International Journal of Environmental Science and Technology (2023) 20:12041–12052
https://doi.org/10.1007/s13762-023-05189-w

ORIGINAL PAPER

Impact of different co-composted poultry manures on the chemical and biological quality of the calcareous soil

S. Maleki[1] · A. Beheshti-Alagha[1] · F. Ranjbar[1] · R. Sharifi[2]

Received: 4 October 2022 / Revised: 27 May 2023 / Accepted: 24 August 2023 / Published online: 19 September 2023

Abstract
There is a gap knowledge regarding combined multiple chemical and biological parameters of the soil after using composted poultry manure. In this study, four types of co-composted poultry manure were added to a calcareous soil at two levels of 5 and 10% (w/w) and after one-month incubation, some chemical and biological properties were measured. The application of different composts led to a significant reduction in soil pH in the range of 0.3–0.5 units. On average, the increase in chemical parameters compared to those in the control was as follows at application levels of 5 and 10%, respectively: 0.61 and 1.19 dS m^{-1} for electrical conductivity, 1.36 and 2.68% for organic carbon, 0.165 and 0.332% for total nitrogen, 3.1 and 7.2 $cmol_c$ kg^{-1} for cation exchange capacity, 101 and 314 mg kg^{-1} for available ammonium, 1210 and 2251 mg kg^{-1} for available nitrate, 177 and 408 mg kg^{-1} for available phosphorus, and 940 and 1882 mg kg^{-1} for available potassium. Control soil had the lowest microbial respiration, microbial biomass carbon (MBC), substrate-induced respiration, and the highest metabolic quotient. The mentioned indices were respectively in the ranges of 136–174 mg C kg^{-1}, 397–517 mg C kg^{-1}, 1354–1482 mg C kg^{-1}, and 0.048–0.050 mg C mg^{-1} MBC day^{-1} at the application level of 10%. Despite the favourable effects of composted poultry manure on the chemical quality of the soil, it is suggested that the level of application should be taken into account to prevent environmental pollution through excessive nitrogen and phosphorus.

Keywords Composted poultry manure · Organic carbon · Available nitrate · Microbial respiration · Microbial biomass carbon

Introduction

Providing the food needed by the growing world population requires an increase in cultivated area or an increase in production per unit area. Since the extent of arable land is limited, the second option has been given more consideration. Excessive use of chemical fertilizers during the last decades and little attention to the significant effects of organic fertilizers on improving soil fertility have caused environmental pollution, ecological damage, reduction in the quality of agricultural products, and loss of nonrenewable resources used to manufacture mineral fertilizers (Choudhary et al. 2018; Liu et al. 2020).

Growing public concerns about human health following the widespread use of mineral fertilizers and the adverse effects of hazardous synthetic chemicals have encouraged farmers to seek safer and more environmentally friendly alternatives (Singh 2018). In addition, factors such as frequent and intensive tillage, planting crops with short growing periods in the cropping system, and continuous monoculture can reduce the amount of soil organic matter (SOM) and increase the risk of soil erosion and greenhouse gas emissions (De Corato 2020). Therefore, the fertilizers used in agriculture should improve the physicochemical and biological conditions of the soil in addition to increasing soil fertility. One of the recommended solutions is to use organic fertilizers in combination with mineral fertilizers (Ayeni and Adetunji 2010).

Organic fertilizers include plant and animal residues in different stages of decomposition, which are used to improve the physical, chemical, and biological properties of the

Editorial responsibility: Agnieszka Galuszka.

✉ F. Ranjbar
f_ranjbar1980@yahoo.com

[1] Department of Soil Science, Faculty of Agriculture, Razi University, Kermanshah, Iran

[2] Department of Plant Protection, Faculty of Agriculture, Razi University, Kermanshah, Iran

soil. Organic fertilizers produce humus, reduce the adverse effects of chemical fertilizers, and increase fertilizer use efficiency (Alvarenga et al. 2017). Soil management in organic systems involves the use of crop residues, manures, composts, and other organic fertilizers to increase SOM (Li et al. 2020). The use of organic fertilizers is recommended due to the long-term improvement of soil properties and transient effects of chemical fertilizers on soil fertility (Diacono and Montemurro 2015). Organic fertilizers play an important role in carbon sequestration and reduce the entry of carbon dioxide into the atmosphere (Stockmann et al. 2013). Other desirable effects include an increase in cation exchange capacity, nutrient recycling, and available water holding capacity and improvement in soil physical and biological properties (Mazumder et al. 2021). Soil organic matter in most soils of Iran, except in the north of the country, is very low (less than one percent) and far from the optimum level of three percent (Keshavarz et al. 2013). Therefore, increasing SOM in arid and semiarid regions through the application of organic fertilizers should be considered.

The poultry industry worldwide grew by 31.5% between 2009 and 2019 (FAOSTAT 2021). Poultry manure is a mixture of organic and inorganic materials and is a potential source of important nutrients for agriculture such as nitrogen (N) and phosphorus (P) (Rizzo et al. 2020). However, its direct use in agriculture causes many environmental problems. It has a high potential for ammonia release due to its high content of protein and amino acids, and as a result, may have adverse effects on environmental health. Poultry manure also contains pathogens, parasites, arthropods, and some physical and chemical components such as potentially toxic elements, microplastics, hormones, insecticides, and veterinary drugs (Wu et al. 2021).

Due to the adverse consequences of direct use of poultry manure, appropriate solutions to eliminate or reduce these problems should be considered. Composting is one of the biological methods used to stabilize, immunize, and mature raw organic wastes such as poultry manure and finally produce a product that can be used as soil amendment. In addition, this process facilitates the storage and transportation of poultry manure by reducing the volume and weight, reducing the population of pathogenic microorganisms and unpleasant odours, and stabilization of nutrients and organic matter (Petric et al. 2017).

The use of composted organic matter plays a key role not only in maintaining the fertility and productivity of agricultural systems but also in improving soil microbial activity, soil structure, soil water holding capacity, soil aeration, and soil buffering capacity. Therefore, the use of compost is considered as a desirable method to improve the quality of agricultural soils (Alvarenga et al. 2017).

Soil quality can be determined indirectly by measuring various physical, chemical, and biological parameters. Macro and micronutrients, SOM, and CEC are among the important chemical properties affecting soil quality (Alvarenga et al. 2017). Due to the sensitivity of soil biological properties to land management and environmental changes, the determination of some parameters related to soil microbial activity such as microbial biomass carbon (MBC), basal respiration (BR), and substrate-induced respiration (SIR) is very important in assessing soil quality (Veum 2014; Nandhini et al. 2023).

Despite the widespread use of poultry manure in the soil, there is a gap in the knowledge regarding the application of composted poultry manure as a soil amendment. Few studies have combined multiple chemical and biological parameters of the soil after using composted poultry manure. Depending on the characteristics of the primary raw materials, the properties of the prepared composts can be different, and as a result, their effects on the soil characteristics are diverse. Therefore, this study was conducted to investigate the effect of different levels of four types of co-composted poultry manure on some soil chemical and biological characteristics.

This research was conducted between February 2021 and May 2021 in the Department of Soil Science, Razi University, Kermanshah, western Iran.

Materials and methods

Preparation and characterization of composts

Poultry manure, wheat straw, and natural zeolite were used to prepare the composts. Zeolite was a type of clinoptilolite with a purity of 54% and contained 23% quartz according to XRD. Mineral additives such as zeolite are commonly used to reduce greenhouse gas emissions, salinity, and ammonia volatilization during composting (Chan et al. 2016). Four different mixing ratios (w/w) were considered for co-composting the raw materials: 85% poultry manure + 15% wheat straw (C1), 75% poultry manure + 25% wheat straw (C2), 75% poultry manure + 15% wheat straw + 10% zeolite (C3), and 65% poultry manure + 25% wheat straw + 10% zeolite (C4). To investigate the effect of zeolite on the chemical characteristics of composted poultry manure, C1 and C2 were free of zeolite, while C3 and C4 were prepared in the presence of zeolite. The raw materials with specified mixing ratios (i.e. C1, C2, C3, and C4) were transferred to 20-L barrels in three replications (i.e. 12 barrels). The total mass of each mixture was 10 kg per barrel. Then, the mixtures were moistened with distilled water up to 60% (w/w). The barrels were covered with plastic nylons and placed in a greenhouse. On the lid of the barrels, 5 holes with a radius of 2 cm were created at intervals of 20 cm from each other. The composting time was 19 weeks, and the barrels were aerated weekly. After maturity, composts C1, C2, C3, and C4 were air-dried, passed through a 2-mm sieve, and stored for subsequent chemical analyses and addition to the soil.

The pH and electrical conductivity (EC) were measured in the 1:10 (w/v) solid to distilled water extract using the 86,502 AZ Bench Top Water Quality Meter—pH/ORP/mV and 86,503 AZ Bench Top Conductivity Meter, respectively. Organic carbon (OC) was determined by dry oxidation in an electric furnace at a temperature of 500 °C. Potassium (K) was measured using the flame photometer in the extract obtained from dry digestion. The Unico 2100 UV–vis spectrophotometer was used to determine P and N in the extracts obtained from dry digestion and wet digestion, respectively (Rowell 1994; Jones 2001).

Preparation of composts and their characterization have been presented in more details in the previous study (Maleki et al. 2023). The properties of prepared composts are given in Table 1.

Preparation of soil treatments

A composite soil sample was taken from a depth of 0–20 cm from an agricultural land, then air-dried, and passed through a 2 mm sieve. Particle size distribution, and equivalent calcium carbonate were determined using hydrometer and back titration methods, respectively (Rowell 1994; Jones 2001). Soil texture was clay loam and equivalent calcium carbonate was 25.1%. The soil sample was divided into 27 subsamples of 400 g, and then prepared composts (C1, C2, C3, and C4) were separately added to the subsamples at two levels of 5% and 10% by mass in three replicates (i.e. 24 treated samples). The remaining three subsamples were considered as controls (without adding compost). Amendment application rates up to 5% (w/w) are commonly used in soil remediation studies (Seyedsadr et al. 2022). However, higher application rates (i.e. 10, 15, 25, 35, and 45% w/w) are also found (Mazumder et al. 2021). Organic matter is one of the most important key factors affecting soil biological indicators. Therefore, the application rate of 10% was chosen as a higher application level than the common rates. Control and treated soil samples were incubated for one month at 25 °C and moisture close to field capacity.

Chemical and biological analysis of treated soils

At the end of the incubation period, chemical parameters including total N, available nitrate (NO_3^-) and ammonium (NH_4^+) in 2 M KCl extract, available *P* in 0.5 M $NaHCO_3$ (Olsen) extract, and available K in the extract taken with 1M ammonium acetate, pH, and EC in the extract of 1:2 soil to distilled water (w/v), and CEC were measured in control and treated soils (Rowell 1994). Biological indicators were determined as follows: microbial respiration or carbon mineralized (C_{min}) (Anderson 1982), SIR (Alef and Nannipieri 1995), MBC (Horwath and Paul 1994), and metabolic quotient (qCO_2) (Suman et al. 2006).

All experiments were performed in three replications. Analysis of variance was performed using a completely randomized design and comparing the mean of the data was done based on Duncan's multiple range test at the level of 5% using SAS software.

Results and discussion

pH and EC in compost-treated soils

Figure 1a shows the pH values in compost-treated soils. The highest pH value (i.e. 7.38) was observed in the control. The pH values in the treated soils decreased significantly

Table 1 Some chemical characteristics of composted poultry manures (Maleki et al. 2023)

Compost	$pH_{1:10}$	$EC_{1:10}$ (dS m^{-1})	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	C/N
C1	7.10	5.94	300	46.6	23.9	20.4	6.44
C2	7.21	6.36	297	45.0	17.3	26.1	6.60
C3	6.90	6.64	293	43.0	19.0	19.0	6.81
C4	7.39	6.42	298	45.6	21.3	17.6	6.54

C1: 85% poultry manure + 15% wheat straw, C2: 75% poultry manure + 25% wheat straw, C3: 75% poultry manure + 15% wheat straw + 10% Zeolite, and C4: 65% poultry manure + 25% wheat straw + 10% zeolite

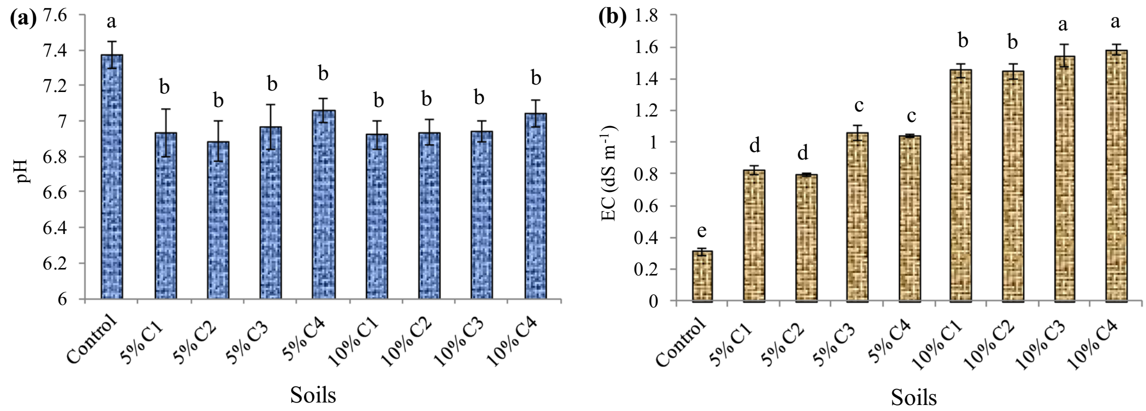

Fig. 1 pH **a** and EC **b** in control and compost-treated soils at application levels of 5% and 10% (The bars indicate the standard deviation and dissimilar letters represent a significant difference ($P<0.05$) by Duncan's multiple range test) C1: 85% poultry manure + 15% wheat straw, C2: 75% poultry manure + 25% wheat straw, C3: 75% poultry manure + 15% wheat straw + 10% Zeolite, and C4: 65% poultry manure + 25% wheat straw + 10% zeolite

compared to the control, but no significant difference was observed between the pH values of treated soils. The reduction of pH in treated soils compared to the control was in the range of 0.3–0.5 units. Decreased soil pH following the application of organic compounds can occur due to the slight increase in carbon dioxide pressure and dissolution of calcium carbonate as well as the release of organic acids such as malic acid, citric acid, and oxalic acid (Boutasknit et al. 2020). In addition, the application of organic compounds leads to an increase in soil organic nitrogen, followed by the nitrification process associated with the release of H^+ and a decrease in soil pH (Meng et al. 2020; Strawn et al. 2020).

The EC values in compost-treated soils are indicated in Fig. 1b. The lowest EC (0.132 dS m^{-1}) was obtained in the control. With the increasing application of compost in the soil, EC increased significantly due to the release of soluble salts and mineral ions from the compost into the soil. In addition, the decomposition of organic fertilizers causes the release of organic acids that react with poorly soluble salts and increase their solubility (Dhaliwal et al. 2023). The EC value in soils treated with 5% and 10% compost was in the range of 0.80–1.06 dS m^{-1} and 1.58–1.45 dS m^{-1}, respectively. Soils treated with composts C3 and C4 had higher EC, which can be due to the higher salinity of these two composts than composts C1 and C2 (Table 1). The average increase in EC of soils treated with 5 and 10% compost was 0.61 and 1.19 dS m^{-1}, respectively, compared to the control soil. Increased EC in soils treated with organic residues under incubation conditions has been reported in previous studies (Gulser et al. 2010; Roy and Abul Kashem 2014; Jalali et al. 2020). The comparison of Figs. 1a and 1b shows that the decrease in pH was accompanied by the increase in EC. An increase in the partial pressure of carbon dioxide caused by the decomposition of organic compounds in the soil leads to an increase in the solubility of soil carbonates, especially calcium carbonate. This process leads to a decrease in pH and an increase in EC. Also, the dissociation of organic acids leads to the formation of protons and organic anions, which decrease pH and increase EC, respectively (Boutasknit et al. 2020; Jalali et al. 2020).

OC and total N in compost-treated soils

Figure 2a indicates the amounts of OC in control and compost-treated soils. One of the important effects of adding organic compounds to soil is the increase of OC. The OC content in compost-treated soils increased significantly ($P<0.05$) compared to control. The highest amounts of OC were observed in treatments containing 10% compost, whereas the lowest amount (i.e. 0.585%) was measured in the control (Fig. 2a). The OC content varied from 1.72 to 2.11% and 2.86 to 3.50% in treatments containing 5% and 10% compost, respectively. In other words, the amount of OC in soils treated with different composts increased between 1.13% and 2.91% compared to the control. Broken et al. (2002) showed that the application of vermicompost and compost increased the amount of soil organic carbon (SOC). Ayeni and Adetunji (2010) and Adeley et al. (2010) reported a significant increase in SOC because of using poultry manure.

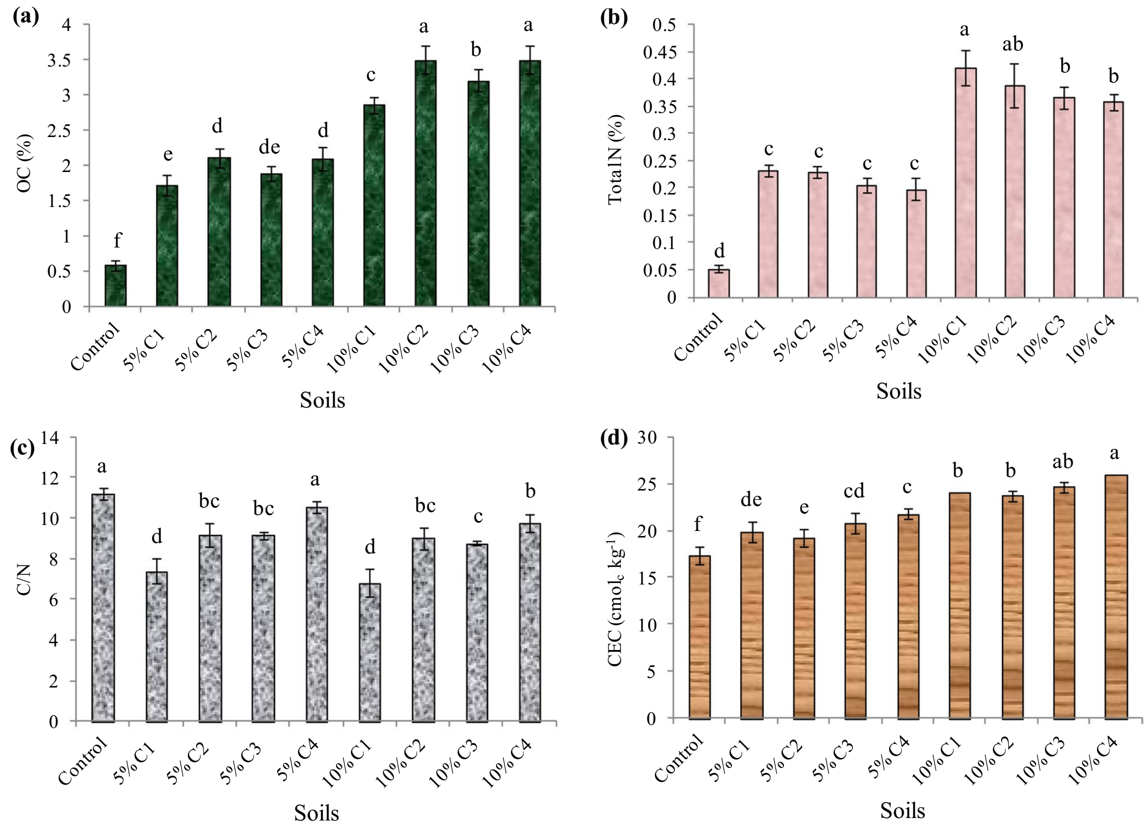

Fig. 2 OC **a**, total N **b**, C/N ratio **c**, and CEC **d** in control and compost-treated soils at application levels of 5% and 10% (The bars indicate the standard deviation and dissimilar letters represent a significant difference ($P<0.05$) by Duncan's multiple range test) C1: 85% poultry manure + 15% wheat straw, C2: 75% poultry manure + 25% wheat straw, C3: 75% poultry manure + 15% wheat straw + 10% Zeolite, and C4: 65% poultry manure + 25% wheat straw + 10% zeolite

The amount of total N in control and compost-treated soils is shown in Fig. 2b. Application of compost significantly ($P<0.05$) increased total N content in the treated soils compared to the control and higher values were observed in the soils treated with 10% compost. Total N values were in the range of 0.198–0.232% and 0.358–0.321% at application levels of 5 and 10%, respectively. In general, the application of composts caused total N to increase from 0.146 to 0.369% compared to the control soil. A decreasing trend in total N from treatment C1 to treatment C4 at each application level is due to the reduction of the amount of poultry manure used in the preparation of these composts. However, this reduction was not significant based on the results of ANOVA (Fig. 2b). Cayci et al. (2017) reported an increase in OC and total N contents following the application of fresh and composted chicken manure in the soil under incubation conditions.

Figure 2c shows the C/N ratio values in control and compost-treated soils. The highest C/N (i.e. 11.2) was obtained in the control soil, while it decreased significantly in the treated soils ($P<0.05$). The C/N was in the range of 7.4–10.6 at 5% compost application level. Among the treatments, the C/N ratio was the lowest in the soil treated with C1, probably due to the higher N content in this compost. In addition, the values of C/N in treatments containing 10% compost were lower compared to those in treatments containing 5% compost. The lowest C/N value (i.e. 6.8) was observed in the soil treated with compost C1, and the highest value (i.e. 9.8) was obtained for the soil treated with compost C4. Application of composted poultry manure was associated with a significant increase in OC and total N in the treated soils compared to the control. However, this ratio significantly decreased in treated soils because the impact of increasing N on changing the C/N ratio of soil was greater than the effect of increasing C. Furthermore, C/N ratios in composts were lower in comparison with untreated soil. Mazumder et al. (2021) reported that the application of 45%

compost in the soil caused 5400% increase in total N and 14.29% in OC, followed by a decrease in C/N.

CEC in compost-treated soils

Figure 2d shows CEC values in control and compost-treated soils. This parameter is one of the important soil properties and indicates the ability of soil to adsorb cations, especially those necessary for plant nutrition, and thus prevents them from leaching. The CEC in control was 17.4 $cmol_c\ kg^{-1}$ and increased significantly ($P < 0.05$) as a result of adding composts. The values of this parameter were higher in treatments containing 10% compost than in treatments containing 5% compost. CEC values in compost-treated soils varied from 19.3 to 21.8 $cmol_c\ kg^{-1}$ at the application level of 5%. Further increase of CEC in soils treated with composts C3 and C4 is probably due to the presence of zeolite in these treatments in addition to organic compounds. Zeolite is an aluminosilicate of the tectosilicate group in which silicon and aluminium cations share their oxygen ligands in tetrahedron coordination. Negative charges caused by isomorphic substitution are neutralized by electrostatically adsorbed exchange cations. Therefore, adding zeolite to the soil leads to an increase in CEC. In addition, CEC increased to a greater extent in treatments containing 10% compost so that it varied from 23.7 to 25.9 $cmol_c\ kg^{-1}$. Compared to the control, CEC increased in treatments containing 5% and 10% compost in the range of 1.9–4.4 $cmol_c\ kg^{-1}$ and 6.3–8.5 $cmol_c\ kg^{-1}$, respectively. Organic compounds have a significant amount of negative surface charges due to their large number of carboxylic and phenolic functional groups, which their protonation leads to an increase in soil CEC. Walker and Bernal (2008) reported that application of poultry manure at the rates of 20 and 30 g kg^{-1} increased CEC by 3–5 units. Jalali et al. (2020) showed that CEC in soils treated with crop residues increased by 2.6–5.6 units

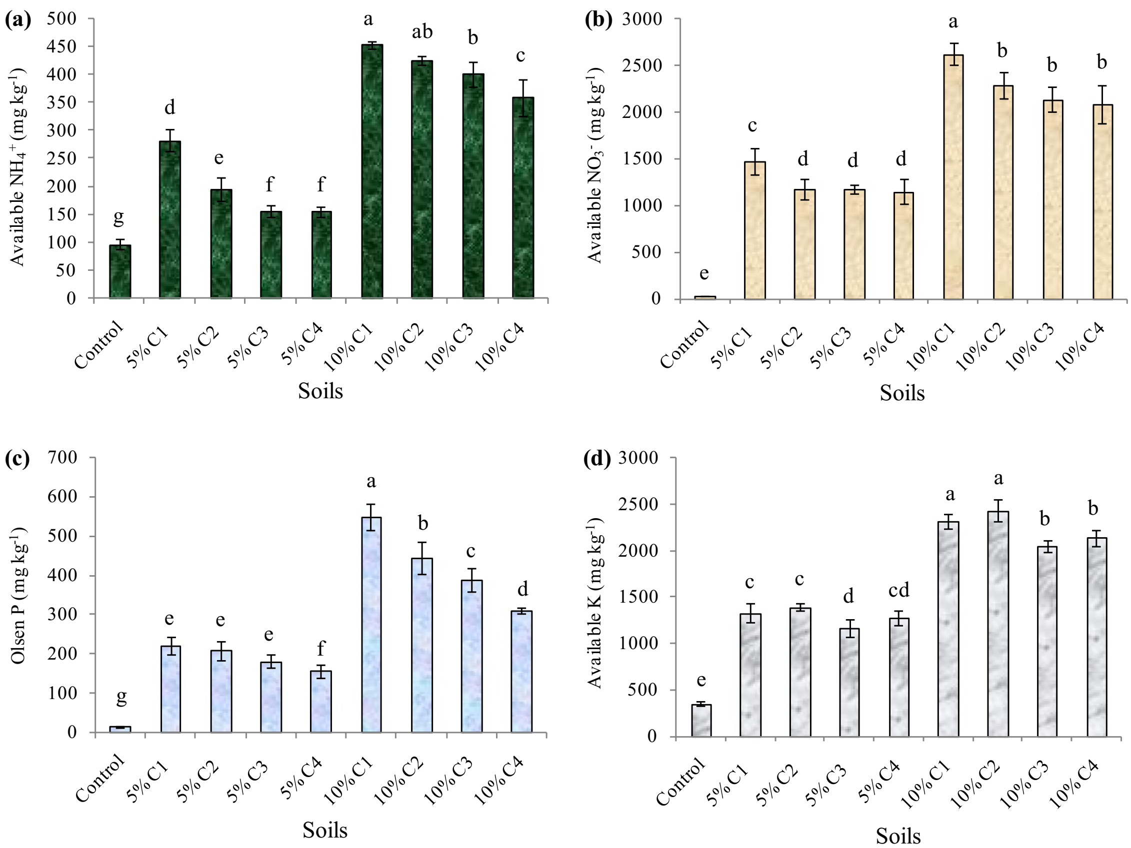

Fig. 3 Available NH_4^+ **a**, NO_3^-, P **c**, and K **d** in control and compost-treated soils at application levels of 5% and 10% (The bars indicate the standard deviation and dissimilar letters represent a significant difference ($P < 0.05$) by Duncan's multiple range test) C1: 85% poultry manure + 15% wheat straw, C2: 75% poultry manure + 25% wheat straw, C3: 75% poultry manure + 15% wheat straw + 10% Zeolite, and C4: 65% poultry manure + 25% wheat straw + 10% zeolite

compared to the control after one-month incubation. Mazumder et al. (2021) reported an increase of 1.58% in the CEC of the soil treated with 45% of plant residue compost.

Available NH_4^+ and NO_3^- in compost-treated soils

Figure 3a shows that the amount of available NH_4^+ in the control soil was 96.8 mg kg^{-1} at the end of the incubation and increased significantly ($P < 0.05$) in compost-treated soils. Composted poultry manure contains organic N, so, microorganisms release NH_4^+ into the soil during the ammonification process. A C/N ratio less than 20 causes the net N mineralization through the ammonification and nitrification processes (Havlin et al. 2005; Impraim et al. 2022). The amount of available NH_4^+ in treated soils varied from 156 mg kg^{-1} in the soil treated with compost C4 to 283 mg kg^{-1} in the soil treated with compost C1 at the application level of 5%. Higher total N content and lower C/N ratio can be the reason for higher NH_4^+ release in the soil treated with compost C1. The amount of available NH_4^+ in the soil was in the range of 360–454 mg kg^{-1} at the application level of 10%. Compared to the control, the average increase in NH_4^+ content in soils treated with composts at application levels of 5 and 10% was 101 and 314 mg kg^{-1}, respectively.

The available NO_3^- contents in control and compost-treated soils are represented in Fig. 3b. The control soil had the lowest NO_3^- (i.e. 32.6 mg kg^{-1}), while it varied from 1147 to 1473 mg kg^{-1} at the level of 5% compost application. The higher amount of NO_3^- in the soil treated with compost C1 is likely due to the greater total N content and the higher rate of nitrification process. The amount of available NO_3^- varied in the range of 2080–2628 mg kg^{-1} at the application level of 10%. Similar to the level of 5%, the highest amount of NO_3^- was observed in the soil treated with compost C1 and the lowest one was in the soil treated with compost C4. Compared to the control, application of 5 and 10% of different composts caused the available NO_3^- to increase by an average of 1210 and 2251 mg kg^{-1}, respectively. The low C/N ratio in organic fertilizers and favourable soil pH for the nitrification process leads to further NO_3^- production in the soil (Impraim et al. 2022). The amount of NH_4^+ was much lower compared to the amount of NO_3^- in the treated soils, while this trend was not observed in the control. This could be due to the leaching of NO_3^- from the control soil before it was sampled from the field, whereas incubation was spent in a closed system and the NO_3^- produced through the nitrification process remained in the treated soils. It has been reported that after 40 weeks of application of 3% fresh poultry manure and 3% sheep manure in the calcareous sandy loam soil, the amount of NO_3^- in the treated soils was 1353 and 677 mg kg^{-1}, respectively (Zarabi 2014). The nitrification process occurs in the pH range between 6 and 9.4 (Havlin et al. 2005). So, a significant amount of NO_3^- is produced following the application of raw and composted poultry manure in neutral and alkaline soils, and there is a possibility of NO_3^- leaching and groundwater contamination. As a result, the use of such organic fertilizers should be considered based on the amount of NO_3^- produced and the nitrogen requirement of the plant.

Available P and K in compost-treated soils

The amount of available P (Olsen P) in the control soil was 14.8 mg kg^{-1} and increased significantly ($P < 0.05$) with increasing the level of compost application (Fig. 3c). The available P varied from 156 to 220 mg kg^{-1} in compost-treated soils at the application level of 5%. Higher available P in soils treated with compost C1 may be due to the higher amount of poultry manure in this compost (Table 1) and consequently, the greater release of P. The amount of Olsen P varied from 310 to 549 mg kg^{-1} at the level of 10% compost application. The application of composts at the levels of 5 and 10% caused the amount of available P to increase by an average of 177 and 408 mg kg^{-1}, respectively. The release of a significant amount of P in treated soils can be due to the low C/P ratio (i.e. < 200) in composts (Table 1). According to the amount of Olsen P in the control soil, there is no need to use fertilizers containing P in this soil under real conditions. Therefore, organic fertilizers containing poultry manure with high levels of P should be used based on soil test and plant nutritional requirements to prevent environmental pollution caused by excessive amounts of P in agricultural soils. Sharpley et al. (2004) investigated the availability of P in soils treated with four types of poultry manure and reported that the available P varied between 4 and 64 mg kg^{-1} in untreated soils and between 82 and 2840 mg kg^{-1} in treated soils. In addition to total P content in organic residues, the rate of P release depends on the rate of decomposition. The faster the decomposition, the greater P is released into the soil. Jalali and Ranjbar (2009) reported a significant positive correlation ($r = 0.96$) between P content in the residues and P release as well as a significant negative correlation ($r = -0.98$) between C/P ratio in the residues and P release.

The amount of available K was 351 mg kg^{-1} in the control and increased significantly ($P < 0.05$) by adding composts to the soil (Fig. 3d). The range of available K varied from 1274 to 1394 mg kg^{-1} at the application level of 5%. The

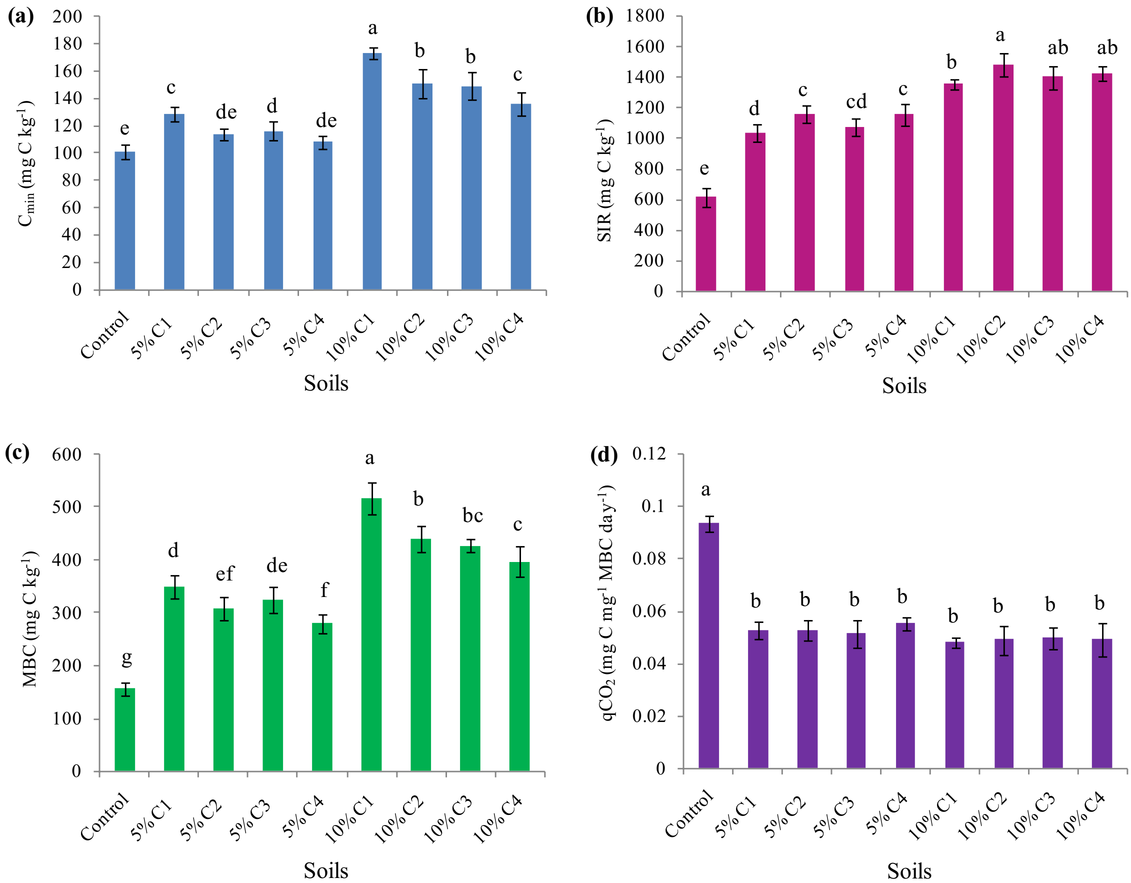

Fig. 4 Microbial respiration (C_{min}) **a**, substrate-induced respiration (SIR) **b**, microbial biomass carbon (MBC) **c**, and metabolic quotient (qCO_2) **d** in control and compost-treated soils at application levels of 5% and 10% (The bars indicate the standard deviation and dissimilar letters represent a significant difference ($P < 0.05$) by Duncan's multiple range test) C1: 85% poultry manure + 15% wheat straw, C2: 75% poultry manure + 25% wheat straw, C3: 75% poultry manure + 15% wheat straw + 10% Zeolite, and C4: 65% poultry manure + 25% wheat straw + 10% zeolite

higher level of available K in the soil treated with compost C2 may be due to the higher total K content in this compost (Table 1). At the rate of 10% compost application, available K ranged from 2047 to 2433 mg kg^{-1}. On average, the application of composts at two levels of 5 and 10% increased soil available K by 940 and 1882 mg kg^{-1}, respectively. Jalali (2011) reported that the amount of K released from calcareous soils treated with organic compounds after four weeks of incubation was between 300 and 990 mg kg^{-1}. It was also stated that the maximum release of K was obtained in the treatment with the highest total K content, while the minimum release of K was observed in the treatment with the lowest total K content. An increase in the level of N, P, and K in soils treated with vegetable residue compost and animal manure compost with an application rate of 3% has been reported (Bashir et al. 2021). Mazumder et al. (2021) reported that the levels of P and K in the soil treated with 45% of plant residues compost increased by 209.5% and 21.2%, respectively.

Microbial respiration in compost-treated soils

Figure 4a shows C_{min} values in control and compost-treated soils. This parameter increased in the soil with the addition of compost. Increased soil respiration indicates increased soil microbial activity and increased carbon dioxide production. The control soil had the lowest microbial respiration level (102 mg C kg^{-1}). The range of C_{min} at the level of 5%

compost application ranged from 108 to 129 mg C kg^{-1}. The increase in C_{min} in the soil treated with compost C1 is probably due to the lower C/N ratio in this compost (Table 1) and its higher biodegradability. The use of organic fertilizers in the soil causes an increase in OC, N, and P and as a result increases microbial activity (Boutasknit et al. 2020). A low C/N ratio increases the rate of decomposition of organic residues by microorganisms and the production of carbon dioxide. The comparison of means showed that the application of composts C2 and C4 did not make a significant difference in C_{min} compared to the control. With increasing the level of compost in the soil from 5 to 10%, a further increase in soil microbial respiration was observed. The parameter C_{min} in soils treated with composts at the level of 10% ranged from 136–174 mg C kg^{-1}. Compost C1 increased the population of microorganisms in the soil and microbial respiration to a greater extent due to its higher level of poultry manure. In addition, the lower C/N ratio in compost C1 provided better conditions for degradation by microorganisms compared to other composts.

SIR in compost-treated soils

Figure 4b shows SIR values in control and compost-treated soils. This parameter indicates the soil microbial respiration after adding an accessible substrate such as glucose and reflects the active microbial population of the soil (Luo and Zhou 2006). The lowest SIR value was observed in the control soil (614 mg C kg^{-1}), which indicated the lower population and activity of microorganisms after adding glucose to this soil. The value of this parameter increased in compost-treated soils due to the increase in the microbial population. The range of SIR varied from 1036 to 1156 mg C kg^{-1} and 1354 to 1482 mg C kg^{-1} at compost application levels of 5 and 10%, respectively. The comparison of means showed that with increasing compost level from 5 to 10%, a significant change occurred in SIR ($P < 0.05$), but no significant difference was observed between treatments at both application levels. The most important factor limiting the microbial activity in the soil environment is the lack of easily accessible sources of carbon (Chen et al. 2003). The measurement of parameter SIR is one of the basic methods for quantitative estimation of soil microbial biomass as the highly active and unstable part of SOC. Therefore, the population and activity of microorganisms, the rate of microbial respiration, and SIR increase with the availability of SOC.

MBC in compost-treated soils

Soil microbial biomass is the mass of all soil microorganisms and includes carbon, nitrogen, phosphorus, and sulphur, which constitutes an important part of soil organic matter and plays an important role in soil dynamics (Tang et al. 2019). Figure 4c shows MBC in control and compost-treated soils. The lowest MBC was obtained in the control (156 mg C kg^{-1}). Application of composts at two levels of 5% and 10% significantly ($P < 0.05$) increased this parameter in treated soils compared to the control. The MBC ranged from 281 to 350 mg C kg^{-1} at the application level of 5%. Most likely, compost C1 with the highest amount of poultry manure led to the introduction of a large population of microorganisms into the soil and increased MBC to a greater extent. In contrast, compost C4 with the lowest amount of poultry manure caused the lowest MBC among treatments. In addition, higher MBC in the soil treated with compost C1 can be attributed to lower C/N and higher concentration of nutrients (i.e. N and P) compared to other composts (Sharifi et al 2014). The MBC varied from 397 to 517 mg C kg^{-1} in treatments containing 10% compost. The amounts of OC and MBC in the treated soils increased significantly ($P < 0.05$) compared to the control (Figs. 2a and 4c). However, the contribution of MBC to OC was 2.66% in the control, while it was in the range of 1.34–2.04% and 1.14–1.81% in the treatments containing 5% and 10% compost, respectively. The decrease in the MBC/OC ratio in the treated soils indicates an increase in the rate of microbial activity and respiration. In other words, the ratio of the carbon consumed in microbial metabolism (i.e. carbon released as CO_2) to the carbon assimilated by microorganisms was higher in compost-treated soils compared to the control (Nandhini et al. 2023). Normally, the participation of MBC in OC of soils varies in the range of 1–3% (McGonigle and Turner 2017).

The results showed that the addition of organic fertilizers to the soil, as a substrate for microorganisms, significantly increased their population over a period of one month. Typically, the bulk of soil microbial biomass is inactive, occurring due to food constraints. Therefore, the microbial activity and MBC in the soil increase following the application of organic fertilizers such as composts. On the other hand, composts contain a large population of microorganisms. Borken et al. (2002) reported an increase in the microbial respiration and MBC of the soil as a result of compost application. Zaman et al. (2004) showed that the consumption of municipal waste compost played an important role in increasing MBC due to the increase in total C, N, and dissolved organic carbon in the soil. The increase in MBC is generally one of the positive consequences of using organic fertilizers in the soil. The simple, bioavailable substrates released from organic fertilizers in the soil stimulate microbial activity and increase soil respiration and MBC (Nandhini et al. 2023).

qCO_2 in compost-treated soils

The values of qCO_2 in control and compost-treated soils are represented in Fig. 4d. Metabolic quotient indicates the amount of microbial respiration i.e. the amount of carbon mineralized per unit MBC (the amount of carbon used to grow and form new microbial cells) per unit time. This parameter was significantly ($P < 0.05$) higher in the control compared to compost-treated soils. The value of qCO_2 was 0.093 mg C mg^{-1} MBC day^{-1} in the control and ranged from 0.048 to 0.055 mg C mg^{-1} MBC day^{-1} in treated soils. The comparison of means did not show a significant difference between treated soils at application levels of 5% and 10%. A decrease in this biological index in treated soils indicates an increase in the population of microorganisms and further production of microbial biomass. An increase in this index in the soil may not be a good sign because it indicates the mineralization of a significant part of OC through the microbial activity and respiration and its loss from the soil in the form of carbon dioxide. In other words, the lower the qCO_2, the greater the contribution of the energy source to the anabolism of microorganisms rather than their catabolism (Landi et al. 2000).

Conclusion

The results of this study showed that the amounts of EC, OC, total N, CEC, and available NH_4^+, NO_3^-, P, and K in the soil increased significantly with the application of different composted poultry manures. Compost C1 had the greatest effect in increasing total N and P in the soil due to its higher N and P content. The highest OC content was obtained in the soil treated with compost C2. The maximum increase of CEC occurred in soils treated with composts C3 and C4 due to the presence of zeolite. The increase in available P, K, and NO_3^-, even at the application level of 5%, was higher than the critical limits for Iranian soils (15, 180, and 22 mg kg^{-1}, respectively). The application of composted poultry manure improved the chemical quality of the soil. However, it is suggested that the level of application should be taken into account to prevent environmental pollution through excessive N and P. In this regard, it is more desirable to reduce the participation ratio of poultry manure in the co-composted mixture. The results also showed that soil biological characteristics changed in a short period of one month. Biological parameters including microbial respiration, SIR, and MBC increased following the use of composted poultry manure. An increase in these parameters can indicate an increase in microbial activity and biological quality of treated soils. The greatest values of microbial respiration, SIR, and MBC were obtained in the soil treated with compost C1 due to its higher C content and lower C/N ratio compared to other composts. It is important to note that the results of this study were obtained in a closed system under laboratory incubation without the presence of plants. Therefore, they may be different under real field conditions and in the presence of plants. In this study, some chemical and biological indicators were investigated. It is suggested that the release of micronutrients and biotoxicity in soils treated with composted poultry manure should be taken into consideration in future studies.

Acknowledgements We would like to express our sincere gratitude to Department of Soil Science of Razi University in which this research was conducted.

Author contributions SM performed software, formal analysis, visualization, and interpretation of data, AB-A conducted conceptualization, methodology, validation, investigation, supervision, and project administration, FR provides conceptualization, methodology, validation, software, investigation, supervision, interpretation of data, and writing original draft, RS did conceptualization, methodology, and validation. All authors read and approved the final manuscript.

Funding No funding was received for conducting this study.

Data availability The datasets analyzed during the current study can be available from the corresponding author on reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

Adeley EO, Ayeni LS, Ojeniyi SO (2010) Effect of poultry manure on soil physico-chemical properties, leaf nutrient contents and yield of yam (*Dioscorea rotundata*) on Alfisol in Southwestern Nigeria. J Am Sci 6(10):871–878

Alef K, Nannipieri P (1995) Methods in applied soil microbiology and biochemistry. Academic Press, London

Alvarenga P, Palma P, Mourinha C, Farto M, Dôres J, Patanita M, Cunha-Queda C, Natal-da-Luz T, Renaud M, Sousa JP (2017) Recycling organic wastes to agricultural land as a way to improve its quality: a field study to evaluate benefits and risks. Waste Manage 61:582–592

Anderson JPE (1982) Soil respiration. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis, Part 2, Chemical and microbiological properties. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, pp 831–872

Ayeni LS, Adetunji MT (2010) Integrated application of poultry manure and mineral fertilizer on soil chemical properties, nutrient uptake, and yield and growth components of maize. Nat Sci 8(1):60–67

Bashir S, Gulshan AB, Iqbal J, Husain A, Alwahibi MS, Alkahtani J, Dwiningsih Y, Bakhsh A, Ahmed N, Khan MJ, Ibrahim M, Diao ZH (2021) Comparative role of animal manure and vegetable waste induced compost for polluted soil restoration and maize growth. Saudi J Biol Sci 28(4):2534–2539

Borken W, Muhs A, Beese F (2002) Changes in microbial and soil properties following compost treatment of degraded temperate forest soils. Soil Biol Biochem 34:403–412

Boutasknit A, Anli M, Tahiri A, Raklami A, Ait-El-Mokhtar M, Ben-Laouane R, Ait Rahou Y, Boutaj H, Oufdou K, Wahbi S, El Modafar C, Meddich A (2020) Potential effect of horse manure-green waste and olive pomace-green waste compost on physiology and yield of garlic (*Alluim sativum* L.) and soil fertility. Gesunde Pflanzen 72:285–295

Cayci G, Temiz C, Ok S (2017) The effect of fresh and composted chicken manures on some soil characteristics. Commun Soil Sci Plant Anal 48(13):1528–1538

Chan MT, Selvam A, Wong JWC (2016) Reducing nitrogen loss and salinity during "struvite" food waste composting by zeolite amendment. Bioresour Technol 200:838–844

Chen CR, Condron LM, Davis MR, Sherlick RR (2003) Seasonal changes in soil phosphorus and associated microbial properties under adjacent grassland and forest in NewZealand. For Ecol Manag 177:35–43

Choudhary M, Panday SC, Meena VS, Singh S, Yadav RP, Mahanta D, Mondal T, Mishra PK, Bisht JK, Pattanayak A (2018) Long-term effects of organic manure and inorganic fertilization on sustainability and chemical soil quality indicators of soybean-wheat cropping system in the Indian mid-Himalayas. Agric Ecosyst Environ 257:38–46

De Corato U (2020) Soil microbiota manipulation and its role in suppressing soil-borne plant pathogens in organic farming systems under the light of microbiome-assisted strategies. Chem Biol Technol Agric 7:17

Dhaliwal SS, Sharma V, Shukla AK, Verma V, Kaur M, Singh P, Gaber A, Hossain A (2023) Effect of addition of organic manures on basmati yield, nutrient content and soil fertility status in north-western India. Heliyon 9(3):e14514

Diacono MA, Montemurro F (2015) Review Effectiveness of Organic Wastes as Fertilizers and Amendments in Salt-Affected Soils. Agriculture 5:221–230

FAOSTAT (2021) Statistics of food and agricultural commodities production. Food and Agriculture Organization of the United Nations

Gulser C, Demir Z, Serkan IC (2010) Changes in some soil properties at different incubation periods after tobacco waste application. J Environ Biol 31:671–674

Havlin L, Beaton JD, Tisdale SL, Nelson WL (2005) Soil fertility and fertilizers: an introduction to nutrient management, 7th edn. Pearson Educational Inc, Upper Saddle River, New Jersey

Horwath WR, Paul EA (1994) Microbial biomass. In: Buxton DR (eds) Methods of soil analysis. Part 2: Microbiological and biochemical properties. SSSA Book Series, No.5. Madison, Wisconsin, pp 753–773

Impraim R, Weatherley A, Chen D, Suter H (2022) Effect of lignite amendment on carbon and nitrogen mineralization from raw and composted manure during incubation with soil. Pedosphere 35(2):785–795

Jalali M (2011) Comparison of potassium release of organic residues in five calcareous soils of western Iran in laboratory incubation test. Arid Land Res Manag 25(2):101–115

Jalali M, Ranjbar F (2009) Rates of decomposition and phosphorus release from organic residues related to residue composition. J Plant Nutr Soil Sci 172:353–359

Jalali M, Saeedi Lotf M, Ranjbar F (2020) Changes in some chemical properties of saline-sodic soils over time as affected by organic residues: an incubation study. Polish J Soil Sci 53(1):1–20

Jones JB (2001) Laboratory guide for conducting soil tests and plant analysis. CRC Press

Keshavarz P, Zangiabadi M, Abbaszadeh M (2013) Relationship between soil organic carbon and wheat grain yield as affected by soil clay content and salinity. Iran J Soil Res 27(3):359–371 ((**In Persian**))

Landi L, Renella G, Moreno JL, Falchini L, Nannipieri P (2000) Influence of cadmium on the metabolic quotient, L-:D-glutamic acid respiration ratio and enzyme activity: microbial biomass ratio under laboratory conditions. Biol Fertil Soils 32:8–16

Li H, Zhang T, Tsang DCW, Li G (2020) Effects of external additives: biochar, bentonite, phosphate, on co-composting for swine manure and corn straw. Chemosphere 248:125927

Liu HY, Huang X, Tan WF, Di HJ, Xu JM, Li Y (2020) High manure load reduces bacterial diversity and network complexity in a paddy soil under crop rotations. Soil Ecol Letters 2:104–119

Luo YQ, Zhou X (2006) Soil respiration and the environment. Academic Press, Elsevier

Maleki S, Ranjbar F, Beheshti-Alagha A, Sharifi R (2023) Release kinetics of carbon, nitrogen, Phosphorus, and potassium during co-composting of poultry manure mixed with different ratios of wheat straw and zeolite. Waste Biomass Valori 14:57–68

Mazumder P, Akhil PM, Jyoti KM, Mishra U, Kalamdhad AS (2021) Enhancement of soil physico-chemical properties post compost application: Optimization using response surface methodology comprehending central composite design. J Environ Manage 289:112461

McGonigle TP, Turner WG (2017) Grasslands and croplands have different microbial biomass carbon levels per unit soil organic carbon. Agriculture 7(7):57

Meng X, Yan J, Zuo B, Wang Y, Cui Z (2020) Full-scale of composting process of biogas residues from corn stover anaerobic digestion: physical-chemical, biology parameters and maturity indexes during whole process. Bioresour Technol 302:122742

Nandhini DU, Janaki P, Somasundaram E (2023) Comparison of biological soil quality indicators under different nutrient management techniques in semi-arid parts of India. Org Agric 13:321–334

Petric I, Šestan A, Šestan I (2017) Influence of wheat straw addition on composting of poultry manure. Process Saf Environ Prot 87(3):206–212

Rizzo PF, Bres PA, Young BJ, Zubillaga MS, Riera NI, Beily ME, Argüello A, Crespo DC, Sánchez A, Komilis D (2020) Temporal variation of physico-chemical, microbiological, and parasitological properties of poultry manure from two egg production systems. J Mater Cycles Waste Manag 22(4):1140–1151

Rowell DL (1994) Soil Science: methods and applications. Longman Group, Harlow

Roy S, Abul Kashem MD (2014) Effects of organic manures in changes of some soil properties at different incubation periods. J Soil Sci 4(3):81–86

Seyedsadr S, Šípek V, Jačka L, Sněhota M, Beesley L, Pohořelý M, Kovář M, Trakal L (2022) Biochar considerably increases the easily available water and nutrient content in low-organic soils amended with compost and manure. Chemosphere 293:133586

Sharifi M, Lynch DH, Hammermeister A, Burton DL, Messiga AJ (2014) Effect of green manure and supplemental fertility amendments on selected soil quality parameters in an organic potato rotation in Eastern Canada. Nutr Cycling Agroecosyst 100:135–146

Sharpley AN, McDowell RW, Kleinman PJ (2004) Amounts, forms and solubility of phosphorus in soils receiving manure. Soil Sci Soc Am J 68:2048–2057

Singh B (2018) Are nitrogen fertilizers deleterious to soil health? Agronomy 8(4):48

Stockmann U, Adams MA, Crawford JW, Field DJ, Henakaarchchi N, Jenkins M (2013) The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agric Ecosyst Environ 164:80–99

Strawn DG, Bohn HL, O'Connor GA (2020) Soil chemistry. John Wiley & Sons

Suman A, Lal M, Singh AK, Gaur A (2006) Microbial biomass turnover in Indian subtropical soils under different sugarcane intercropping systems. Agron J 98:698–704

Tang J, Zhang J, Ren L, Zhou Y, Gao J, Luo L, Yang Y, Peng Q, Huang H, Chen A (2019) Diagnosis of soil contamination using microbiological indices: a review on heavy metal pollution. J Environ Manage 242:121–130

Veum KS, Goyne KW, Kremer RJ, Miles RJ (2014) Biological indicators of soil quality and soil organic matter characteristics in an agricultural management continuum. Biogeochem 117:81–99

Walker DJ, Bernal MP (2008) The effect of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil. Bioresour Technol 99:396–403

Wu RT, Cai YF, Chen YX, Yang YW, Xing SC, Liao XD (2021) Occurrence of microplastic in livestock and poultry manure in South China. Environ Pollut 277:116790

Zaman M, Matsushima M, Chang S, Inubushi K, Nguyen L, Goto S, Kanek OF, Yoneyama T (2004) Nitrogen mineralization, N2O production and soil microbiological prosperities as affected by long-term application of sewage sludge composts. Biol Fertil Soils 40:101–109

Zarabi M. (2014) A comparison of nitrate release and net N mineralization from calcareous soil amended with fresh sheep manure and poultry manure. Proceedings of the 3rd national conference on health, environment & sustainable development, Bandar Abbas. https://civilica.com/doc/251025 (In Persian)