Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lcss20

Organic Amendment Effects on Microbial Population and Microbial Biomass Carbon in the Rhizosphere Soil of Soybean

Bibhuti B. Das [a] & M. S. Dkhar [a]

[a] Microbial Ecology Laboratory, Department of Botany, NorthEastern Hill University, Shillong, India

Version of record first published: 13 Jul 2012.

Communications in Soil Science and Plant Analysis, 43:1938–1948, 2012

ISSN: 0010-3624 print / 1532-2416 online
DOI: 10.1080/00103624.2012.689401

Organic Amendment Effects on Microbial Population and Microbial Biomass Carbon in the Rhizosphere Soil of Soybean

BIBHUTI B. DAS AND M. S. DKHAR

Microbial Ecology Laboratory, Department of Botany, NorthEastern Hill University, Shillong, India

The aim of the study was to determine microbial populations and microbial biomass carbon in the rhizosphere soil of soybean cultivated under different organic treatments: plant compost (PC), vermicompost (VER), farmyard manure (FYM), and integrated plant compost (IPC). The serial dilution plate method was employed to enumerate the rhizosphere soil fungi and bacteria. Results showed that microbial populations and biomass carbon were affected by the application of organic amendments. Fungal population was the greatest in the VER plot for two crop cycles, whereas bacterial population was the greatest in the VER in the first crop cycle and FYM for the second crop cycle. Tukey's test at $P \leq 0.05$ *showed that change in microbial biomass carbon in the sites studied over time was significant, with the greatest in FYM. In our study, addition of organic amendments affected the soil physicochemical properties, which in return affected the rhizosphere microbial characteristics.*

Keywords Microbial biomass carbon, microbial population, organic amendments, rhizosphere

Introduction

It is well established that microbial life only occupies a minor volume of soil localized in the hot spots such as the rhizosphere soil (Nannipieri et al. 2003) where microflora has continuous access to a flow of low- and high-molecular-weight organic substrates derived from roots. The rhizosphere is the soil volume surrounding the rhizoplane, and the term was first coined by Hiltner in 1904 (Brimecombe, Lelj, and Lynch 2001). The soil is the habitat of both fungi and bacteria, which have positive and negative effects on the growth and development of plants (Kurek and Kobus 1990; Pieta 1987). Both biotic and abotic factors affect the quantitative and qualitative compositions of the population of microorganisms. Plants secrete various organic compounds to the soil through roots, and after the harvest leaves crop residues with the proper chemical composition. Root exudates, the main source of amino acids, sugars, vitamins, phenols, organic acids, and metal ions, affect the composition of the microorganism population in the soil, especially in the rhizosphere (Curl 1982; Darcy 1982; Funck-Jensen and Hockenhull 1984; Pieta 1985; Rovira 1965). The use of organic amendments to increase the fertility of the soil also enhances the growth of

Received 30 September 2010; accepted 26 September 2011.
Address correspondence to Bibhuti B. Das, Microbial Ecology Laboratory, Department of Botany, Northeastern Hill University, Shillong, 793022, India. E-mail: bibhu20@yahoo.co.in

micrflora in the rhizosphere region. Microflora benefit the plants through different mechanisms of action, including (i) the production of secondary metabolites such as antibiotics, cyanide, and hormone-like substances; (ii) the production of siderophores; (iii) antagonism to soil-borne root pathogens; (iv) phosphate solubilization; and (v) dinitrogen fixation. The establishment of rhizosphere microflora possessing any of these characteristics is interesting because they may influence plant growth. Organic amendments, depending on the degree of maturity, provide a rich medium supporting a greater microbial activity (Chen et al. 1988) and may also contain a diverse microbial population (McKinley and Vestal 1984).

Applications of organic amendments can cause changes in the physical, chemical, and biological properties of soils. Applying organic amendments has been shown to increase soil microbial activity (Liu and Ristaino 2003), microbial diversity (Girvan et al. 2004; Grayston et al. 2004), and bacterial densities (van Bruggen and Semenov 2000). Gelsomino et al. (2004) compared organic and conventional agricultural systems by examining their effects on soil microbial biomass, microbial activity, and substrate utilization and documented an enhancement of microbial biomass in the plots with organic amendments. The soil microbial biomass is fundamental to maintaining soil functions because it represents the main source of soil enzymes that regulate transformation processes of elements in soils (Böhme and Böhme 2006). It has been suggested as a possible indicator of soil environment quality and is employed in national and international monitoring programs. Microbial biomass carbon (C) is often closely related to organic matter, and soil organic material is also altered with floristic composition, plant phenology, and soil fertility (Quideau et al. 2001; Warembourg and Estelrich 2001). The objective of the study was to compare the effect of four types of organic amendments on the microbial composition and microbial biomass **C** of soybean rhizosphere.

Materials and Methods

Study Site and Rhizosphere Soil Sampling

Field experiments were conducted on a soybean plot for two crop cycles, from May to September 2007 and 2008, at the Agronomy Experimental Farm of the Indian Council of Agricultural Research, Barapani, Shillong, Meghalaya, India. The soil of the experimental site is sandy loamy and is situated in the geographic location of 25° 38′ N and 91° 52′ E at an altitude of 830 m above sea level. A high-yielding variety of soybean (JS80-21) was sown for investigation. The experimental field was divided into five plots with each having three replicates. Each triplicate plot had a size of 6.5 m^2 with spacing of 30 × 15 cm R × P (row by row and plot by plot). Among the five plots, four were treated with organic amendments. One plot had no treatment and was considered as the control (CON) plot. The optimum doses of fertilizer applied in the field were farmyard manure (FYM) 15 t ha^{-1}, vermicompost (VER) 7.5 t ha^{-1}, integrated plant compost (IPC) 5 t ha^{-1}, and plant compost (PC) 15 t ha^{-1}. According to the type of treatment, each of the plots were considered as PC, VER, IPC, FYM, and CON without fertilizers.

Soybean roots and rhizosphere soil were collected directly beneath the plant crown from experimental plots. At each plot, three plants located in the middle were randomly selected for sampling. The soil samples containing the soybean crown and root material, as collected from the field, were stored at 4 °C until they were processed. Inoculum from each collection was prepared by compositing subsamples from the three plants sampled at each plots and sieving the rhizosphere soil through a 2-mm sieve to remove rocks and large litter fragments. Additional root material was clipped free from the primary root, cut into 2-cm pieces, and combined with the soil sieving for isolation of microorganisms. About 300 g of each rhizosphere soil sample was air dried and stored at 4 °C for chemical analysis. The mean data of 2007 and 2008 were used to interpret the effects of different organic amendments on microbial and chemical characteristics.

Isolation and Counting of Microorganisms

The serial dilution plate technique (Johnson and Curl 1972) was employed to enumerate the rhizosphere soil fungi and bacteria. Martin's rose bengal agar medium (Martin 1950) and nutrient agar medium were used for isolation of fungi and bacteria respectively. The inoculated Petri plates were incubated at 25 ± 1 °C for 5 days and 30 ± 1 °C for 24 h for fungi and bacteria respectively. After the incubation period, the colony-forming units were counted and expressed as CFU g^{-1} of soil on a moisture-free basis.

Soil Microbial Biomass

Microbial biomass carbon (C) was determined by the chloroform fumigation incubation method (Anderson and Ingram 1993).

Soil Physicochemical Properties

Soil temperature was noted using a soil thermometer at the time of sample collection. pH of the samples was read using an electronic digital pH meter. The moisture content was determined by drying the samples in a hot-air oven at 105 °C for 24 h. Organic carbon (C_{org}) was measured by the method given by Anderson and Ingram (1993). Total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) were determined by the Kjeldahl method (Jackson 1973), molybdenum blue method (Allen et al. 1974), and flame photometer method (Jackson 1973), respectively. Soil respiration was determined by the absorption and titration method (MacFadyen 1970).

Statistical Analysis

Statistical analysis was done by using Origin 7.0 SRO v 7.0220 (B220) (Origin Lab Corporation, Northampton, Mass.) and Statistica v 6.0 (StatSoft, Tulsa, Okla.). Data collected were subjected to analysis of variance (ANOVA). Significant means were detected using Tukey's test at the 5% probability level. Diversity of fungi was calculated using the Shannon–Wiener index (H) (Shannon and Wiener 1963).

Results and Discussion

Fungal Population

The mean fungal population for the first year reached the greatest value of 25.23 × 10^3 CFU g^{-1} dry soil for the VER plot, and the lowest value of 11.37 × 10^3 CFU g^{-1} dry soil was observed in the CON plot. Fungal population for the first year exhibited significant variation between organically treated plots and the CON plot according to Tukey's test at $P \leq 0.05$ (Figure 1). Similarly, the second year also showed the greatest fungal value of 23.65 × 10^3 CFU g^{-1} dry soil in the VER plot, and the lowest value of 16.66 × 10^3 CFU

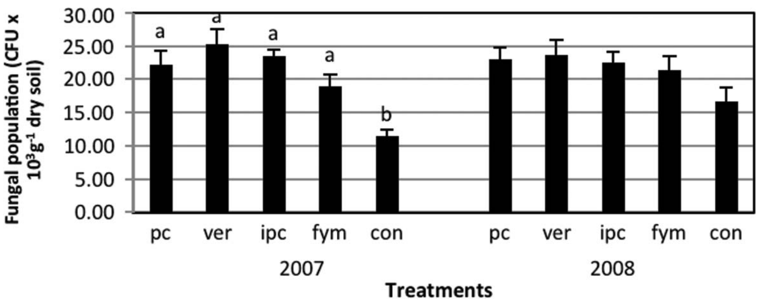

Figure 1. Fungal population of the rhizosphere soil under different organic treatments during the two growing seasons of soybean. Means ± SE with the same letter on top do not differ significantly, whereas means with different letters on top differ significantly according to Tukey's test (ANOVA) ($P \leq 0.05$). Note: pc, plant compost, ver, verimcompost; ipc, integrated plant compost; fym, farmyard manure; and con, control.

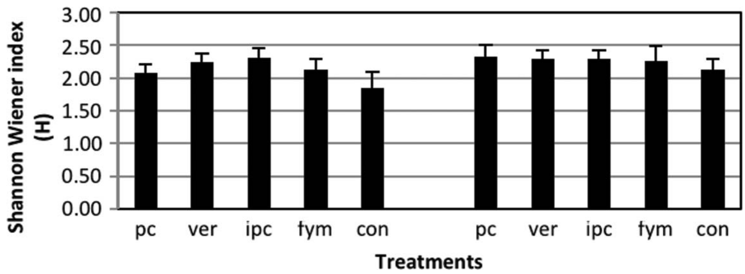

Figure 2. Shannon Wiener index (H) of the rhizosphere soil fungi under different organic treatments during the two growing seasons of soybean. Means ± SE. Note: pc, plant compost; ver, verimcompost; ipc, integrated plant compost; fym, farmyard manure; and con, control.

g^{-1} dry soil was recorded from the CON plot. No significant variation in fungal population was exhibited in the second year (Figure 1). The Shannon–Wiener index (H) of fungal diversity showed the greatest value in the IPC treatment (2.31) and the least value in the CON plot (1.35) for the first year. During the second year, the PC treatment (2.33) showed the greatest H of fungal diversity, and the least was exhibited by the CON plot (2.13) (Figure 2). In the first year, the greater fungal population in VER was further evidenced from the correlation among fungal population, available P, and microbial biomass C and in the second year among fungal population, exchangeable K, and bacterial population (Figure 3).

Bacterial Population

Bacterial population in both the sampling years showed significantly greater values in the organically treated plots than the CON plot. The mean bacterial population for the first year was greatest in VER, 55.19 × 10^5 CFU g^{-1} dry soil and the least in the CON plot, 30.89 × 10^5 CFU g^{-1} dry soil. The VER and FYM plots exhibited significant variation in bacterial population according to Tukey's test at $P \leq 0.05$ (Figure 4) whereas in the second year organically treated plots exhibited significant variation in bacterial population with the CON plot according to Tukey's test at $P \leq 0.05$, with the greatest value recorded

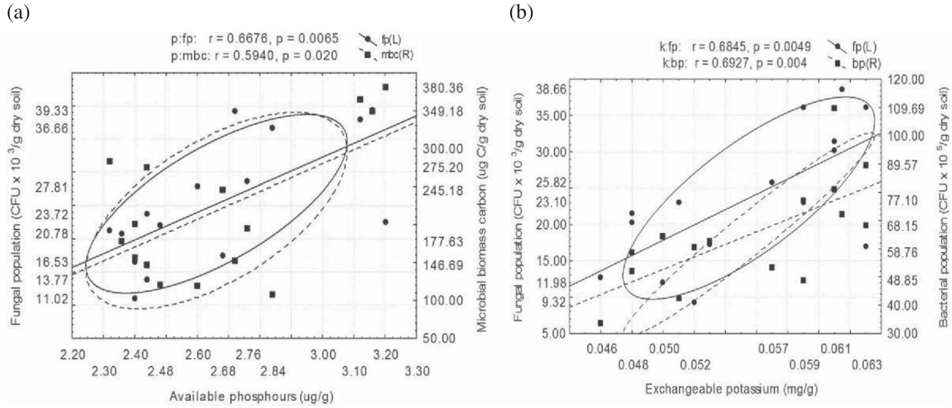

Figure 3. Correlation coefficient of fungal population with available phosphorus for the first year (a) and fungal population with exchangeable potassium for the second year (b). Note: fp, fungal population; bp, bacterial population: and mbc, microbial biomass carbon.

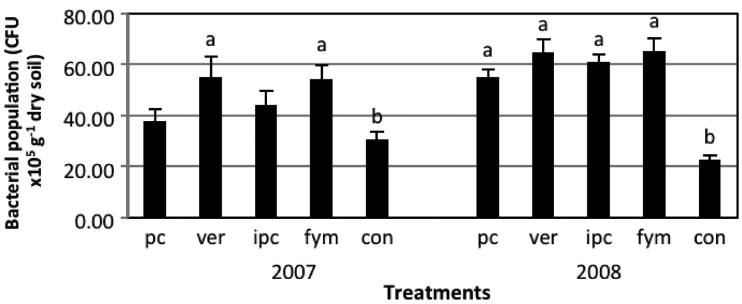

Figure 4. Bacterial population of the rhizosphere soil under different organic treatments during the two growing seasons of soybean. Means ± SE with the same letter on top do not differ significantly, whereas means with different letters on top differ significantly according to Tukey's test (ANOVA) ($P \leq 0.05$). Note: pc, plant compost; ver, verimcompost; ipc, integrated plant compost; fym, farmyard manure; and con, control.

in FYM, 65.33×10^5 CFU g^{-1} dry soil and the least recorded in CON, 22.68×10^5 CFU g^{-1} dry soil (Figure 4).

Microbial Biomass Carbon

Microbial biomass C in the rhizosphere soil samples collected under different organic treatments and the CON plot exhibited a significant treatment effect, where the mean value for the first year under FYM treatment reached the maximum value of 320.27 μg Cg^{-1} dry soil and in the CON plot with a minimum value of 163.03 μg Cg^{-1} dry soil. The FYM and IPC plots exhibited significant variation with the PC and CON plots according to Tukey's test at $P \leq 0.05$ (Figure 5). A similar trend in biomass C was exhibited in the second year with the greatest value recorded in FYM (451.04 μg Cg^{-1} dry soil) and the least value recorded in the CON plot (186.6 μg Cg^{-1} dry soil). Organic treatments exhibited significant variation in microbial biomass C with the CON plot according to Tukey's test at $P \leq$ 0.05 (Figure 5).

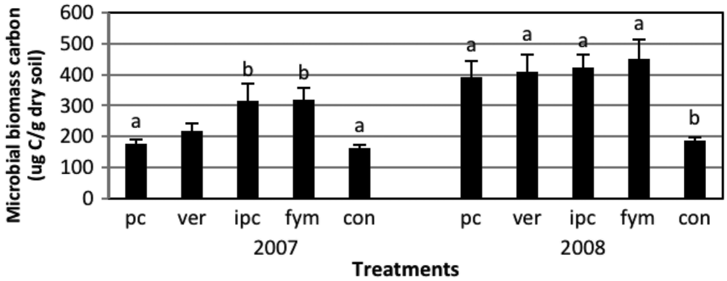

Figure 5. Microbial biomass carbon of the rhizosphere soil under different organic treatments during the two growing seasons of soybean. Means ± SE with the same letters on top do not differ significantly, whereas means with different letters on top differ significantly according to Tukey's test (ANOVA) ($P \leq 0.05$). Note: pc, plant compost; ver, verimcompost; ipc, integrated plant compost; fym, farmyard manure; and con, control.

Physicochemical Properties

Rhizosphere soil exhibited different physicochemical properties according to the different organic amendments. The pH and moisture content were greatest in the PC plot and least in the CON plot. Organically treated plots exhibited significant differences in pH with the CON plot, whereas significant variation in moisture content was observed only between the PC and CON plots (Table 1). Soil organic C was significantly greater in the IPC plots and exhibited significant variation with the CON plot. A similar trend with significant increase was obtained for total N values in organic treatments compared to the CON plot. Exchangeable K was found to be greater in FYM and lower in IPC plots and, no significant variation was observed between the treatments and CON plots. Also, P was greatest in the VER plot and lowest in the IPC plot. The VER plot exhibited significant differences in P values with other organic treatments and CON plots (Table 1).

Discussion

Microbial Populations

It is known that organic matter introduced to soil stimulates soil microbial populations and soil biological activity (Brady and Weil 1999), which is in accordance with the present study where organically treated plots showed an increase in fungal and bacterial population compared to the control plot, where no fertilizer was applied. Among all the organic treatments, the greatest fungal and bacterial populations were observed in VER and FYM plots. Dar (1996) and Marinari et al. (2000) reported an increased soil biological activity and microbiological growth when vermicompost of sewage sludge was added, which enhanced soil microbial biomass by 8–28%. The number of CFU of fungi and bacteria increased when pig manure compost was added to the soil (Weon et al. 1999) and addition of compost to soil increased the incidence of bacteria in the tomato rhizosphere (Alvarez, Gagne, and Anton 1995). It has been reported that addition of organic manure would have resulted in increased secondary and micronutrients in the soil, which might have helped to increase the microbial population (Krishnakumar et al. 2005). The addition of organic materials to agricultural soil (with or without chemical fertilizers) is important for replenishing the annual C losses and for improving both the biological and chemical properties of the soil (Goyal

Table 1
Rhizosphere soil physicochemical properties under organic amendment treatments (means ± SE)

Plots	pH	MC (%)	SOC (%)	N (%)	K (mg g^{-1})	P (ug g^{-1})
PC	5.34 ± 0.08 a	25.43 ± 0.36 a	1.25 ± 0.08	0.33 ± 0.013 a	0.026 ± 0.003	2.05 ± 0.14 a
VER	5.21 ± 0.05 a	23.99 ± 0.51	1.34 ± 0.06	0.32 ± 0.011 a	0.03 ± 0.005	2.67 ± 0.05 b
IPC	5.31 ± 0.08 a	24.69 ± 0.44	1.55 ± 0.07 a	0.37 ± 0.011 a	0.023 ± 0.003	1.92 ± 0.08 a
FYM	5.32 ± 0.03 a	23.35 ± 0.4 b	1.49 ± 0.06	0.32 ± 0.005 a	0.042 ± 0.007	2.09 ± 0.14 a
CON	4.64 ± 0.05 b	23.29 ± 0.35 b	1.22 ± 0.07b	0.25 ± 0.013 b	0.027 ± 0.004	2.03 ± 0.08 a

Notes. MC, moisture content; SOC, soil organic carbon; PC, plant compost; VER, verimcompost; IPC, integrated plant compost; FYM, farmyard manure; and CON, control. Data followed by different letters in a column are significantly different according to Tukey's test at $P \leq 0.05$.

et al. 1999). Furthermore, increased microbial population recorded in organically treated plots might be due to application of different types of organic manures, which provide adequate biomass as a feed for the microbes and help in increasing microbial population in the soil, as evident in the present study. The microorganisms play an important role in degrading complex organic compounds such as cellulose, lignin, and protein. Similar results were also obtained earlier by Prabhuraj et al. (2005), who observed that combination of farmyard manure, sericulture waste compost, green manure, and biofertilizers with NPK recorded significantly greater populations of inoculated phosphate-solubilizing microorganisms and N-fixing bacteria. Also the greater bacterial population in VER and FYM treatments may be due to the ratios of Gram-positive to Gram-negative bacteria and of bacteria to fungi as determined by signature phospholipids fatty acids, which were greater in the organic treatment (Kirchner, Wollum, and King 1993). They also concluded that organic amendment increased the C_{org} of the soil, whereas C_{org} and C/N ratio significantly affect bacteria and eukaryotic community structure. The manure soils also supplied large amounts of readily available C, resulting in a more diverse and dynamic microbial system (Kandeler and Marschner 2003).

Microbial Biomass Carbon

The soil microbial biomass is involved in the decomposition of organic materials and, thus, the cycling of nutrients in soils. It is also frequently used as an early indicator of changes in soil chemical and physical properties resulting from soil management and environmental stresses in agricultural ecosystems (Brookes 1995; Jordan et al. 1995; Trasar-Cepeda et al. 1998). Enhancement of microbial biomass after organic amendment has been reported in long-term (Garcia-Gil et al. 2000) as well as in short-term microcosm experiments (Saison et al. 2006). Our results showed that the addition of organic residues sharply increased the soil microbial biomass C compared to control. This might be attributed to stimulated suitable condition for microbial growth where organic residues have acted as a good substratum for microbial activity. Also, Inubushi et al. (1997) and Leita et al. (1999) indicated that soil treated with FYM, compost, and other organic manure showed a significant increase in total C_{org} and biomass C in response to the increasing amount of organic C added. Application of organic amendments increased the microbial biomass C. There is evidence that increasing inputs of crop residues increase soil organic matter and microbial biomass C (Mahmood et al. 1997; Graham, Haynes, and Meyers 2002), which is in accordance to the present study where the soil organic matter and microbial biomass C was greatest in IPC and FYM.

Physicochemical Properties

Soil pH was found to be an important factor affecting all microbial activities. There were significant changes in soil pH following the addition of different organic treatments compared to the control in the present study. The soil pH was found to be greater in the organic plots than in the control plot as also reported by Gelsomino and Cacco (2004), suggesting that addition of organic amendments induced a significant increase in soil pH. Tang and Yu (1999) reported that the concentration of organic anions in residues and the degree of decompositions of plant residues were important parameters influencing the direction (decrease or increase) and magnitude of changes in the pH of amended soils. The decomposition of organic wastes release calcium (Ca) and magnesium (Mg) nutrients, which could slightly increase the soil pH (Ramaswami and Son 1996). The use of farm-derived sources such as plant residues, compost, manures, and household wastes has commonly been used in the management of soil fertility (Kimani et al. 1998). Plant compost and animal manure are beneficial in soil because they can increase the water-holding capacity (Nandwa 1995), which is in accordance with the present study, where organic treatments showed an increase in moisture content (Table 1). Zak, Tilman, and Parmenter (1994) elucidated the importance of soil organic C, total N, and Olsen P, which were found to be greater in manure amendments, with a significant effect on the composition and quantity of the soil microbial community, a trend that was also observed in the present study of soybean rhizosphere. The greater value of soil C_{org}, N, P, and K in organically treated plots might be due to their greater content in organic amendments.

References

Allen, S. E., H. M. Grinshaw, J. A. Parkinson, and C. Quaramby. 1974. *Chemical analysis of ecological materials*. Oxford: Blackwell Scientific.

Alvarez, M. B., S. Gagne, and H. Anton. 1995. Effect of compost on rhizosphere microflora of the tomato and on the incidence of plant growth-promoting rhizobacteria. *Applied Environmental Microbiology* 61:194–199.

Anderson, J. M., and J. S. I. Ingram (Eds.). 1993. *Tropical soil biology and fertility: A handbook of methods*. Oxford: C.A.B. International.

Böhme, L., and F. Böhme. 2006. Soil microbiological and biochemical properties affected by plant growth and different long-term fertilization. *European Journal of Soil Biology* 42:1–12.

Brady, N. C., and R. R. Weil. 1999. Soil organic matter. In *The nature and properties of soils*, 446–490. Upper Saddle River, N.J.: Prentice Hall.

Brimecombe, M. J., F. A. De Lelj, and J. M. Lynch. 2001. The rhizosphere: The effect of root exudates on rhizosphere microbial populations. In *The rhizosphere: Biochemistry and organic substances at the soil–plant interface*, ed. R. Pinton, Z. Varanini, and P. Nannipieri, 95–140. New York: Marcel Dekker.

Brookes, P. C. 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. *Biology and Fertility of Soils* 19:269–279.

Chen, W., H. A. J. Hoitink, A. F. Schmitthenner, and O. H. Tuovinen. 1988. The role of microbial activity on the suppression of damping-off caused by *Pythium ultimum*. *Phytopathology* 78:314–322.

Curl, E. A. 1982. The rhizosphere: Relation to pathogen behavior and root disease. *Plant Disease* 66:623–630.

Dar, G. 1996. Effects of cadmium and sewage sludge on soil microbial biomass and enzyme activities. *Bioresource Technology* 56:141–145.

Darcy, A. L. 1982. Study of soya and lens exudates, I: Kinetics of exudation of fenolic compounds, amino acids, and sugars in the first days of plant growth. *Plant and Soil* 68:339–403.

Funck-Jensen, D., and J. Hockenhull. 1984. Root exudation, rhizosphere microorganism, and disease control. *Växtskyddsnotiser* 48:49–54.

Garcia-Gil, J. C., C. Plaza, P. Soler-Rovira, and A. Polo. 2000. Long-term effects of municipal soil waste compost application on soil enzyme activities and microbial biomass. *Soil Biology and Biochemistry* 32:1907–1913.

Gelsomino, A., and G. Cacco. 2004. Compositional shifts of bacterial groups in a solarized and amended soil as determined by denaturing gradient gel electrophoresis. *Soil Biology and Biochemistry* 38:91–102.

Gelsomino, C. C., A. Ambrosoli, R. Minati, and P. Ruggiero. 2004. Functional and molecular responses of soil microbial communities under differing soil management practice. *Soil Biology and Biochemistry* 36:1873–1883.

Girvan, M. S., J. Bullimore, A. S. Ball, J. N. Pretty, and A.M. Osborn. 2004. Responses of active bacterial and fungal communities in soil under winter wheat to different fertilizer and pesticide regimens. *Applied and Environmental Microbiology* 70:2692–2701.

Goyal, S., K. Chander, M. C. Mundra, and K. K. Kapoor. 1999. Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical condition. *Biology and Fertility of Soils* 29:196–200.

Graham, M. H., R. J. Haynes, and J. H. Meyers. 2002. Soil organic matter content and quality: Effects of fertilizer applications, burning, and trash retention on a long-term sugarcane experiment in South Africa. *Soil Biology and Biochemistry* 34:93–102.

Grayston, S. J., C. D. Campbell, R. D. Bardgett, J. L. Mawdsley, C.D. Clegg, K. Ritz, B. S. Griffiths, J. S. Rodwell, S. J. Edwards, W. J. Davies, D. J. Elston, and P. Millard. 2004. Assessing shifts in microbial community structure across a range of grasslands of differing management intensity using CLPP, PLFA, and community DNA techniques. *Applied Soil Ecology* 25:63–84.

Hiltner, L. 1904. Uber neuer erfahrungen und probleme auf dem gabiet der bodenbakteriologie and unter besonderer berucksichtingung der grundungung und brache. *Arbitration Deutsche Landwirtschafts Gesellschaft.* 98:59–78.

Inubushi, K., F. Shibahara, K. Hasegawa, and S. Yamamuro. 1997. Effect of added organic matter on microbial biomass nitrogen dynamics and plant uptake in paddy soils. In *Plant nutrition for sustainable food production and environment*, ed. T. Ando, K. Fujita, T. Mae, H. Matsumoto, S, Mori, and J. Sekiya, 777–778. Japan: Kluwer Academic Publishers.

Jackson, M. L. 1973. *Soil chemical analysis*. New Delhi: Prentice Hall India.

Johnson, L. F., and A. E. Curl. 1972. *Method for the research on ecology of soil-borne plant pathogens*. Minneapolis, Minn.: Burgess.

Jordan, D., R. J. Kremer, W. A. Bergfield, K. Y. Kim, and V. N. Cacnio. 1995. Evaluation of microbial methods as potential indicators of soil quality in historical agricultural fields. *Biology and Fertility of Soils* 19:297–302.

Kandeler, P. M. E., and B. Marschner. 2003. Structure and function of the soil microbial community in a long-term fertilizer experiment. *Soil Biology and Biochemistry* 35:453–439.

Kimani, S. K., K. W. Gathina, P. G. Mugare, and G. Cadisch. 1998. Effect of phosphorus and manure application on beans yield in central highlands of Kenya. In *Proceeding of the First All-African Crop Science Congress*. Kampala, Uganda: African Crop Science.

Kirchner, M. J., A. G. Wollum II, and L. D. King. 1993. Soil microbial populations and activities in reduced chemical input agroecosystems. *Journal of the Soil Science Society of America* 57:1289–1295.

Krishnakumar, S., A. Saravanan, S. K. Natarajan, V. Veerabadram, and S. Mani. 2005. Microbial population and enzymatic activity as influenced by organic farming. *Research Journal of Agricultural and Biological Science* 1:85–88.

Kurek, E., and J. Kobus. 1990. Beneficial and harmful effects of rhizosphere microflora on growth and development of plants. *Postepy Mikrobiologii* 29 (1–2): 103–123.

Leita, L., M. de Nobili, C. Mondini, G. Muhlbachova, L. Marchiol, G. Bragata, and M. Contin. 1999. Influence of inorganic and organic fertilization on soil microbial biomass, metabolic quotient, and heavy metal bioavailability. *Biology and Fertility of Soils* 28:371–376.

Liu, B., and J. B. Ristaino. 2003. Microbial community structure in soils from organic and conventional agroecosystems. *Phytopathology* 96:53.

MacFadyen, A. 1970. Soil metabolism in relation to ecosystem energy flow and to primary and secondary production. In *Method of study In soil ecology*, ed. J. Unesco, 167–172. Paris: IBP.

Mahmood, T., F. Azam, F. Hussain, and K. A. Malik. 1997. Carbon availability and microbial biomass in soil under an irrigated wheat–maize cropping system receiving different fertilizer treatments. *Biology and Fertility of Soils* 25:63–68.

Marinari, S., G. Masciandaro, B. Ceccanti, and S. Grego. 2000. Influence of organic and mineral fertilizers on soil biological and physiological properties. *Bioresource Technology* 72:9–17.

Martin, J. P. 1950. Use of acid, rose Bengal, and streptomycin in the plate method for estimating soil fungi. *Soil Science* 69:215–232.

McKinley, V. L., and J. R. Vestal. 1984. Biokinetic analyses of adaptation and succession: Microbial activity in composting municipal sewage sludge. *Applied Environmental Microbiology* 47:933–941.

Nandwa, S. W. 1995. Synchronization between soil nitrogen mineralization and maize uptake through management of maize stover. *The biology and fertility of tropical soil*, 6–7. Nairobi, Kenya: Instaprint.

Nannipieri, P., J. Ascher, M. T. Ceccherini, L. Landi, G. Pietramellara, and G. Renella. 2003. Microbial diversity and soil functions. *European Journal of Soil Science* 54:655–670.

Pięta, D. 1985. Occurrence of free amino acids in root exudates of bean (*Phaseolus vulgaris* L.). *Roczniki Nauk Rolniczych Seria* 15:193–203.

Pięta, D. 1987. Antagonistic effect of saprophytic bacteria of *Bacillus* and *Pseudomonas* species on *Fusarium* infections of cucumber plants. *Rozprawy Zeszyty Naukowe AR Wroclaw* 64:1–55.

Prabhuraj, K., U. D. Bongale, J. Sukumar, H. Sanaulla, and H. Thimma Reddy. 2005. Comparative study on the organic and integrated nutrient management in mulberry. *Progress of Research in Organic Sericulture and Seri-by-products Utilization*, 146–148. Bangalore: Cole Publishing Company.

Quideau, S. A., O. A. Chadwick, A. Benesi, R. C. Graham, and M. A. Anderson. 2001. A direct link between forest vegetation type and soil organic matter composition. *Geoderma* 104:41–60.

Rovira, A. D. 1965. Plant root exudates and their influence upon soil microorganisms. In *Ecology of soil-borne pathogens*, ed. K. F. Bacer and W. C. Snyder. Berkeley: University of California Press.

Ramaswami, P. P., and T. T. N. Son. 1996. Quality compost from agricultural wastes. Paper presented at the National Workshop on Organic Farming for Sustainable Agriculture, Water and Land Management Training and Research Institute, Hyderabad, India. 18–20 January, 1996.

Saison, C., V. Degrange, R. Oliver, P. Millard, C. Commeaux, D. Montange, and X. L. Roux. 2006. Alteration and resilience of the soil microbial community following compost amendment: Effects of compost level and compost-borne microbial community. *Environmental Microbiology* 8:247–257.

Shannon, C. E., and W. Wiener 1963. *The mathematical theory of communication*. Chicago: University of Illinois.

Tang, C., and Q. Yu. 1999. Impact of chemical composition of legume residues and initial soil pH on pH change of a soil after residue incorporation. *Plant and Soil* 215:29–38.

Trasar-Cepeda, C., C. Leirós, F. Gil-Sotres, S. Seoane. 1998. Towards a biochemical quality index for soils: An expression relating several biological and biochemical properties. *Biology and Fertility of Soils* 26:100–106.

Van Bruggen, A. H. C., and A. M. Semenov. 2000. In search of biological indicators for plant health and disease suppression. *Applied Soil Ecology* 15:13–24.

Warembourg, F. R., and H. D. Estelrich. 2001. Plant phenology and soil fertility effects on below-ground carbon allocation for an annual (*Bromus madritensis*) and a perennial (*Bromus erectus*) grass species. *Soil Biology and Biochemistry* 33:1291–1303.

Weon, H. Y., J. S. Kwon, J. S. Suh, and W. Y. Choi. 1999. Soil microbial flora and chemical properties as influenced by the application of pig manure compost. *Korean Journal of Soil Science and Fertility* 32:76–83.

Zak, D. R., D. Tilman, and R. R. Parmenter. 1994. Plant production and soil microorganisms in late successional ecosystem: A continental-scale study. *Ecology* 75:2333–2347.