce large amounts of residues, and a diversity of root architecture, soil cover and residue biochemistry can be maintained. This diversity counteracts the intensive production of root and tuber crops, which necessitates soil disturbance at multiple times during the year and alone results in minimal residue production. Soil organic matter (SOM) holds large pools of organically bound plant nutrients, which, through mineralization, may become available for crop uptake or loss from the soil-plant system through leaching or gaseous losses. Additionally, SOM is important to both soil structure and the potential for soil erosion, to sorption of mobile plant nutrients and retention of pesticides, and to the CO_2 balance between agro-ecosystems and the atmosphere. Thus, SOM levels and turnover rates are intimately linked to soil properties of importance in maintaining an economically and environmentally sustainable agricultural production, and also to soil quality.

Disease Suppression

The improvement of soil quality through organic amendments has a proved effect on crop production and plant health and some of these effects have been related to the enhancement of soil suppressiveness against soil-borne pathogens (Bailey and Lazarovits 2003). Suppressive soil has been described as a soil in which "the pathogen does not establish or persist, establishes but causes little or no damage, or establishes and causes disease for a while but thereafter the disease is less important" (Baker and Cook, 1974). This soil suppressiveness has been reliably related to soil micro-organisms and its activities and for that reason, the effects of the organic amendments on soil microbiota is a key issue in understanding the role of this old management practice on disease suppression.

Some authors (Table 3), have demonstrated the enhancement of soil suppressiveness by both composted and uncomposted amendments (Aryantha *et al*., 2000). Several works have stated that composted materials are more suppressive to root rots than uncomposted ones (Hoitink and Boehm, 1999; Snapp *et al*., 2016). Malandraki *et al*. (2008) and Tamm *et al*. (2010) have consistently demonstrated suppressive effect of composted amendments on soil-borne diseases,

Table 3. Examples of proven plant disease suppression following application of organic amendments.

Pathogen	Crop	Organic amendment	Reference
Fusariumspp	Several hosts	Vegetal compost	Yogev*et al.* (2006)
Phytopthoracinnamomi	White lupin	Fresh and composted poultry manure	Aryantha*et al.* (2000)
	Avocado	Chipped eucalyptus trimmings	Bender *et al.* (1999)
Phythiumultimum	Garden cress	Animal & vegetal compost	Pane *et al.* (2011)
		Bark compost	Erhart*et al.* (1999)
Rhizoctoniasolani	Garden cress	Viticulture waste compost Cow manure compost	Pane *et al.* (2011)
	Basil	Fresh farmyard manure	Tamm *et al.* (2010)
Rosellinianecatrix	Avocado	Vegetal compost	Bonillia*et al.* (2009)
Sclerotinia minor	Garden cress	Composted municipal bio-waste. Composted cow manure	Pane *et al.* (2011)
Scleorotiumrolfsii	Tomato	Vegetal compost, poultry manure, green manure (legumes)	Bulluck and Ristaino (2002)
Verticillium dahlia	Eggplant	Horse manure, municipal green waste, wood shavings	Malandraki*et al.*(2008)

such as damping-off and root rots (*Pythiumultimum, Rhizoctoniasolani, Rosellinianecatrix, Phytophthoraspp*) and wilts (*Fusariumoxysporum* and *Verticilliumdahlia*) in a wide range of crops.Studies have shown that *R. solani*suppression is influenced by the type of compost incorporated (Stone *et al.*, 2004). While the majority of composts are reported to suppress diseases caused by *Pythium*and *Phytophthora*spp., only afew provide consistently high levels of suppression against *R. solani*(Stone *et al.*, 2004). Joshi *et al.* (2009) observed higher disease suppression of *R.solani*by the poultry manure (PM) and plant based compost (LC and UC) treatments as compared to FYM, VC and SMC as reported by Joshi *et al.* (2009)in Table 4.

Mechanisms of Disease Suppression

A number of studies have shown that disease levels are reduced following the incorporation of organic matter into the soil. However, a survey of the plant pathology literature quickly shows

Table 4. Effect of different composts and compost extracts on root rot disease of French bean (Joshi *et al*., 2009).

Treatments	Root rot colonization			
	2005	**% Reduction**	**2006**	**% Reduction**
FYM	43.7	16.8	21.1	20.4
PM	34.4	34.3	13.3	49.8
VC	49.0	6.7	21.6	18.5
LC	28.7	45.3	13.8	47.9
UC	35.0	33.3	17.5	34.0
SMC	42.7	18.7	19.3	27.2
Chemical	28.2	46.3	12.0	54.7
Control	52.5		26.5	

FYM = Farm yard manure; VC = Vermicompost; PM = Poultry manure; LC = Lantana compost; UC = Urtica compost; and SMC = Spent mushroom compost.

that this is a complex phenomenon, and that simply adding organic matter to a soil will not necessarily lower the amount of diseases that develop on plants grown in these amended soils. Several mechanisms have been identified as contributing to disease suppression following the addition of organic matter, and include:

1. The stimulation of non-pathogenic microorganisms that inhibit or kill the pathogens through competition or parasitism. Several studies have shown a reduction in disease associated with increases in general levels of soil-borne fungi and bacteria following the

addition of organic matter, such as the addition of chicken litter or the incorporation of certain cover crops. In some cases the disease reductions were tied to increases in specific organisms such as the bacterium *Pseudomonas putida*, or several species of the biological control fungus *Trichoderma* spp.

2. The release of compounds that is toxic to the pathogens. Some materials, such as composted hardwood bark, may contain compounds that inhibit pathogens under some conditions. Certain types of organic matter have been investigated for their ability to release toxic compounds that inhibit or kill soil-borne plant pathogens. The incorporation of sudangrass has been shown to reduce nematode and fungal diseases of lettuce and potatoes. The fact that sudangrass was able to lower disease levels while equivalent amounts of other types of organic matter were not, and that incorporating two-month-old sudangrass provided better control than three-month-old sudangrass, lends support to the hypothesis that compounds called cyanoglucosides, released by the decomposing grass tissues, are toxic to the pathogens in the soil. Similarly, the incorporation of broccoli residues was shown to be effective for controlling diseases caused by the soil-borne fungi *Fusariumoxysporum*, *Rhizoctoniasolani* and *Verticilliumdahliae*, and for reducing the soil populations of these pathogens.
3. The stimulation of the host plant's disease defense system. Soil-incorporated paper mill residues were shown to lower foliar disease levels of cucumbers and snap beans, and cannery waste added to tomato plots resulted in lower levels of bacterial spot on tomato fruit (Rayees*et al*., 2013). Possible mechanisms suggested for this type of disease suppression include changes in a plant's nutrient status and the phenomenon known as systemic acquired resistance (SAR) or induced systemic resistance (ISR). With systemic acquired resistance, the presence of certain stresses or microorganisms in the root zone is believed to trigger plant defense systems throughout the plant. Thus a change in the root zone results in an increase of disease resistance in the foliage of the plant. This disproves the thinking that disease suppressive soils have the ability to suppress soil-borne and root-infecting plant diseases and that organic amendment cannot have an effect on the levels of foliar diseases as well.
4. Altering of the structure of the microbial communities in the soil or changing the physical and chemical properties of the soil. A study on the effects of organic amendments on potato early dying disease found that higher levels of soil organic matter following additions of organic residues were associated with lower disease levels, with the speculation that the disease reductions were due to increased nutrient holding capacity of the soil, increased water infiltration, and decreased soil crusting.

While the studies on the effects of organic matter amendments show promising results for increasing soil quality; thereby increasing the disease suppressiveness of soils, there are also studies that show little or no disease control following the application of organic matter. In fact, in some circumstances organic matter amendments have been shown to actually increase disease levels. The types of organic matter applied; the physical, chemical, and biological condition of the soil being treated; tillage methods used; and the crops and pathogens present all have an influence on the process.

Conclusion

Organically amendedsoils have a higher biological diversity and activity in the soil and are more stable systems with a larger soil health. The main reason for higher biodiversity in organic soils is the improved soil health which results from the use of organic amendments and the absence of artificial fertilizer, which results in lower nitrate levels in the soil. Root disease severity is generally decreased after few years of judicious application of organic amendments through improvement in soil quality, competition, parasitism, antibiosis, SAR and increased mycorrhizal colonization. Sometimes, initial increase in disease severity is observed, due to inexperience of the farmer. Therefore, it is important to develop indicators for ecosystem health and understand the factors that lead to disease suppression. Even more than conventional farmers, organic farmers need to reach various objectives with a coherent set of cultural practices that will satisfy the requirement of sustained profitability. This can only come through research and development and when fertilizer plans refocuses on "feeding the soil microbes first rather than focusing on fulfilling crops' nutritional needs".

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