INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
15–568/2016/18–3–501–508
DOI: 10.17957/IJAB/15.0113
http://www.fspublishers.org

Full Length Article

Effect of Sewage Sludge and its Biomass Composting Product on the Soil Characteristics and N_2O Emission from the Tomato Planting Soil

Shanying He*, Anan Li and Lei Wang
College of Environmental Science and Engineering, Zhejiang Gongshang University, Zhejiang Provincial Key Laboratory of Solid Waste Treatment and Recycling, Hangzhou 310012*, China*
*For correspondence: heshanying@zjgsu.edu.cn

Abstract

In this study, tomato plants were cultivated in the greenhouse in five consecutive experiments: fertilized with 800 kg N ha^{-1} fresh sludge (S-H), 400 kg N ha^{-1} fresh sludge (S-L), 800 kg N ha^{-1} straw composting product (VM-S), 800 kg N ha^{-1} swine manure composting product (VM-M) and no fertilization (CK), and the soil properties, inorganic nitrogen forms and N_2O emission characteristics were investigated. The results showed that, treatments with composting product significantly increased the soil electrical conductivity (EC) ($p<0.05$), and the VM-M treatment exhibited the largest soil EC. With the addition of sludge and composting products, pH of soil increased significantly ($p<0.05$) and ultimately tend to be neutral, and the inhibitory effect of VM-M on soil acidification was better than VM-S. Soil NO_3^- concentration increased significantly with application of sludge and composting, and the NO_3^- concentration of each treatment decreased gradually with time. Most of the NO_3^- was absorbed by tomato plants, partially leached from the upper soil layer to the lower. Most of the NH_4^+ was oxidized to NO_3^- and partially absorbed by plants. With the equal application of inorganic nitrogen, the promoting effect on the tomato growth was VM-M>VM-S>S-H. In addition, the excess application of nitrogen fertilizer from S-H than S-L did not promote the growth of tomato markedly ($p<0.05$). Compared with the control, N_2O emission from soil was significantly improved by sludge or biomass composting ($p<0.05$). The N_2O emission from all treatments were focused on the first 20 days after fertilization, and the emission of soil N_2O was S-L (0.76 kg N_2O-N ha^{-1} y^{-1}))<VM-M (0.95 kg N_2O-N ha^{-1} y^{-1})<VM-S (1.19 kg N_2O-N ha^{-1} y^{-1})<S-H (1.71 kg N_2O-N ha^{-1} y^{-1}). Therefore, during the utilization of sludge in farmland, the mixed compost by sludge and pig manure could be a priority to prevent soil acidification, promote crop growth and meanwhile reduce the greenhouse gas emission.

Keywords: Sewage sludge; Biomass composting; Tomato plots; Soil characteristics; N_2O emission

Introduction

Global climate change has become one of the most serious problems to humanity in the 21^{st} century (Crowley, 2000). CO_2, CH_4 and N_2O are the three most important greenhouse gases. N_2O can dwell in atmosphere up to 140 years and its global warming potential is 23 and 298 times higher than CH_4 and CO_2 respectively. The latest study has showed that N_2O is the most important factors, which lead to the destruction of the ozone layer and it accounts for skin cancer of humans and the rapid rise of other diseases (Ravishankara *et al.*, 2009). The atmospheric N_2O flux is increasing by 0.2–0.3% per year (Tallec *et al.*, 2008). Agricultural soil is a major source of N_2O emission, which contributes to approximately 70% of the globally anthropogenic N_2O emission (Bouwman, 1990). Since 1980 to 2007, N_2O emission from agricultural lands has increased with an average growth rate of 7.6% annually in China (Zhang *et al.*, 2010a). Among which the contribution rate from input of chemical nitrogen fertilizer, application of organic material and utilization of crop straw was 77.64%、15.57% and 6.46%, respectively (Zhang *et al.*, 2010a). Application of nitrogen fertilizer can cause the release of N_2O by nitrification and denitrification of the soil microorganism. Hence, how to reduce the emission of N_2O during the agricultural production has become an issue of intensive attention.

According to the statistics, by the end of 2010, the urban sewage treatment capacity has reached 1.25×10^8 m^3 in China, and the urban sewage treatment rate was 82%, with an annual output of sludge (water content 80%) 2.04×10^7 t, however, the rate of harmless treatment and disposal of sludge was only 25.1% in 2010 (MOHURD, 2012). Based on the requirement of the "Twelve Five-Year Plan" of the Chinese government, the harmless treatment rate of sludge in the 36 key cities of China should reached 80% in 2015 (GOSC, 2012). Therefore, it is necessary to find effective sludge treatment and disposal methods to deal

To cite this paper: He, S., A. Li and L. Wang, 2016. Effect of sewage sludge and its biomass composting product on the soil characteristics and N_2O emission from the tomato planting soil. *Int. J. Agric. Biol.*, 18: 501–508

with the duel pressure from increasing sludge yield and the improved standard for sludge treatment.

Sewage sludge is rich in organic matter, nitrogen, phosphorus and other nutrients, hence, it's a kind of organic fertilizer with high nutrition and often used to improve soil quality and promote plant growth (Adviento-Borbe *et al*., 2007). It was estimated that 37% of sewage sludge was applied in farmland globally (Togay *et al*., 2008), and this proportion has reached 44.83% in China (Peng and Sun, 2008). In China, sludge compost and land use will be one of the main development directions of sludge's harmless treatment and resource over long periods. However, sewage sludge also contained a lot of heavy metals, pathogens and organic contaminants (Fytili and Zabaniotou, 2008). Biomass composting product of sludge not only contains a large amount of nutrients necessary for plant but can greatly reduce the bacteria content (Harrison *et al*., 2006). However, limited information is available about the soil properties and N_2O emission from the land application processes of the sewage sludge and its mixed composting products including manure or straw biomass. Therefore, in this study, the change of soil properties, inorganic nitrogen forms and N_2O emission characteristics were investigated after the sewage sludge and its mixed composting products were applied in tomato (*Solanum iycopersicum* L.) field, which would help to insight the preservation of soil nitrogen and control of N_2O emission from farmland.

Materials and Methods

Experimental Details and Treatments

Soil preparation: The tested soil is clay which was collected from a farmland in suburban of Hangzhou, Zhejiang province, China. After the removal of animal and plant residues and rocks, the soil sample was air-dried and screened with a 2 mm sieve, then, mixed well. The physical-chemical properties of soil were determined according to the method of conventional soil agro-chemistry analysis (Yang *et al*., 2009) and presented as follows: pH 6.2, electrical conductivity (EC) 1.2 dS m^{-1}, organic matter content 2061.5 mg kg^{-1}, total organic carbon content 8.7 g kg^{-1}, NO_3^- 30.4 mg kg^{-1}, NO_2^- 2.7 mg kg^{-1} and NH_4^+ 7.5 mg kg^{-1}.

Sewage Sludge and Biomass Composting Product Preparation

Sewage (BOD_5 of 983.5 mg L^{-1}) was taken from Qige sewage treatment plant in Hangzhou, Zhejiang province, China. Sewage was aerobically digested in a reactor. The sewage sludge obtained after the addition of a flocculant was passed through a belt filter to reduce water content. Heavy metal Concentrations, toxic organic contaminants and pathogen content in the sewage sludge were low, making the sludge of excellent quality (USEPA, 1994). Swine manure was taken from a large-scale pig farm in Yuhang district of Hangzhou city. The organic carbon (on dry basis), total nitrogen, total phosphorus, total potassium content, and EC of swine manure was 35.1%, 3.7%, 4.1%, 1.4% and 3.04 dS m^{-1}, respectively; their corresponding content in corn straw powder was 48.4%, 0.74%, 0.32%, 1.1% and 0.52 dS m^{-1}, respectively. The composting was carried out by mixing the fresh dehydrated sludge with corn straw powder (particle size <5 mm) or swine manure, with the ratio of sludge/straw (or manure) was 60%/40% (percentage of dry weight mass) at 65% water content. The stable and mature composting product was obtained after condition for one month.

About 3.25 kg (dry weight) of soil was added to PVC tube (16 cm (diameter) × 50 cm (height)) filled with 7 cm of gravel at the bottom and topped up with 3 cm sand. Five treatments were applied to the soil: soil added with no sludge and composting product served as control (C treatment), soil added with 220 g of fresh sludge kg^{-1} soil (S-H treatment), soil added with 110 g of fresh sludge kg^{-1} soil (S-L treatment), soil added with 530 g of straw composting product kg^{-1} soil (VM-S treatment) and soil added with pig manure composting product of 475 g kg^{-1} soil (VM-M treatment). There were 12 parallels for each treatment. The amount of sludge in the high dosage of sludge treatment (S-H) and composting products (in the VM-S and VM-M treatments) added to soil was such that 800 kg N ha^{-1} considering a soil density of 1.4 kg dm^{-3} and that 40% of the organic N added with the sewage sludge was mineralized. 800 kg N ha^{-1} is a dose rate for tomato recommended by the Major Crop Fertilization Guide in China (Zhang *et al*., 2009) and the main crop scientific fertilizing guidance of Chinese Ministry of Agriculture. The amount of sewage sludge added in the low dosage of sludge treatment (S-L) was such that 400 kg N ha^{-1} was added.

Tomato Cultivation and Sample Collection

After washed with clean water, tomato seeds were soaked in distilled water for 4 h at 20ºC and dark condition. Then, seeds were put in a constant-temperature incubator to accelerate germination at 28ºC for 10 h, and then sowed in greenhouse with two tomato plants per tube. The plants were grown in a greenhouse under natural light conditions, with temperatures of 25ºC /15ºC (day/night) and relative humidity of 70%.

Zero, 30, 60 and 90 days after sowing, three PVC tubes were selected at random from each treatment and each soil sample. The entire soil column was removed from the PVC tube and the 0–15 cm and a 15–30 cm layer sampled. The soil of 0–15 cm and 15–30 cm layer was analyzed for EC, pH, NO_3^-, NO_2^-, and NH_4^+ content, at 0, 30, 60 and 90 day. N_2O emission was determined every two days until day 90. On the 90^{th} day, the above-ground parts of tomato plants were harvested, rinsed with distilled water and dried the surface using bibulous paper, then, the average weight and height of the plants' shoot for each treatment were measured.

Emission of N_2O

A cylindrical PVC chamber with a size of 16 cm (diameter) × 50 cm (height) was placed on the tomato cultivation tube and air-tied sealed. A plastic pipe was connected to the top of the PVC chamber, and gas samples were collected using medical plastic syringe which extracted gas from the plastic pipe at 0, 5, 15 and 30 min after the upper PVC cylindrical chamber was placed. It was based on the hypothesis that at 0 min the gas concentration into the PVC cylindrical chamber is equal to the gas concentration outside the PVC cylindrical chamber, and values were corrected for the available headspace and values of 0 min were subtracted to values of 5, 15 and 30 min. The N_2O concentrations were analyzed using a gas chromatography (Agilent 7890A). The detector temperature, column temperature and the injection port temperature was 350 ºC, 60 ºC and 100 ºC, respectively. The N_2O flux was calculated by $F=\rho\times h\times(dc/dt)\times(273/T)$, where F was the N_2O flux (μg N m^{-2} h^{-1}), ρ was the N_2O density under the standard condition (1.26×10^9 μg m^{-3}), h was the effective height of the sampling gas chamber, dc/dt was the change rate with time of the N_2O concentration in the sampling gas chamber, and dc/dt was calculated by the linear regression analysis of the gas concentrations obtained at the four time points, T was the absolute temperature of soil (K). The emission summary of N_2O during the measurement period (90 d) was calculated by:

$$C = \sum_{i=1}^{n} \left(\frac{Fi + Fi + 1}{2} \times 24 \times D\right)$$

Where C was the emission summary of N_2O per square meter (μg N m^{-2}), F_i and F_{i+1} was the N_2O flux of the time i and time i+1, respectively D was the sampling interval days between the sampling time i and time i+1 (D was 2 d in this study), and n was the total sampling times (n was 45 in this study). Furthermore, the annual emission of N_2O per hectare was calculated (kg N_2O-N ha^{-1} y^{-1}).

Statistical Analyses

The data are shown as means ± standard deviation (SD) of three replicates. The significant differences among different treatments were analyzed by ANOVA ($P < 0.05$) with SPSS 19.0.

Results

Change of Soil EC and pH

As shown in Table 1, in both layers of 0–15 and 15–30 cm, soil EC under composting treatments were significantly higher than other treatments ($p<0.05$). VM-M treatment resulted in the largest EC values (0.32~0.64 dS m^{-1}), and its initial EC was 6, 4 and 2 times higher than the C, S-H and VM-S treatment. On day 90, soil EC in the VM-M treatment was 3.6, 2.4 and 1.5 times of that in the C, S-H and VM-S treatment, respectively in the 0–15 cm layer, and 2.7, 2.3 and 1.7 times, respectively in the 15–30 cm layer.

In the 0–15 cm layer, pH changes little with time (Table 1). Soil pH were significantly increased by the addition of sludge or composting product, as compared to C ($p<0.05$). The pH value showed similar variety trend in the two soil layers, however, pH in the 15–30 cm layer was slightly lower than that in the 0–15 cm layer (Table 1).

Concentration of Soil Inorganic Nitrogen

As shown in Fig. 1, concentrations of NO_3^- in 0-15 cm layer of all treatments decreased gradually with time, with the smallest decrease found in the composting product treatments. Concentrations of NO_3^- were significantly higher with sludge or composting product treatment ($p<0.05$). Except for the control, concentrations of NO_3^- in the 15–30 cm layer of all treatments increased on the 30th day and then decreased, with the composting treatments being the most significant. Additionally, concentrations of NO_3^- in each treatment were significantly higher than the control ($p<0.05$).

The NO_2^- in both the 0–15 cm and 15–30 cm layers were less than 3 mg N kg^{-1} and were similar in all treatments (Fig. 1). NO_2^- decreased firstly and then increased slightly in both 0–15 cm and 15–30 cm layers. In the initial period, the sludge treatments showed the highest NH_4^+-N concentrations (14 and 31 mg kg^{-1} soil in the S-L and S-H treatment, respectively). Between days 0 and 30, NH_4^+-N concentrations decreased in all treatments. Moreover, NH_4^+-N concentrations were similar in all treatments after 30 days (Fig. 1).

Effect on the Plant Growth

On the day 90, in the S-H, S-L, VM-S and VM-M treatment, the shoot biomass of tomato plant was 1103, 1009, 1383 and 1515 g $plant^{-1}$ respectively, which increased 29.6%, 18.6%, 62.5% and 78%, respectively of that in the C treatment; plant height of the aboveground was 51.3, 49.1, 54.5 and 56.8 cm respectively, which was 24.5%, 19.2%, 32.3% and 37.9% higher respectively than that of the C treatment.

N_2O Emission

As shown in Fig. 3, large amount of N_2O emitted from soil on the first day and declined thereafter. N_2O emission decreased rapidly between 3 and 7 days and even negatively, but increased again from the 9th day and decreased to very low after day 21. In this study, N_2O emission in the S-H, S-L, VM-S and VM-M treatment was 1.71, 0.76, 1.19 and 0.95 kg N_2O-N ha^{-1} y^{-1}, respectively. In comparison with C, soil N_2O emission was significantly enhanced by sewage sludge or biomass composting product ($p<0.05$).

Table 1: Varieties of soil EC and pH value in 0-15cm and 15-30 cm layers with time under different treatments

Index	Soil layer/(cm)	0–15					15–30				
	Time /(d)	CK	S-H	S-L	VM-S	VM-M	CK	S-H	S-L	VM-S	VM-M
EC/(dS m^{-1})	0	0.10±0.02	0.16±0.00	0.12±0.01	0.31±0.02	0.64±0.02	0.10±0.02	0.16±0.00	0.12±0.01	0.31±0.02	0.64±0.02
	30	0.11±0.01	0.19±0.03	0.13±0.01	0.26±0.01	0.35±0.01	0.14±0.01	0.17±0.03	0.11±0.02	0.20±0.04	0.32±0.01
	60	0.09±0.00	0.20±0.01	0.10±0.02	0.29±0.02	0.39±0.00	0.12±0.02	0.19±0.03	0.13±0.01	0.17±0.00	0.37±0.01
	90	0.11±0.01	0.17±0.01	0.12±0.01	0.27±0.01	0.40±0.00	0.13±0.01	0.15±0.00	0.12±0.01	0.21±0.01	0.35±0.01
pH	0	6.2±0.1	7.6±0.0	7.4±0.1	7.2±0.0	7.0±0.1	6.2±0.1	7.6±0.0	7.4±0.1	7.2±0.0	7.0±0.1
	30	6.4±0.1	7.5±0.1	7.4±0.0	7.3±0.0	7.4±0.1	6.3±0.0	7.5±0.0	7.5±0.1	7.0±0.0	7.2±0.0
	60	6.3±0.0	7.8±0.2	7.5±0.0	7.5±0.1	7.5±0.1	6.2±0.1	7.6±0.1	7.2±0.0	7.3±0.0	7.2±0.0
	90	6.2±0.2	7.7±0.0	7.5±0.1	7.4±0.1	7.6±0.0	6.2±0.0	7.4±0.0	7.4±0.1	7.3±0.0	7.4±0.1

Mean ± standard deviation

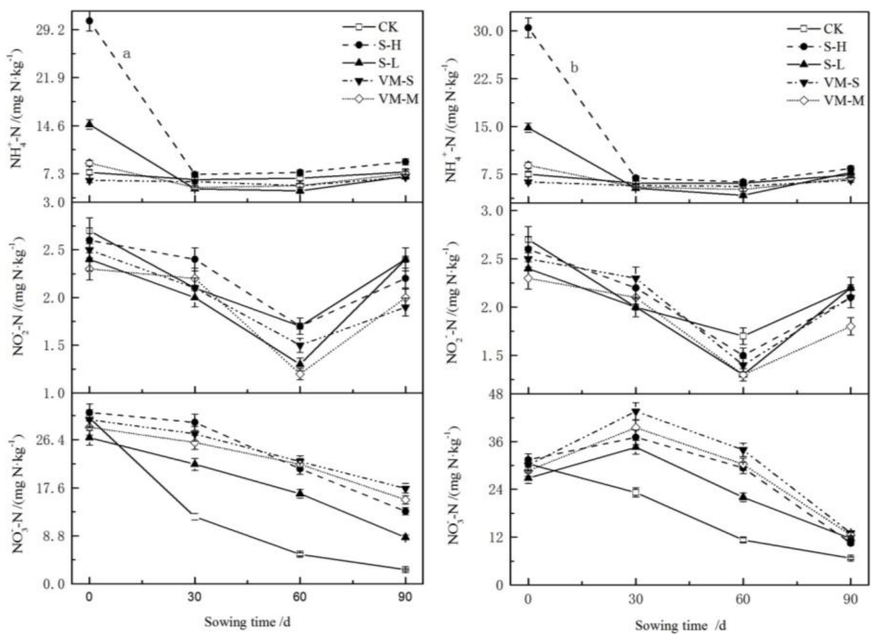

Fig.1: Concentrations of NH_4^+, NO_2^- and NO_3^- in the 0–15 cm and 15–30 cm layers changed with time under different treatments

Discussion

EC and pH Values

The EC value reflects the soluble salt content of organic matters as well as their potential toxicity to plants. When EC is higher than 4 dS m^{-1}, plant growth and germination rate would decrease and wilting occurs (Yang *et al*., 2012). The pig manure has the largest salt content (EC value of the pig manure, straw and sludge was 3.04, 0.52, 0.47 dS m^{-1} respectively), so when applied to soil the EC increased the most. Similarly, Perez-Murcia *et al*. (2006) reported that EC increased about four times when the sludge compost added to peat land. When mushroom compost was applied to farmland, soil EC also increased significantly because of the high concentration of Na in the compost (Courtney and Mullen, 2008).

The high content of soluble salt in sludge and composting product would lead to the increase of pH in soil (Cheng *et al*., 2007), while the degradation of organic matter will produce NH_4^+ and humic acid (Komilis and Ham, 2006), thus their combined effect of these two oppositely charged ions regulates the pH of composting product towards to be neutral (Pramanik *et al*., 2007). Furthermore, results of this study indicated that the effect of composting product of sludge and pig manure on the inhibition of soil acidification was slightly better than that of sludge and straw. Similarly, Li (2004) reported that organic manure could effectively ameliorate the soil acidification, with pig manure being more effective than horse manure, chicken manure and straw. With the increasing of organic manure application, the buffering capacity for soil acidification enhanced.

Dynamics of soil NO_3^-, NO_2^- and NH_4^+

The NO_3^- concentration in soil varied greatly (Fig. 1), because it can be absorbed by plants, and be fixed by microorganism in the absence of NH_4^+ or reduced to N_2O or

Table 2: The reported N_2O emissions induced by organic manure application

Land type and organic manure added	N_2O emission as reported	N_2O emission amount /kg N_2O-N ha^{-1} y^{-1}	Reference
Greenhouse tomato plants:			The present study
Sewage sludge (high content)	19.5 μg N m^{-2} h^{-1}	1.71	
Sewage sludge (low content)	8.63 μg N m^{-2} h^{-1}	0.76	
Straw compost	13.58 μg N m^{-2} h^{-1}	1.19	
Pig manure compost	10.82 μg N m^{-2} h^{-1}	0.95	
Apple orchard soil:			Ge *et al*., 2014
Maize straw (0.86 g N kg^{-1}) and pure nitrogen 250 kg ha^{-1}	1.50 kg N ha^{-1}	1.50	
Biochar (corn straw pyrolysised in low temperature of 400℃: 4.96 g N ha^{-1}) and pure nitrogen 250 kg ha^{-1}	1.58 kg N ha^{-1}	1.58	
Vegetables land with purple soil in Shanghai (260 N kg ha^{-1}):			He *et al*., 2014
20% of fresh pig manure and 80% of carbamide			
20% of pig manure compost and 80% of carbamide	2.953 kg N_2O ha^{-1}	1.88	
	2.181 kg N_2O ha^{-1}	1.39	
Rice paddy field:			Li *et al*., 2013
20% of pig manure and 80% of carbamide	869.87 g N_2O ha^{-1}	0.53	
20% of pig manure compost and 80% of carbamide	1279.11 g N_2O ha^{-1}	0.81	
20% of biogas slurry fertilizer and 80% of carbamide	859.9 g N_2O ha^{-1}	0.54	
Rice paddy field with sandy loam:			Ma *et al*., 2013
Maize stalk returned of 55.4 kg N ha^{-1}	338.72 kg N_2O ha^{-1}	338.72	
Maize stalk compost of 107.9 kg N ha^{-1}	307.8 kg N_2O ha^{-1}	307.8	
Maize stalk returned in the form of residue of 181 kg N ha^{-1}	346.66 kg N_2O ha^{-1}	346.66	
Maize stalk returned in the form of black toner of 14 kg N ha^{-1}	278.41 kg N_2O ha^{-1}	278.41	
Greenhouse paddy field:			Zhong *et al*., 2013a
Pig manure mixed with mushroom residue compost (21.84 g N kg^{-1})	0.13g N_2O t^{-1}	34.75	
Greenhouse radish land:			Zhong *et al*., 2013b
Sewage sludge and mushroom residue compost (339.98 kg N ha^{-1})	0. 487 mg N_2O m^{-2} h^{-1}	26.73	
Early rice field:			Shi *et al*., 2011
Late rice straw returning (22 kg N ha^{-1}) and fertilizer (83 kg N ha^{-1})	14.99 μg N_2O m^{-2} h^{-1}	0.45	
Paddy field:			Luo *et al*., 2010
Rice straw and soya-bean cake compost (104 kg N ha^{-1})	12.41 g N m^{-2}	124.1	
Alfalfa (104 kg N ha^{-1})	12.01 g N m^{-2}	120.1	
Greenhouse potting soyabean:			Fernández-Luqueño *et al*., 2009
Earthworm casts	19.2 ng N kg h^{-1}	1.42	
Culture flask:			Luo *et al*., 2008
Earthworm	590.2 μg N_2O-N kg^{-1}	2.48	
Crop stalk	1415.4 μg N_2O-N kg^{-1}	5.94	
Earthworm and crop stalk	2046.3 μg N_2O-N kg^{-1}	8.59	
Fresh cow manure stacked in different forms	Summer 3.81-20.2 μg N_2O kg^{-1} h^{-1} Autumn 0.25-0.69 μg N_2O kg^{-1} h^{-1}	89-472.37 5.85-15.59	Lu *et al*., 2008
Barley field:			Perala *et al*., 2006
Excrements of livestocks 28.6 t ha^{-1}	7.33 g N ha^{-1} d^{-1}	2.6	
Excrements of livestocks 14.3 t ha^{-1} and 50 kg NH_4NO_3-N ha^{-1}	4.4 g N ha^{-1} d^{-1}	1.6	
Grazing pasture	26.4 g N ha^{-1} d^{-1}	9.6	Saggar *et al*., 2004

N_2 under anaerobic condition. In addition, NO_3^- may leach out. The NO_3^- concentrations in both 0–15 cm and 15–30 cm layers of the C treatment showed the largest decrease (Fig. 1). Since no NO_3^- leaching occurred and N_2O emission was very low (1.85 ng N m^{-2} h^{-1}), the decrease of NO_3^- concentration was mainly caused by the absorption of plants. Santibanez *et al*. (2007) reported that NO_3^- is of potential to leach when soil applied with sludge, and especially at high rates of the sludge application. In this study, although soil water content did not exceed the field capacity, water movement still exists in soil profile as the NO_3^- concentrations decreased in the 0–15 cm layer in all treatments, while it increased in the 15–30 cm layer at day 30 (Fig. 1). Later on, NO_3^- concentrations in the 15-30 cm layer decreased due to the absorption by plants.

The accumulation of NO_2^--N in soils was mainly resulted from the soil nitrification process under incubation conditions (Bao, 2009). The results of this study showed that as an intermediate product of the nitrification process, NO_2^- accumulated little in the 0–30 cm layer and its accumulation was directly related to the NH_4^+-N concentration in soil. NH_4^+ was oxidized to NO_{3-} and taken up by crops or volatilized in the form of NH_3. However, Cordovil *et al*. (2007) suggested that NH_3 volatilization was very low as soil pH was 7.6. Hence, most of NH_4^+ was oxidized to NO_3^- which resulted in NO_3^- concentration increased at day 30. In addition, some NH_4^+ might be taken up by plants (Volk *et al*., 1992).

Growth of Tomato Plant

In this study, we have tried to add similar amount of inorganic nitrogen in the initial in the VM-S, VM-M and S-H treatments. After 90 days' cultivation, the biomass and height of the aboveground part of tomato plant were significantly higher in the VM-S and VM-M treatments than that of the fresh sludge and the control treatments ($p<0.05$), and VM-M treatment was the most effective on promoting tomato growth (Fig. 2). Similarly, Fernández-Luqueño *et al.* (2009) reported that vermicompost compost was more effective on promoting the growth of bean than fresh sludge. In addition, there was no significant difference of plant biomass and height between the S-H and S-L treatments (Fig. 2), indicating that the additional nitrogen fertilizer applied in the S-H treatment did not play a marked role in improving the tomato growth.

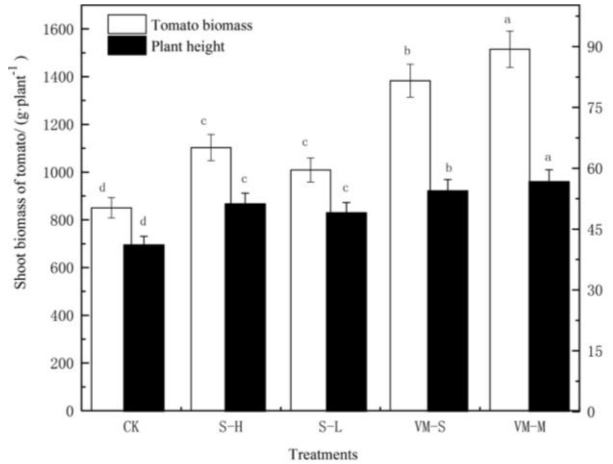

Fig. 2: Biomass and height of the aboveground part of tomato plant under different treatments. Different letters meant the significant difference among treatments ($p<0.05$)

Emission of N_2O

Soil N_2O emission is controlled by complex soil processes and soil factors, among which nitrification and denitrification are the most important. Harrison and Webb (2001) suggested that nitrification is the dominant factor for soil N_2O emission, while Beck-Friis *et al.* (2000) considered that N_2O may be either a byproduct of ammonium oxidation or the end product of incomplete reduction of NO_3^-. The application with organic fertilizer can promote the N_2O emission from soil (Li *et al.*, 2005). Fig. 3 showed that fertilization with composting product by sludge and pig manure was more helpful to reduce N_2O emission than that with fresh sludge or composting product by sludge and straw. Several reports have indicated that the application with straw, livestock and poultry manure and biogas residue to farmland instead of chemical fertilizers can reduce the N_2O emission from soil (Ding *et al.*, 2010; Zhang *et al.*, 2012; He *et al.*, 2014). In contrast, some reports showed that emission of N_2O was not changed or even increased after the application of organic manure or returning straw to field (Zheng *et al.*, 2008; Zhang *et al.*, 2010b; Jiang *et al.*, 2012). These conflicting results might be attributed to the different C/N ratios of organic matters, activities of carbon and nitrogen components, soil conditions and even plant species in the different studies (Jäger *et al.*, 2011; Rizhiya *et al.*, 2011; Riya *et al.*, 2012), and their related transformation processes of nitrogen remains to be further studied. In addition, as shown in Table 2, N_2O emission observed in this study was between the ranges, which have been reported. It can be concluded that the distinct soil types, crop species and types of nitrogen fertilizer can cause the significant difference of the N_2O emissions. Therefore, the nitrification and denitrification are influenced by the environmental factors, crop systems, field management measures, organic manures, hydrological conditions and etc. (Zou *et al.*, 2007; Ellert and Janzen, 2008).

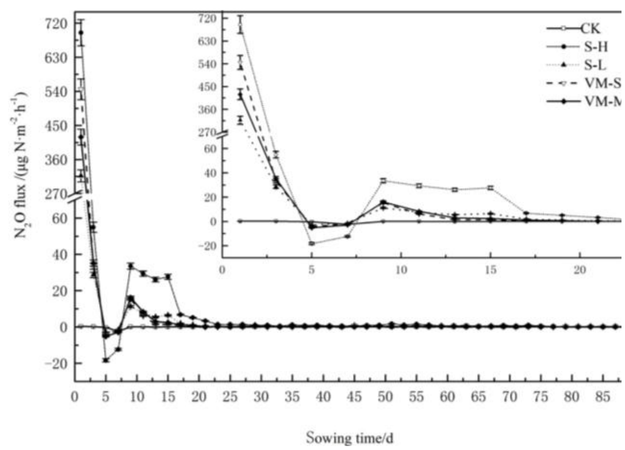

Fig. 3: Soil N_2O emission under different treatments

In this study, N_2O emission was mainly found in the first 20 days and especially in the first day. Accordingly, the report by Eicher (1990) based on the analysis of the direct measurements of fertilizer-derived N_2O emissions from 104 field experiments published before 1990 showed that large amount of N_2O emission was on the first day and declined thereafter. In consistent with our result, Yang *et al.* (2012) reported that N_2O emission from the soil amended with compost was mainly focused in the first 22 days. Zhong *et al.* (2013a,b) revealed the effects of sewage sludge and mushroom residues compost on the N_2O emissions from field cultivated with radish, and showed that the peaks of N_2O release were appeared at day 2, 10 and 14 and N_2O emission was also mainly concentrated in the first 20 days. The repaid decrease and even the negative emission of N_2O (Fig. 3) was likely due to that the amount of reduction of N_2O to N_2 was larger than the production of N_2O. Soil has the potential for to absorb N_2O from atmosphere when the N_2O production is less than N_2O reduction. The uptake of N_2O seems to be related to the availability of the mineral nitrogen (Chapuis-Lardy *et al.*, 2007). This process would be influenced by soil factors such as temperature, pH and oxygen content, but the effects of these factors were not always in consistent with expected. It might be dependent on the main form of N_2O reducing processes in soil and the other related factors. Besides the denitrification, nitrifier-denitrification and aerobic denitrification could also participate in the reducing processes of N_2O (Chapuis-Lardy *et al*., 2007). Additionally, other processes such as the abiotic reactions with soil minerals may also be involved in the net N_2O consumption.

Conclusion

Application with compositing product from sludge and pig manure or straw significantly increased the soil EC, and the VM-M treatment exhibited the largest EC. Soil pH increased significantly by addition of sludge and its composting product and tended eventually to be neutral. The VM-M treatment was more effective on inhibitory the soil acidification than VM-S and sludge treatment. Soil NO_3^- concentration decreased gradually with time, and it was significantly higher in sludge and composting product treatment. Soil NO_3^- was mainly absorbed by tomato plant and partially leached. Most of the NH_4^+ was oxidized to NO_3^- and partly absorbed by plants. With the equal application of inorganic nitrogen, the promoting effect on the tomato growth was VM-M>VM-S>S-H, and the excess application of nitrogen fertilizer from S-H than S-L did not promote the growth of tomato markedly. N_2O emission from soil was significantly improved by sludge or biomass composting, and the emission of soil N_2O was S-L<VM-M<VM-S<S-H. Hence, the mixed compost by sludge and pig manure can greatly help to prevent soil acidification, promote crop growth and meanwhile reduce the greenhouse gas emission during the utilization of sludge in farmland.

Acknowledgments

The authors wish to acknowledge financial support from the Zhejiang Provincial National Science Foundation of China (LY13C030001) and National Natural Science Foundation of China (41501521).

Reference

Adviento-Borbe, M.A.A., M.L. Haddix, D.L. Binder, D.T. Walters and A. Dobermann, 2007. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. *Global Change Biol.*, 13: 1972–1988

Bao, J.D., 2009. Nitrite accumulation and influential factors of in soil nitrogen during nitrification process. *Master's Degree Thesis* of Northwest A&F University, China

Beck-Friis, B., M. Pell, U. Sonesson, H. Jonsson and H. Kirchmann, 2000. Formation and emission of N_2O and CH_4 from compost heaps of organic household waste. *Environ. Monit. Assess*, 62: 317–331

Bouwman, A.F., 1990. Exchange of greenhouse gases between terrestrial ecosystem and the atmosphere. *In*: *Soils and the Greenhouse Effect*, pp: 61–127. Wiley, New York, USA

Chapuis-Lardy, L., N. Wrage, A. Metay, J.L. Chotte and M. Bernoux, 2007. Soils, a sink for N_2O? A review. *Global Change Biol.*, 13: 1–17

Cheng, H.F., W.P. Xu, J.L. Liu, Q.J. Zhao, Y.Q. He and G. Chen, 2007. Application of composted sewage sludge (CSS) as a soil amendment for turf grass growth. *Ecol. Eng.*, 29: 96–104

Cordovil, C.M.D.S., F. Cabral and J. Coutinho, 2007. Potential mineralization of nitrogen from organic wastes to ryegrass and wheat crops. *Bioresour. Technol.*, 98: 3265–3268

Courtney, R.G. and G.J. Mullen, 2008. Soil quality and barley growth as influenced by the land application of two compost types. *Bioresour. Technol.*, 99: 2913–2918

Crowley, T.J., 2000. Causes of climate change over the past 1000 years. *Science*, 289: 270–277

Ding, W.X., K. Yagi, Z.C. Cai and F.X. Han, 2010. Impact of long-term application of fertilizers on N_2O and NO production potential in an intensively cultivated sandy loam soil. *Water Air Soil Poll.*, 212: 141–153

Eicher, M.J., 1990. Nitrous oxide emissions from fertilized soils: summary of available data. *J. Environ. Qual.*, 19: 272–280

Ellert, B.H. and H.H. Janzen, 2008. Nitrous oxide carbon dioxide and methane emissions from irrigated cropping systems as influenced by legumes manure and fertilizer. *Can. J. Soil Sci.*, 88: 207–17

Fernández-Luqueño, F., V. Reyes-Varela, C. Martínez-Suárez, R.E. Reynoso-Keller, J. Méndez-Bautista, E. Ruiz-Romero, F. López-Valdez, M.L. Luna-Guido and L. Dendooven, 2009. Emission of CO_2 and N_2O from soil cultivated with common bean (*Phaseolus vulgaris* L.) fertilized with different N sources. *Sci. Total Environ*., 407: 4289–4296

Fytili, D. and A. Zabaniotou, 2008. Utilization of sewage sludge in EU application of old and new methods -a review. *Renew. Sust. Energ. Rev.*, 12: 116–140

GOSC (General Office of the State Council of the People's Republic of China), 2012. *"Twelve Five" National Urban Sewage Treatment and Recycling Facilities Construction Plan*. Beijing, China

Harrison, E.Z., S.R. Oakes, M. Hysell and A. Hay, 2006. Organic chemicals in sewage sludge. *Sci. Total Environ*., 367: 481–497

Harrison, R. and J. Webb, 2001. A review of the effect of N fertilizer type on gaseous emissions. *Adv. Agron.*, 73: 65–108

He, F.F., Y.S. Liang, Z.Y. Yi, X.M. Rong, A.P. Wu and Q. Liu, 2014. Effects of combined application of manure and chemical fertilizer on the nitrification in acid vegetable soil. *Plant Nutr. Fert. Sci.*, 20: 534–540

Jäger, N., C.F. Stange, B. Ludwig and H. Flessa, 2011. Emission rates of N_2O and CO_2 from soils with different organic matter content from three long-term fertilization experiments-a laboratory study. *Biol. Fert. Soils*, 47: 483–494

Jiang, N.N., Y.E. Li, L. Hua, Y.F. Wan and S.W. Shi, 2012. Effect of different nitrogen sources and straw adding on N_2O emission from vegetable soil. *Chin. J. Soil Sci.*, 43: 219–223

Komilis, D.P. and R.K. Ham, 2006. Carbon dioxide and ammonia emissions during composting of mixed paper yard waste and food waste. *Waste Manage.*, 26: 62–70

Li, C.S, S. Frolking and K. Butterbach-Bahl, 2005. Carbon sequestration in arable soils is likely to increase nitrous oxide emissions off setting reduction in climate radiative forcing. *Clim. Change*, 72: 321–338

Li, X.L., 2004. Study on the operational effect of fertilizer on the production of green food-Cucumber. *Master's Degree Thesis* of JiLin Agricultural University, China

MOHURD (Ministry of Housing and Urban-Rural Development of the People's Republic of China), 2012. *Chinese Urban Drainage and Sewage Treatment Status Bulletin*. Beijing, China

Peng, Q. and Z.J. Sun, 2008. Present status and development of sewage sludge's treatment and utilization in China. *J. Energ. Eng.*, 5: 47–50

Perez-Murcia, M.D., R. Moral, J. Moreno-Caselles, A. Perez-Espinosa and C. Paredes, 2006. Use of composted sewage sludge in growth media for broccoli. *Bioresour. Technol.*, 97: 123–230

Pramanik, P., G. K. Ghosh, P.K. Ghosal and P. Banik, 2007. Changes in organic-C, N, P and K and enzyme activities in vermin compost of biodegradable organic wastes under liming and microbial inoculants. *Bioresour. Technol.*, 98: 2485–2494

Ravishankara, A.R., J.S. Daniel and R.W. Portmann, 2009. Nitrous Oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. *Science*, 326: 123–125

Riya, S., S. Zhou, Y. Watanabe, M. Sagehashi, A. Terada and M. Hosomi, 2012. CH_4 and N_2O emissions from different varieties of forage rice (*Oryza sativa* L.) treating liquid cattle waste. *Sci. Total Environ.*, 419: 178–186

Rizhiya, E.Y., L.V. Boitsov, N.P. Buchkina and G.G. Panova, 2011. The Influence of crop residues with different C: N ratios on the N_2O emission from a loamy sand Soddy Podzolic soil. *Eurasian Soil Sci.*, 44: 1144–1151

Santibanez, C., R. Ginocchio and M.T. Varnero, 2007. Evaluation of nitrate leaching from mine tailings amended with biosolids under Mediterranean type climate conditions. *Soil Biol. Biochem.*, 39: 1333–1340

Tallec, G., J. Garnier, G. Billen and M. Gousailles, 2008. Nitrous oxide emissions from denitrifying activated sludge of urban wastewater treatment plants, under anoxia and low oxygenation. *Bioresour. Technol*, 99: 2200–2209

Togay, N., Y. Togay and Y. Dogan, 2008. Effects of municipal sewage sludge doses on the yield, some yield components and heavy metal concentration of dry bean (*Phaseolus vulgaris* L.). *Afr. J. Biotechnol.*, 7: 3026–3030

USEPA, A plain English guide to the EPA Part 503 biosolids rule US EPA/832/r-93/003, 1994. United States Environmental Protection Agency Office of Wastewater Management, Washington, USA

Volk, R., S. Chaillous, A. Mariotti and J.F. Morotgaudry, 1992. Beneficial-effects of concurrent ammonium and nitrate nutrition on the growth of *Phaseolus vulgaris*-a N^{15} study. *Plant Physiol. Bioch.*, 30: 487–4893

Yang, F., G.X. Li, T. Jiang and B.L. Zhang, 2012. Vermicomposting treatment of vegetable waste and its greenhouse gas emissions. *Transact. Chin. Soc. Agric. Eng.*, 28: 190–196

Yang, Y.F., Y.C. Xu, Z. Yao, H.Y. Jin, S.X. Xu and J.J. Yang, 2009. Salinity characteristics of greenhouse vegetable soils in Shanghai Pudong New Area. *Soils*, 41: 1009–1013

Zhang, F.S., X.P. Chen and Q. Chen, 2009. *Fertilizer Guidelines for the Main Crops in China*. Agricultural University Press, Beijing, China

Zhang, J., H. Li, L.G. Wang and J.J. Qiu, 2012. Analysis of the characteristics of nitrous oxide emission from a winter wheat-green onion rotation system and the influencing factors. *J. Agro-Environ. Sci.*, 31: 1639–1646

Zhang, Q., X.T. Ju and F.S. Zhang, 2010a. Re-estimation of direct nitrous oxide emission from agricultural soils of China via revised IPCC 2006 guideline method. *Chin. J. Eco-Agric.*, 18: 7–13

Zhang, Z.X., Y.E. Li, L. Hua, Y.F. Wan and N.N. Jiang, 2010b. Effects of different fertilizer levels on N_2O flux from protected vegetable land. *Transact. Chin. Soc. Agric. Eng.*, 26: 269–275

Zheng, X.H., B.L. Mei, Y.H. Wang, B.H. Xie, Y.S. Wang, H.B. Dong, H. Xu, G.X. Chen, Z.C. Cai, J. Yue, J.X. Gu, F. Su, J.W. Zou and J.G. Zhu, 2008. Quantification of N_2O fluxes from soil-plant systems may be biased by the applied gas chromatograph methodology. *Plant. Soil*, 311: 211–234

Zhong, J., Y. Wei, H. Wan, Y.L. Wu, J.X. Zheng, S.H. Han and B.F. Zheng, 2013a. Greenhouse gas emission from the total process of swine manure composting and land application of compost. *Atmos. Environ.*, 81: 348–355

Zhong, J., Y.S. Wei, Z.F. Zhao, M.J. Ying, G.S. Zhou, J.J. Xiong, P.C. Liu, Z. Ge and G.Q. Ding, 2013b. Emission of greenhouse gas and ammonia from the full process of sewage sludge composting and land application of compost. *Chin. J. Environ. sci.*, 34: 2186–2194

Zou, J.W., Y. Huang, X.H. Zheng and Y.S. Wang, 2007. Quantifying direct N_2O emissions in paddy fields during rice growing season in mainland China: dependence on water regime. *Atmos. Environ.*, 41: 8030–8042

(Received 28 May 2015; Accepted 26 October 2015)