Chemical and Biological Indicators of Soil Quality in Conventional and Organic Farming Apple Orchards

Yoon-Jung Lee and Jong-Bae Chung*

Division of Life and Environmental Sciences, Daegu University, Gyeongsan 712-714, Korea

Received April 27, 2007; Accepted May 27, 2007

Organic farming systems based on ecological concepts have the potential to produce sustainable crop yields with no decline in soil and environmental qualities. Recent expansion of sustainable agricultural systems, including organic farming, has brought about need for development of sustainable farming systems based on value judgments for key properties of importance for farming. Chemical and microbiological properties were chosen as indicators of soil quality and measured at soil depth intervals of 5-20 and 20-35 cm in conventional and organic-based apple orchards located in Yeongchun, Gyeongbuk. The orchards were two adjacent fields to ensure the same pedological conditions except management system. Soil pH in organic farming was around 7.5, whereas below 6.0 in conventional farming. Organic farming resulted in significant increases in organic matter and Kjeldahl-N contents compared to those found with conventional management. Microbial populations, biomass C, and enzyme activities (except acid phosphatase) in apple orchard soil of organic farming were higher than those found in conventional farming. Higher microbial quotient (C_{mic}/C_{org} ratio) and lower microbial metabolic quotient for CO_2 (qCO_2) in organic farming confirmed that organic farming better conserves soil organic carbon. Biological soil quality indicators showed significant positive correlations with soil organic matter content. These results indicate organic-based farming positively affected soil organic matter content, thus improving soil chemical and biological qualities.

Key words: *apple orchard, biological indicator, conventional farming, microbial activity, microbial biomass, organic farming, soil quality*

Industrialized agriculture system dependent on large inputs of fertilizers and pesticides is generally unstable, the potential for maximum yield being inevitably associated with risks due to the instability of the ecosystem. Although industrialized agricultural pattern is still the main stream of farming, farmers are more interested in creating sustainable farming systems that have the potential to produce similar yields year after year with no decline in soil and environmental qualities [Bezdicek *et al.*, 1984].

Sustainable agriculture systems based on ecological concepts promote biodiversity, recycle plant nutrients, protect soil from erosion, conserve and protect water, use minimum tillage, and integrate crop and livestock enterprises in the farms. Sustainable agriculture is also a way of raising healthy foods for consumers and animals, without harming the environment. Organic farming is one of the common sustainable agriculture systems. Organic farmers do not use synthetic fertilizers and pesticides, and attempt to close nutrient cycle on their farms, protect the quality of the environment, and enhance beneficial biological interactions and processes [Vandermer, 1995].

Soil, one of our most valuable resources, regulates the global biogeochemical cycles, filters and remediates anthropogenic pollutants, and enables food production. Sustainable soil fertility management is the most important practice for long-term sustainable crop production, and in organic farming it relies on a long-term integrated approach rather than the more short-termed very targeted solutions commonly found in the conventional agriculture [Watson *et al.*, 2002].

Soil quality is a necessary indicator of sustainability in land management [Herrick, 2000], and depends on a large number of physical, chemical and biological soil properties. Characterization of the soil quality requires the selection of indicators most sensitive to the changes in management

*Corresponding author
Phone: +82-53-850-6755; Fax: +82-53-850-6759
E-mail: jbchung@daegu.ac.kr

Abbreviations: qCO_2, metabolic quotient of CO_2

practices [Doran *et al.*, 1994]. However, a good soil quality in one farming system may not be so good in another, and thus rendering the quantitative assessment of soil quality difficult. Over the last several years, researchers have attempted to establish minimum data sets of physical, chemical, and biological properties that can be used as quantitative indicators in soil quality assessments [Andrews *et al.*, 2002; Carter, 2002; Doran *et al.*, 1994; Frankenberger and Dick, 1983; Herrick, 2000]. Soil biological properties are mostly controlled by microorganisms, and the key processes controlled by these organisms include decomposition of organic materials and plant residues, increased nutrient availability of P, Mn, Fe, Zn, and Cu, nitrogen fixation, biological control of pests, biodegradation of pesticides and pollutants, and improved soil aggregation [Paul and Clark, 1989]. For the assessment of soil biological quality, a variety of biochemical and microbial properties including microbial population and diversity, biological activities, and disease suppressiveness should be analyzed.

In Korea, the history of sustainable farming systems is relatively short, and only few farms have followed the regulations for sustainable farming for more than one decade. However, sustainable farming has been rapidly expanding, and development of sustainable farming systems necessarily must be based on value judgments for key properties of importance for farming [Lee *et al.*, 2004]. The build-up of a large and active soil microbial biomass is critically important for sustaining the productivity of soils in organic farming systems [Vandermer, 1995].

In this study, we investigated the effect of organic soil management on soil biological properties of apple orchards. Because individual soil biological indicator vary both seasonally and spatially, and also many physical and chemical properties affect soil biological quality [Arshad and Martin, 2002], we selected side-by-side apple orchards adopting conventional and organic farming systems and compared their soil chemical and biological properties.

Materials and Methods

Study area and soil sampling. The conventional and organic-based apple orchards selected for this study were located in Yeongchun, Gyeongbuk (latitude 36°01'N and longitude 128°60'E). The organic-based apple orchard has been managed without using synthetic fertilizers and pesticides since 1999. The selected apple orchards were two adjacent fields to ensure the same pedological conditions except for the management system. The soil type in the area is classified as Daegu series. Daegu soils are loamy skeletal, nonacid, mesic family of Lithic Eutrudepts. The soil fertility management of the two fields differs markedly, but is representative for the conventional and organic farming (Table 1). Characteristics of the fermented compost used in the organically managed apple orchard are listed in Table 2.

Soil samples were collected from two different depths (5-20 and 20-35 cm) at each of the three sites in both conventional and organic-based apple orchards in September 2006 with randomized sampling points. Large pieces of raw organic materials were removed from the soil surface before collecting the samples. Field moist soil was sieved (2 mm) and divided into two subsamples. One was immediately stored at 4°C in plastic bags loosely tied to ensure sufficient aeration and to prevent moisture loss until assaying of the microbiological and enzymatic activities. The other was air-dried for chemical analysis.

Chemical analyses. Soil pH and EC were measured in a 1 : 5 soil to water extract using Mettler 350 pH meter (Mettler-Tokedo Ltd., Essex, England) and Orion Mate 90 conductivity meter (Corning Co., Corning, NY, USA). Total organic carbon was determined by dichromate oxidation following Walkley and Black procedure [Nelson and Sommers, 1982]. Total nitrogen was determined by Kjeldahl distillation method after sulphuric acid digestion using Se, $CuSO_4$, and K_2SO_4 as catalysts [Bremner and Mulvaney, 1982]. Ammonium (NH_4-N) and nitrate (NO_3-N) in the soils were extracted with 2 M KCl, and their contents were determined using the FIA-5000 autoanalyzer (FOSS Tecator, Höganäs, Sweden). Available phosphorus (P) was measured following Lancaster method [NIAST, 1988].

Soil microbial population and biomass. Microbial populations were determined by soil dilution plating on various agar media [NIAST, 1988]. For each of the three subsamples from each composite soil sample, 10 g soil was weighed and added to 90 mL sterilized water, vigorously stirred for 30 min, and serially diluted (10^2-10^7). Colony counts for microorganisms were determined using a spread plate technique to inoculate five replicate agar plates per dilution prior to incubation for adequate colony growth. Aerobic bacteria were enumerated on YG media (yeast extract 1 g, glucose 1 g, K_2HPO_4 0.3 g, KH_2PO_4 0.3 g, $MgSO_4 7 \cdot H_2O$ 0.2 g, agar 15 g, distilled water 1 L, pH 6.8-7.0) after 14 days incubation at 28°C. Gram (-) bacteria were grown on YG media containing 5 mL of 0.1% crystal violet solution for 3 days at 28°C. Fluorescent *Pseudomonas* were grown on Pseudo 1 media (K_2HPO_4 1 g, $MgSO_4 7H_2O$ 0.5 g, KCl 0.2 g, $NaNO_3$ 5 g, sodium deoxycholate 1 g, betaine 5 g, agar 15 g, distilled water 1 L, pH 7.2-7.4) for 2 days at 28°C. For counts of mesophilic *Bacillus*, the serial dilutions of soil samples heated at 80°C for 30 min were inoculated on YG media and incubated for 3 days at 28°C. Fungi were grown on

Martin media (KH_2PO_4 1 g, $MgSO_4 7 \cdot H_2O$ 0.5 g, peptone 5 g, glucose 10 g, rose bengal 0.033 g, agar 20 g, distilled water 1 L, streptomycin 33 mg L^{-1}) for 5 days at 28°C. Actinomycetes were enumerated on starch-casein agar media (starch 10 g, casein 1 g, K_2HPO_4 0.5 g, cyclohexamide 0.05 g, agar 15 g, distilled water 1 L) after 14 days incubation at 25°C.

Soil microbial biomass C was determined using a chloroform fumigation extraction method [Vance *et al.*, 1987]. The microbial biomass C was calculated as the difference in extractable C between the fumugated and unfumigated samples using a conversion factor of 0.45 [Jenkinson *et al.*, 2004].

Microbial respiration rates. Soil respiration was determined as the rate of CO_2 evolution for each sample as described by Marinari *et al.* (2006). Metabolic quotient of CO_2 (qCO_2) was calculated by dividing respiration rate by microbial biomass carbon.

Soil enzyme activities. Dehydrogenase activity was determined by colorimetric measurement of the reduction of 2,3,5-triphenyltetrazolium chloride to triphenylformazan according to the method of Casida *et al.* (1964). Acid and alkaline phosphatases were assayed according to the methods described by Tabatabai (1982). The procedure involves the spectrophotometric determination of *p*-nitrophenol released by soil during incubation at 37°C. Protease was assayed by spectrophotometric determination of amino acid leucine released from N-carbobenzoxy-L-phenylalanyl-L-leucine by soil during incubation at 37°C [NIAST, 1988]. Urease activity was determined based on the measurement of the NH_4^+ released by urease when soil was incubated with THAM buffer, urea solution, and toluene at 37°C for 2 h [Tabatabai, 1982].

Statistical analysis. Duncan's multiple range test was used to separate means when the *F*-value indicated differences at the $P < 0.05$ level using SAS program [SAS Institute, 1995].

Results and Discussion

Soil chemical properties. Chemical properties of the apple orchard soils as affected by organic manuring and chemical fertilization are shown in Table 3.

In the conventional farming apple orchard soil pH was in a weak acidic condition and the pH value was slightly lower than the recommended optimum range of 6.0-6.5 for tree crops [NIAST, 1999]. However, soil pH in the organically managed apple orchard was near the neutral condition. High pH in the organically managed soil could be due to the long-term application of high pH organic materials. Liebig and Doran (1999) found that soil pH values in organic farms were closer to neutral and were generally higher than those found in the conventional farms. Although not significantly different, soil EC was also slightly higher with conventional soil management. Neither inorganic nor organic fertilization appeared to cause soil salinization.

Organic matter contents in the soil of organic management were higher in both depths than those subjected to the conventional management. This result could be due to the higher rate of organic material input in the organically managed apple orchard (Table 1). The use of organic materials have been shown to maintain soil organic matter at higher levels than inorganic fertilization [Marriott and Wander, 2006; Tu *et al.*, 2006a]. In addition, organic practices significantly increased the soil extractable C content [Tu *et al.*, 2006b]. Although several years of contrasting soil management was not sufficient to produce a consistent difference in soil organic matter content, the steady use of organic materials on organic farms is considered important in maintaining the level of soil organic matter [Marinari *et al.*, 2006]. Depending on the soil type, climate, management, and capacity of the soil to store organic matter, organic C levels may increase linearly with the amount of organic matter input [Carter, 2002].

Table 1. Management practices employed on the conventionally and organically managed apple orchards

Farming system	Organic matter input	Chemical input	Tillage method
Organic farming	Fermented compost application (30 Mg ha^{-1}) on the surface of the soil within the drip line in December	Several foliar applications of nutrients between May and September	None
Conventional farming	Composted manure application (10 Mg ha^{-1}) in December	1 Mg ha^{-1} (N-P-K=17-21-17) in February and 100 kg ha^{-1} (N-P-K=17-21-17) in June	Ploughing 0.2 m deep every year

Table 2. Characteristics of the fermented compost used in the organically managed apple orchard

pH (1:5 H_2O)	EC	Organic matter	Total N	NH_4-N	NO_3-N	Total P
	dS m^{-1}	------- g kg^{-1} -------		------ mg kg^{-1} ------		g kg^{-1}
7.4	8.9	639	33.6	659	70	15.8

Table 3. Soil chemical properties of apple orchards under organic and conventional managements

Farming system and soil depth	pH (1:5 H_2O)	EC	Organic matter	Total N	NH_4-N	NO_3-N	Available P
		dS m^{-1}	----- g kg^{-1} -----		---------- mg kg^{-1} ----------		
Organic							
5-20 cm	7.4a[†]	0.87bc	55.8a	3.4a	1.3b	10.5b	541.4b
20-35 cm	7.6a	0.75c	38.1b	2.4b	1.3b	6.8b	481.8b
Conventional							
5-20 cm	5.8b	1.21a	35.5bc	2.3b	4.2a	26.0a	845.9a
20-35 cm	6.0b	0.97b	32.1c	1.2c	3.3ab	23.4a	888.3a

[†]Means within a column followed by the same letter are not significantly different at $P < 0.05$.

The organically managed apple orchard soil also had a higher total N content than that of the conventionally managed orchard. Such high total soil N content in the organically managed orchard could be due to the application of organic materials, as reported previously by several other researches [Blaise *et al.*, 2004; Gerhardt, 1997; Marriott and Wander, 2006]. Soil NH_4-N and NO_3-N contents were higher in both depths in the conventional farming soil compared with that of the organic farming apple orchard. Blaise *et al.* (2004) found higher NH_4-N and NO_3-N contents in cotton fields subjected to organic management than with the modern method of cultivation. Marinari *et al.* (2006) also found that NH_4-N and NO_3-N contents were continuously higher during the growing season in organic farming soil compared with conventional farming soil. However, Liebig and Doran (1999) reported that soil NO_3-N was significantly higher on the surface 30.5 cm of the conventional farm as compared with the organic farm. The soil mineral N content could differ significantly depending on the amount and time of organic and inorganic N fertilizer applications. The high NH_4-N and NO_3-N contents in the soils of conventional based apple orchard found in this study could be due to the additional fertilization during the mid season.

Available P was higher with the conventional farming than organic. The annual addition of soluble P fertilizer could be the reason for the higher accumulation of available P in the soil of conventional farming apple orchard. Nonetheless, in spite of the relatively lower available P content found in the organic farming apple orchard soil, the level of available P, 480-540 mg kg^{-1}, was sufficient for crop production. Liebig and Doran (1999) found that trends in the extractable P between organic and conventional farms were not consistent, and variation in the extractable P level was greater in conventional farms.

Previous works reported on the changes in the soil quality in terms of increased organic C, total N, and available P contents of organic soil as compared to those from conventional soil fertility managements [Andrews *et al.*, 2002; Gerhardt, 1997; Liebig and Doran, 1999]. The higher pH and higher organic matter and total N contents in the organic farming apple orchard soil could be the results of long-term effects of organic soil fertility management. Although Blaise *et al.* (2004) found higher contents of mineral N and $NaHCO_3$ extractable P in cotton fields of organic cultivation than those from modern cultivation, the contents of inorganic nutrients in the soil would vary depending on the amount and time of chemical and organic fertilizer applications. As mentioned by Liebig and Doran (1999), having an appropriate balance of nutrients for crop growth at critical times during the growing season is an essential factor to achieve optimal soil function for promoting a more sustainable agriculture. A relatively consistent supply of available mineral nutrients would be available for crop growth during the growing season through mineralization of organic matter in the organic-based farming.

Soil microbial population and biomass. The effects of organic and conventional farming systems on the microbial populations of apple orchard soils are shown in Table 4. Organic soil fertility management significantly increased total bacterial populations. Populations of Gram (-) bacteria and *Pseudomonas* were about 10-fold higher in the organically managed soil than in the conventionally managed soil. Mesophilic *Bacillus* population was also higher in the organically managed soil. However, actinomycetes, which are more autochthonous-type organisms, varied only slightly between the soil fertility management systems. Although not significantly different, populations of fungi were relatively higher in the conventionally managed soil in comparison to the organically managed one. Microbial biomass is among the most labile pools of organic matter, serving as an important reservoir of plant nutrients, such as N and P [Marumoto *et al.*, 1982]. Microbial biomass was significantly higher in the apple orchard managed organically than conventionally (Fig. 1), possibly due to

Table 4. Effects of organic and conventional soil fertility managements on the microbial populations in apple orchard soils

Farming system and soil depth	Aerobic bacteria (×10⁴)	Gram (-) bacteria (×10³)	Fluorescent *Pseudomonas* (×10³)	Mesophilic *Bacillus* (×10³)	Fungi (×10²)	Actinomycetes (×10⁴)
	---------- Organisms g^{-1} dry soil ----------					
Organic						
5-20 cm	75.5 ± 9.5a†	148.3 ± 36.9a	177.5 ± 43.1a	66.4 ± 1.6a	30.3 ± 1.3c	33.8 ± 2.9a
20-35 cm	77.5 ± 3.9a	168.5 ± 14.6a	179.8 ± 16.5a	51.9 ± 3.0b	32.0 ± 0.8c	43.5 ± 16.7a
Conventiona						
5-20 cm	29.5 ± 4.1b	18.5 ± 3.1b	16.0 ± 4.2b	37.7 ± 7.1c	36.8 ± 6.0ab	26.7 ± 6.7a
20-35 cm	17.5 ± 4.8c	22.2 ± 4.8b	19.3 ± 4.1b	31.6 ± 5.1c	38.8 ± 2.9a	27.8 ± 12.1a

†Means within a column followed by the same letter are not significantly different at $P < 0.05$.

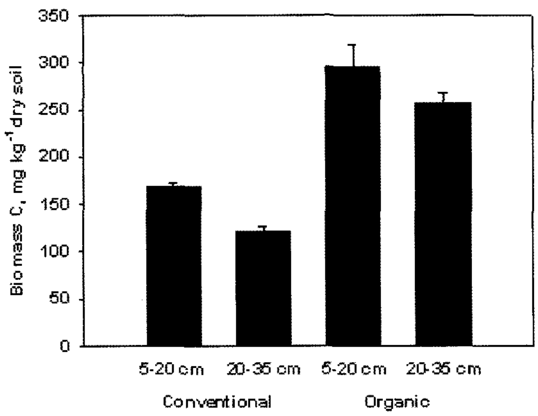

Fig. 1. Effects of conventional and organic managements on the biomass C in apple orchard soils.

the increased microbial populations in the organically managed apple orchard soil. Populations of aerobic bacteria, Gram (-) bacteria, *Pseudomonas*, and mesophilic *Bacillus*, and content of biomass C were significantly correlated with the soil organic matter content (Table 5).

It has been well documented that manure and other organic amendments can have numerous gross effects on the soil microbial populations and biomass under different climatic and soil conditions [Marinari *et al.*, 2006; Melero *et al.*, 2006]. The higher microbial populations and biomass in organic farming system are due to the greater supply of available C and improvement of other soil physical and chemical characteristics [Schjønning *et al.*, 2002]. The relatively higher fungal population in the conventionally managed apple orchard in this study could be due to the acidic reaction of the soil. Many fungi are insensitive to high hydrogen ion concentrations and fungi make up a relatively larger percentage of the community in acid soil. Elmholt and Labouriau (2005) found that soil fungal populations varied significantly between organic and conventional farming systems, and postulated that the fungal population could be associated with certain management factors being more prevalent in one farming system than the other. Filamentous fungi are known to be rather insensitive to farming system as assessed by dilution plating [Shannon *et al.*, 2002].

The ratio of microbial C (C_{mic}) to total organic C (C_{org}) is an indication of the quality of soil organic matter for microbial biomass establishment, and studies have found the ratio is significantly affected by the farming systems and was greater in the organic farming as compared to the conventional farming system [Anderson and Domsch, 1989; Marinari *et al.*, 2006; Melero *et al.*, 2006]. In this study, a significantly higher C_{mic}/C_{org} ratio was found in organic-based apple orchard as compared to the conventional one, indicating a better soil quality (Fig. 2). The considerably higher values of C_{mic}/C_{org} ratios are probably due to the easily available carbon fraction of the introduced organic material [Moscatelli *et al.*, 2005].

Soil microbial respiration rate. Effects of conventional and organic farming on the microbial respiration rate and qCO_2 are presented in Table 6. Soil microbial respiration

Table 5. Correlation coefficients between soil organic matter content and microbial populations (n = 16)

	Aerobic bacteria	Gram (-) bacteria	Fluorescent *Pseudomonas*	Mesophilic *Bacillus*	Fungi	Actinomycetes	Biomass C
Organic matter	0.385**	0.605*	0.665**	0.911**	-0.707**	0.099	0.613*

*$p < 0.05$; **$p < 0.01$.

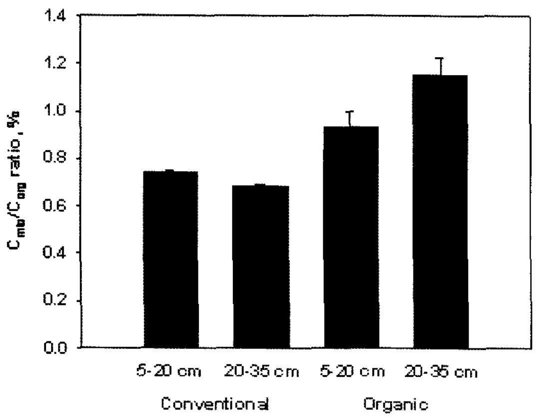

Fig. 2. Effects of conventional and organic managements on the microbial quotient (C_{mic}/C_{org} ratio) in apple orchard soils.

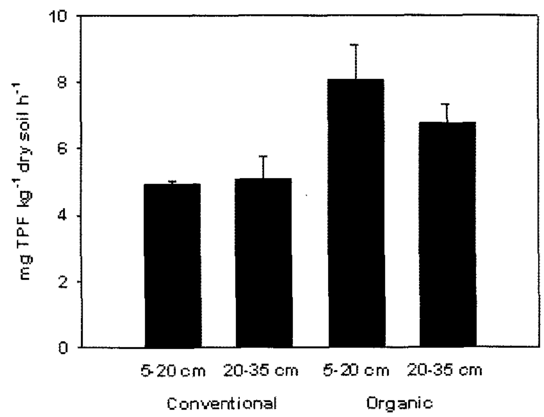

Fig. 3. Dehydrogenase activities in apple orchard soils as affected by conventional and organic managements. Vertical bars are standard deviations.

Table 6. Effects of conventional and organic farmings on the microbial respiration rate and metabolic quotient for CO_2 (qCO_2) in apple orchard soils

Farming system and soil depth	Microbial respiration rate	Microbial metabolic quotient[†] (qCO_2)
	mg CO_2 kg^{-1} soil day^{-1}	day^{-1}
Organic		
5-20 cm	69.5 ± 6.0b[‡]	0.24 ± 0.04c
20-35 cm	69.3 ± 0.1b	0.27 ± 0.01bc
Conventional		
5-20 cm	93.5 ± 9.2a	0.41 ± 0.01a
20-35 cm	64.3 ± 2.3b	0.31 ± 0.03b

[†]Microbial metabolic quotient was calculated by dividing respiration rate by biomass carbon.
[‡]Means within a column followed by the same letter are not significantly different at $P < 0.05$.

rate, measuring the microbial activity, was highest in 5-20 cm depth soil of the conventional farming apple orchard, whereas, 20-35 cm depth soils, the respiration rate was not significantly different between conventional and organic farming apple orchards. The qCO_2 was higher in the conventional than organic farming apple orchard, and the highest value was found in 5-20 cm depth soil of the conventional farming. This indicates microorganisms in the organic farming soils need less energy to maintain their biomass than ones from the conventional farming soils. In general, comparatively low qCO_2 values are a typical feature of the diverse and highly interrelated communities and thus can be used as a specific indicator of soil quality managed under organic and conventional conditions [Anderson and Domsch, 1993]. Higher respiration rate was found in smaller microbial communities of the conventional farming systems [Hopkins and Shiel, 1996], and high soil qCO_2 values was found in soils with less available nutrients [Agnelli *et al.*, 2001]. The higher C_{mic}/C_{org} ratio and lower qCO_2 in organic farming found in this study also support the hypothesis that organic farming better conserves soil organic carbon as reported by Marinari *et al.* (2006).

Soil enzyme activities. Because soil enzymes react to changes in soil management more quickly than other variables, they can be used as potential indicators of soil quality for sustainable management [Garcia *et al.*, 2000]. The measurement of dehydrogenase activity is particularly useful in assessing the overall microbial activity since it is linked to the microbial oxidation of organic substances and can provide an index of endogenous soil microbial activity [Casida *et al.*, 1964]. In this study, the activity of dehydrogenase was significantly higher in the soils of organically managed apple orchard than the conventional one (Fig. 3), indicating that the soil microbial metabolism was greatly enhanced as a result of the organic material application. According to Tejada *et al.* (2006), the amendment of organic materials to soil increased dehydrogenase activity, because the added material may contain intra- and extracellular enzymes, thus stimulating the microbial activity in the soil.

In soils phosphatase in soils is derived mostly from the microbial population [Tabatabai, 1982] and has been suggested as a good index of microbial activity [Frankenberger and Dick, 1983]. Alkaline phosphatase activity was significantly higher in the soils of organically managed apple orchard, whereas acid phosphatase activity was higher in the soils of conventionally managed apple orchard (Fig. 4 and 5). Acid phosphatase activity has been reported to be predominant in acid soils, whereas alkaline phosphatase dominates in alkaline soils [Dick and Tabatabai, 1984]. Kremer and Li (2003) showed that phosphatase activity in soils under organic management

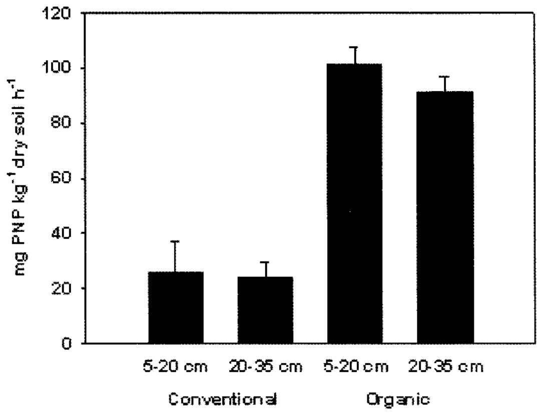

Fig. 4. Alkaline phosphatase activities in apple orchard soils as affected by conventional and organic managements. Vertical bars are standard deviations.

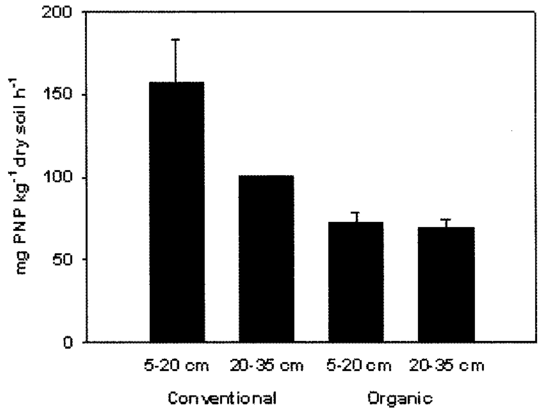

Fig. 5. Acid phosphatase activities in apple orchard soils as affected by conventional and organic managements. Vertical bars are standard deviations.

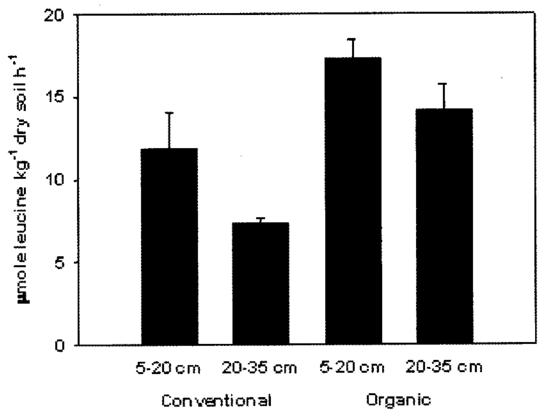

Fig. 6. Protease activities in apple orchard soils as affected by conventional and organic managements. Vertical bars are standard deviations.

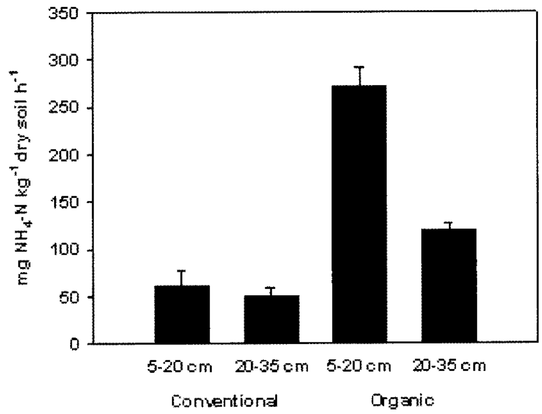

Fig. 7. Urease activities in apple orchard soils as affected by conventional and organic managements. Vertical bars are standard deviations.

was higher than that under conventional management. Alkaline phosphatase activity was closely related to the soil organic matter content [Melero *et al.*, 2006]. Acid phosphatase activity was correlated with organic C and highly dependent on the soil pH [Paz Jimenez, 2002]. The higher acid phosphatase activity in lower organic matter soil of the conventionally managed apple orchard found in this study indicates that acidic soil condition could be a more important controlling factor for the enzyme than the organic matter content. The application of organic fertilizer generally increases the rate of organic-P mineralization in the soil and may have positive implications for nutrient cycling and soil fertility [Garcia *et al.*, 1994; Tejada *et al.*, 2006; Chang *et al.*, 2007].

Activities of protease and urease were also higher in the apple orchard soils under organic than conventional management (Fig. 6 and 7). Both hydrolase enzymes are associated with mineralization of organic nitrogen and also sensitive indicators of management-induced changes in the soil quality due to their strong relationship with the soil organic matter content [Masciandaro and Ceccanti, 1999].

Increasing the organic matter, total nitrogen, and available phosphorus content could serve as a basis for increasing both the biological and enzymatic soil activities. Activities of all five enzymes investigated in the apple orchards were higher in the 5-20 cm depth soils, and activities of the enzymes except acid phosphatase were significantly correlated with the soil organic matter content (Table 7).

Soil organic matter contents were significantly higher in apple orchards under organic farming system compared to those found under conventional farming system. Soil biological parameters including microbial populations and biomass, and enzyme activities were strongly influenced by the farming system, and these parameters showed significant positive correlations with the soil organic matter content. These results indicate that for

Table 7. Correlation coefficients between soil organic matter content and enzyme activities (n=16)

	Dehydrogenase	Alkaline phosphatase	Acid phosphatase	Protease	Urease
Organic matter	0.748**	0.947**	-0.396	0.837**	0.889**

*$P < 0.05$; **$P < 0.01$.

successful soil quality management, input of organic materials is of importance, and long-term organic-based farming positively affect the soil organic matter content, thereby improving the soil chemical and biological qualities.

Acknowledgments. The authors thank Dr. Ul-Gum Kang of Youngnam Agricultural Research Institute for assistance in soil microbial population measurements.

References

Agnelli A, Ugolini FC, Corti G, and Pietramellara G (2001) Microbial biomass C and basal respiration of fine earth and highly altered rock fragments of two forest soils. *Soil Biol Biochem* **33**, 613-620.

Anderson TH and Domsch KH (1993) The metabolic quotient for CO_2 (*q*CO2) as a specific activity parameters to assess the effect of environmental conditions, such as pH, on the microbial biomass of forest soils. *Soil Biol Biochem* **25**, 393-395.

Andrews SS, Mitchell JP Mancinelli R, Karlen DL, Hartz, TK, Horwath WR, Pettygrove SG, Scow KM, and Munk DS (2002) On-farm assessment of soil quality in California's Central Valley. *Agron J* **94**, 12-22.

Arshad MA and Martin S (2002) Identify critical limit for soil quality indicators in agroecosystems. *Agric Ecosyst Environ* **88**, 153-160.

Bezdicek DF, Power JF, Keeney DR, and Wright MJ (19840 Organic farming: Current technology and its role in a sustainable agriculture. American Society of Agronomy, Madison, WI, USA.

Blaise D, Rupa TR, and Bonde AN (2004) Effect of organic and modern method of cotton cultivation on soil nutrient status. *Commun Soil Sci Plant Anal* **35**, 1247-1261.

Bremner JM and Mulvaney CS (1982) Nitrogen-Total. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, Page AL *et al.* (eds.) p. 595-624, SSSA, Madison, WI, USA.

Carter MR (2002) Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. *Agron J* **94**, 38-47.

Casida LE, Klein DA Jr, and Santoro T (1964) Soil dehydrogenase activity. *Soil Sci* **98**, 371-376.

Chang EH, Chung RS, and Tsai YH (2007) Effect of different application rates of organic fertilization on soil enzyme activity and microbial population. *Soil Sci Plant Nutr* **53**, 132-140.

Dick WA and Tabatabai MA (1984) Kinetic parameters of phosphatase in soils and organic waste materials. *Soil Sci* **137**, 7-15.

Doran JW, Coleman DC, Bezdicek DF, and Stewart BA (1994) In *Defining Soil Quality for a Sustainable Environment*. SSSA Special Publication Number 35. Soil Science Society of America, Madison, WI, USA.

Elmholt S and Labouriau R (2005) Fungi in Danish soils under organic and conventional farming. *Agric Ecosyst Environ* **107**, 65-73.

Frankenberger WT Jr and Dick WA (1983) Relationship between enzyme activities and microbial growth and activity indices in soil. *Soil Sci Soc Am J* **47**, 945-951.

Garcia C, Hernandez T, Costa F, and Ceccanti B (1994) Biochemical parameters in soils regenerated by the addition of organic wastes. *Waste Manage Res* **12**, 457-466.

Garcia C, Hernandez T, and Rolden A (2000) Changes in microbial activity after abandonment of cultivation in a semiarid Mediterranean environment. *J Environ Qual* **26**, 285-291.

Gerhardt RA (1997) A comparative analysis of the effects of organic and conventional farming systems on soil structure. *Biol Agric Hort* **14**, 139-157.

Herrick JE (2000) Soil quality: an indicator of sustainable land management? *Appl Soil Ecol* **15**, 75-83.

Hopkins DW and Shiel RS (1996) Size and activity f soil microbial communities in long-term experimental grassland plots treated with manure and inorganic fertilizers. *Biol Fertil Soils* **22**, 66-70.

Jenkinson, DS, Brookes PC, and Powlson DS (2004) Measuring soil microbial biomass. *Soil Biol Biochem* **36**, 5-7.

Kremer RJ and Li J (2003) Developing weed-suppressive soils through improved soil quality management. *Soil Tillage Res* **72**, 193-202.

Lee YJ, Choi DH, Kim SH, Lee SM, Lee YH, Lee BM, and Kim TW (2004) Long-term changes in soil chemical properties in organic arable farming systems in Korea. *Korean J Soil Sci Fert* **37**, 228-234.

Liebig MA and Doran JW (1999) Impact of organic production practices on soil quality indicators. *J Environ Qual* **28**, 1601-1609.

Marinari S, Mancinelli R, Campiglia E, and Grego S (2006) Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. *Ecol Indicators* **6**, 701-711.

Marriott EE and Wander MM (2006) Total and labile soil organic matter in organic and conventional farming systems. *Soil Sci Soc Am J* **70**, 950-959.

Marumoto T, Anderson JPF, and Domsch KH (1982) Mineralization of nutrients from soil microbial biomass. *Soil Biol Biochem* **14**, 469-475.

Masciandaro G and Ceccanti B (1999) Assessing soil quality in different agro-ecosystems through biochemical and chemico-structural properties of humic substances. *Soil Tillage Res* **51**, 129-137.

Melero S, Porras JCR, Herencia JF, and Madejon E (2006) Chemical and biochemical properties in a silty loam soil under conventional and organic management. *Soil Tillage Res* **90**, 162-170.

Moscatelli MC, Lagomassino A, Marinari S, De Angelis P, and Grego S (2005) Soil microbial indices as bioindicators of environmental changes in a poplar plantation. *Ecol Indicators* **5**, 171-179.

Nelson DW and Sommers LE (1982) Total carbon, organic carbon, and organic matter. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, Page AL *et al.* (eds.) p. 539-579, SSSA, Madison, WI, USA.

NIAST (1988) In *Methods of Soil Chemical Analysis*. National Institute of Agricultural Science and Technology, Suwon, Korea.

NIAST (1999) In *A guidance of fertilization for crops*. National Institute of Agricultural Science and Technology, Suwon, Korea.

Paul EA and Clark FE (1989) In *Soil Microbiology and Biochemistry*. Academic Press, Inc. New York, USA.

Paz Jimenez M de la, Horra AM de la, Pruzzo L, and Palma RM (2002) Soil quality: a new index based on microbiological and biochemical parameters. *Biol Fertil Soils* **35**, 302-306.

SAS Institute (1995) SAS/EIs software reference (2nd ed.) SAS Institute, Cary, NC, USA.

Schjønning P, Elmholy S, Munkholm LJ, and Debosz K (2002) Soil quality of humid sandy loams as influenced by organic and conventional long-term management. *Agric Ecosyst Environ* **88**, 195-214.

Shannon D, Sen AM, and Johnson DB (2002) A comparative study of the microbiology of soils managed under organic and conventional regimes. *Soil Use Manage* **18**, 274-283.

Tabatabai MA (1982) Soil Enzymes. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, Page AL *et al.* (eds.) p. 903-947, SSSA, Madison, WI, USA.

Tejada M, Hernandez MT, and Garcia C (2006) Application of two organic amendments on soil restoration: Effects on the soil biological properties. *J Environ Qual* **35**, 1010-1017.

Tu C, Louws FJ, Creamer NG, Mueller JP, Brownie C, Fager K, Bell M, and Hu S (2006a) Response of soil microbial biomass and N availability to transition strategies from conventional to organic farming systems. *Agric Ecosyst Environ* **113**, 206-215.

Tu C, Ristaino JB, and Hu S (2006b) Soil microbial biomass and activity in organic tomato farming systems: Effects of organic inputs and straw mulching. *Soil Biol Biochem* **38**, 247-255.

Vance ED, Brookes PC, and Jenkinson DS (1987) An extraction method for measuring soil microbial biomass C. *Soil Biol Biochem* **19**, 703-707.

Vandermer J (1995) The ecological basis of alternative agriculture. *Annu Rev Ecol Systematics* **26**, 703-707.

Watson CA, Atkinson D, Gosling P, Jackson LR, and Rayna FW (2002) Managing soil fertility in organic farming systems. *Soil Use Manage* **18**, 239-247.