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^{15}N 标记的莴苣残体、废纸浆及容重对土壤反硝化及矿化作用的动态影响

DYNAMIC EFFECTS OF SOIL BULK DENSITY ON DENITRIFICATION AND MINERALISATION BY ^{15}N LABELLED LETTUCE RESIDUE AND PAPER WASTES

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华　珞：研究员，中国农业科学院原子能利用研究所副所长。1981年毕业于山西农业大学土壤化学系。1989年获苏联季米利亚捷夫农学院生物学博士学位，1990～1992年在北京农业大学从事博士后研究工作，1995～1996年在英国爱丁堡大学农学院进行欧共体项目合作研究。

HUA Luo: Professor, deputy director of Institute for Application of Atomic Energy, CAAS. Received Ph D degree in biology at Moscow Timilyazev Agricultural Academy, U. S. R. in 1989, was engaged in postdoctor research at Beijing Agricultural University from 1990 to 1992 and worked as senior scientific visitor at Scottish Agricultural College UK. for cooperative research supported by EC from 1995 to 1996.

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^{15}N 标记的莴苣残体、废纸浆及容重对土壤反硝化及矿化作用的动态影响

华 珞 A. J. A. Vinten* 陈 清

（中国农业科学院原子能利用研究所，北京
*苏格兰农业学院，英国·爱丁堡）

摘 要

介绍了不同量的^{15}N 标记的莴苣残体、废纸浆及土壤容重对反硝化及矿化作用的动态影响。试验结果表明：仅施加莴苣残体能在短期内（8 d）增加土壤中反硝化作用，其 N_2O 释放最大量为对照的 15 倍；仅施用废纸浆在同期内不能增加 N_2O 释放量。与上述两种处理比较，二者混合施用可以刺激微生物活性和增加反硝化作用，但却比仅施莴苣残体的处理 N_2O 释放量小，说明同单纯施用莴苣残体相比混合施用可以增加氮的固定。CO_2 释放量在不同处理中的全部 107 天中呈递减趋势，混合施用的处理中 CO_2 释放量每天均高于其它处理。在上述处理中，通过施加不同的压力（2，6，18 kg）造成三种不同土壤容重。试验结果表明，70%的样本随容重增加 N_2O 与 CO_2 释放量增加，但差异显著性较弱或不明显。土壤容重的增加影响废纸浆的分解速率和 NO_3^- 与 NH_4^+ 浓度。

Dynamic Effects of Soil Bulk Density on denitrification and Mineralisation by ^{15}N Labelled Lettuce Residue and Paper Wastes

HUA Luo A. J. A. Vinten* CHEN Qing
(Institute for Application of Atomic Energy, CAAS, Beijing
* Scottish Agricultural College, Edinburgh, UK)

ABSTRACT

Two laboratory incubation experiments aimed to study the denitrification and mineralisation influenced by different additives (^{15}N labelled lettuce residue, paper wastes and mixture of both) and soil bulk densities were carried out by means of acetylene inhibition at the constant 15 ℃ for 107 and 90 days, respectively. The results showed that the changes of N_2O, CO_2 emission rates, inorganic nitrogen (NO_3^- and NH_4^+), total N and ^{15}N abandance in the soils which were affected by adding lettuce residue, paper wastes and mixture of both were investigated. Soil denitrification rate increased after lettuce residue was added into soil for 8 days. The maximum rate of N_2O emission was 15 times higher than that in soil without any additive. However, paper wastes did not increase N_2O emission in the first 8 days compared with other treatments, mixed residue and paper wastes could promote soil microbial activity, but N_2O emission was lower than that in the soil with lettuce residue added and higher than that with paper wastes, indicating that mixture of residue and paper wastes was benefit to soil nitrogen immobilisation. CO_2 emission in all the treatments were declined to the same level on the 107th day. In the treatment added mixed residues and paper wastes, the released CO_2 quantities were higher than those in other treatments every day. Effect of different bulk density on N_2O and CO_2 emission were response to the change of bulk density, it seems that N_2O and CO_2 emission increased with bulk density. High bulk density could affect decomposition of paper wastes and NO_3^-, NH_4^+ concentration.

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INTRODUCTION

N_2O is one of the major greenhouse gases, absorbing infrared radiation 250 times more than CO_2 and affecting the stratospheric ozone budget (Robertson, 1993). Its content in atmosphere has increased during the past years by about 0.25% per year to the present average concentration of 310 nl/L (Elkins and Rossen, 1989). The contribution of agricultural practices to present anthropogenic N_2O emission is estimated to be 70%～92% (Mosier, 1993; Duxbury et al., 1993). Besides water management, N fertilisation and management of crop residues are important factors which affected the release of N_2O from soil during biological and chemical denitrification and nitrification (Firestone and Davidson, 1989; Hutchinson and Davidson, 1993). Some other factors, such as release of root materials and exudates (Klemedtsson et al., 1987; Christensen et al., 1990), the activity of plant roots consumes O_2 (Cribbs and Mills, 1979; Klemedtsson et al., 1987) and soil pH change (Marschner et al., 1986) also affect soil microbial process related to denitrification and N_2O emission. Input of organic material to soil could stimulate microbial activity and create favourable conditions for N_2O formation. Mechanical disturbance can increase aeration and N_2O emission for a short period of time due to release of soil air enriched in N_2O (Matthias et al., 1980; Bremner and Blackmer, 1980b). Soil compaction can increase both denitrification rate (Torbert and Wood, 1992) and N_2O emission rate (Hansen et al., 1993).

In Scotland, paper mills produce large quantities of cellulose-rich wastes, which constitute a significant disposal problem. While such waste is often deposited in landfill sites, application to agricultural land is also an alternative. This waste may prove an effective means to reduce nitrate leaching down, immobilisation of nitrogen or reduce denitrification of excess nitrate in the soil. General studies of the dynamic effects of mixed paper mills and lettuce residue on denitrification and mineralisation in above soil were carried out in order to seek for the ways of reducing pollution atmosphere by N_2O and promoting biological immobilisation. It is postulated that the amount of immobilisation, total denitrification and N_2O/N_2 ratio of denitrated gas, derived from paper waste/crop residue amended soils be affected by soil bulk density, so that the effects of different soil bulk density on N_2O and CO_2 emission will provide evidences for scientific management of crop residue and paper waste in the field.

1 MATERIALS AND METHODS

1.1 Soil site

The experimental soil was obtained from on a commercial vegetable field at Balmalcolm Farm, Cupar, Fife (National Grid Reference GR318084) in March 1995. The site has a long history of intensive green salad and vegetable cropping. The previous crop was lettuce and the altitude is 40 m above sea level.

1.2 Materials

The soil collected from 0～20 cm in the field was a freely drained humus-iron podzol of the hexpath series based on the Eckford Association (Soil Survey of Scotland, 1982). The coarse texture of this sandy soil (with some silt bands) results in low moisture- and nutrient-retention capacities. Its total N, P, K content, organic matter and pH were 1230 mg/kg, 739 mg/kg, 1583 mg/kg, 2.7% and 6.5 respectively. The characterisitics of paper waste were shown in Table 1.

Table 1 The Characteristics of Paper Mill Sludge (on Fresh Weight Basis, Paterson, 1995)

Dry matter / %	pH	Nitrogen / %	Carbon / %	C : N ratio	Phosphorus as P_2O_5/%
35	6.9	0.48	11.8	25 : 1	0.25

1.3 Methods

Experiment Ⅰ:

100 g fresh soil was mixed well with two kinds of organic matter and incubated in a 570 cm^3 flask according to the treatments: (1) Control (CK); (2) 0.5 g ^{15}N labelled (abandance, 25.71%) fresh lettuce residues with water content (WC) of 72.8% (R); (3) 2.5 g fresh paper wastes with WC of 34.31% (P); (4) mixture of lettuce residues and paper wastes (R+P) with three replicates in each treatment. The soil samples with gravimetric WC of 21.48% were cultivated at 15 ℃ and air-proofed conditions.

N_2O emission rate was determined by gas chromatography (Hewlett Packard 5890 Series 2 with and ECD detector) at the 1, 2, 3, 8 incubation days. Prior to N_2O determination, the flasks were flushed for 2 h, and 10% acetylene (C_2H_2) was filled into flask for 24 h. CO_2 emission rate was determined by gas chromatography (Hewlett Packard 5890 Series 2 with a TCD detector) at the 2, 3, 8, 14, 21, 30, 63, 107 days. Total soil nitrogen and ^{15}N abandance were determined by mass spectrometer (VG Micromass 622) interfaced with a Carlo Erba 1400 Automatic Nitrogen Analyser. Soil samples were extracted by 1 mol/L KCl, NH_4^+-N and NO_3^--N were determined by Chemlab autoanalyser (Crooke and Simpson, 1971; Best, 1976).

Experiment Ⅱ:

250 g fresh soil (WC 13.7%) was pressed in a bulk density (BD) ring of 209 cm^3, and compacted to three BD levels by oedometer. The soil at constant moisture was incubated at 15 ℃ and air-proofed bottles of 665 cm^3. Three treatments, added lettuce residues (R), added paper wastes (P) and mixture of paper waste and lettuce residue were as follows:

R: 5 g fresh lettuce residue (WC 72.75%) labelled by 17.63% ^{15}N abandance (total N% 5.3) was added into 250 g fresh soil.

P: 15 g fresh paper mill waste (WC 34.31%) was added into 250 g fresh soil.

R+P: 5 g fresh lettuce residues (WC 72.75%) and 15 g fresh paper mill residue (WC 34.31%) were added into 250 g fresh soil.

N_2O, CO_2 concentrations in vessel were measured at the 0, 1, 3, 5, 10, 15, 30, 68, 90 days, 10% C_2H_2 was filled into the vessel atmosphere for 24 h before each measurement. After measuring samples were flushed for 2 h, the bung closed and samples incubated at 15 ℃. Extractable NO_3^- and NH_4^+, total N and ^{15}N content of soil samples were measured at the 0, 30, 68, 90 days.

2 RESULTS AND DISCUSSIONS

2.1 Effects of added lettuce residue and paper waste on denitrification

In experiment Ⅰ, denitrification rate was stimulated by adding lettuce residue, N_2O emission was over 15 times higher than that in CK treatment (without any additives) in the first incubation day, although the stimulating effect declined with incubation time, it was 5.0 times higher than that in CK treatment at the 3rd day. By the 8th day, N_2O release in R treatment declined to that in CK treatment. Paper wastes did not stimulate N_2O emission, however the mixture of lettuce residue and paper waste also increased N_2O emission, this effect was less than that in R treatment (see Table 2).

Table 2 N_2O Emission from Soils Incubated at 15 ℃ with 10% Acetylene (μg N/kg dry soil day)

Incubation Day	Control	Lettuce residue*	Paper waste**	Paper waste** +Lettuce residue*
1	7±1.0	102±14.5	7±5.4	75±5.4
2	45±0.1	76±10.2	45±4.1	29±4.1
3	2±7.3	10±8.1	2±0.1	4±0.2
8	1±0.1	1±0.1	1±0.1	1±0.0
Total	61	211	61	119

* Added at a rate of 0.6 g · kg^{-1} soil dry weight;

** Added at a rate of 11.1 g · kg^{-1} soil dry weight.

The results in Table 3 indicated that when incubation started in experiment Ⅰ, relative high nitrate content in RP treatment as compared with ammonium could provide enough substrate for strong denitrification on the first day and N_2O emission was the highest in R treatment during the first 8 day. This phenomenon that denitrification rate was increased affected by NO_3^- addition was similiar to those from other researches (Ryden, 1983; Vinther, 1984; Colbourn and Harper, 1987; Samson et al., 1990; Ambus and Lowrance, 1991).

Table 3 Extractable NH_4^+-N, NO_3^--N Content (μg/g fresh soil)

Treatment	d	NH_4^+-N	NO_3^--N
Soil (S)	0	0.21	1.03
Paper (P)	0	0.23	1.07
Residue (R)	0	0.97	4.11
S+RP	30	6.00	0.21
S+RP	63	0.00	12.79
CK	107	0.37	10.42
S+R	107	0.26	24.74
S+P	107	0.78	10.00
S+RP	107	0.52	20.96

Notes: CK——control; R——Residue; P——Paper waster; RP——Residue and paper waste.

At the 30th day, NH_4^+ content increased to 6.00 $\mu g/g$ FW in RP treatment, but NO_3^- content decreased to 0.2 $\mu g/g$ FW due to mineralization of lettuce residue and paper waste and ammonification for 30 days, active denitrification could lead to decrease of NO_3^- content. At the 63rd and 107th days nitrate content increased with NH_4^+ content decline.

In experiment Ⅰ, mixture of lettuce residue and paper waste (C/N ratio 25 : 1) which riched in organic carbon and easily mineralisable N could promote soil denitrification rate, however lettuce residues released more inorganic nitrogen than paper wastes (see Table 3). The data of ^{15}N loss in Table 4 could explain this losses of ^{15}N in R and RP treatments occurred during investigating time. Although paper waste also contained high total N (see Table 4), N decompositioned was very slow compared to lettuce residues. In addition, paper wastes contained lots of organic carbon (see Table 1), which stimulated micro-organisms' activity and increased N biological immobilisation. So added paper waste could not increase denitrification and N_2O loss, on the contrary, added mixture of lettuce residues and paper wastes could increase N_2O loss compared to CK treatment (see Table 2).

Table 4 ^{15}N Losses from Soil during Incubation in the Experiment I

Treatment	Incubation day	^{15}N%	Total N%	^{15}N mg/kg dry soil	Losses ^{15}N mg/kg dry soil
S+R	63	1.161	0.11	15.45	8.08
S+R+P	63	1.027	0.13	16.15	7.42
CK	107	0.374	0.12	5.43	—
S+R	107	1.069	0.123	15.91	7.66
S+P	107	0.376		5.78	—
S+R+P	107	0.896	0.13	14.08	9.49

Table 5 Effects of Soil Bulk Density (g/cm^3) on Denitrification by Using Paper Waste and Lettuce Residue (μg N/kg dry soil/day)

Treatment	Soil BD	Incubation day 1	3	7	10	15	30	60	68	90
CK-L	1.29	1.0	1.3	2.2	1.4	1.0	0.9	1.2	0.8	1.8
CK-M	1.46	0.9	1.0	1.0	1.0	1.7	0.9	0.8	0.8	0.8
CK-H	1.51	1.3	1.1	0.9	1.3	1.0	1.0	1.0	0.8	0.7
R-L	1.27	373.1	171.5	640.7	246.7	21.5	4.3	13.7	2.5	0.9
R-M	1.45	554.6	165.8	569.6	239.8	23.3	15.1	1.5	0.9	1.0
R-H	1.52	840.7	164.3	685.3	264.8	28.2	20.1	3.5	1.9	1.2
P-L	1.28	993.5	2.0	1.8	1.2	1.0	0.9	50.5	3.0	0.6
P-M	1.40	1245	22.4	1.1	1.1	1.1	1.3	126.9	4.5	0.9
P-H	1.48	1904	36.6	2.1	1.7	1.3	0.7	69.5	4.1	2.0
RP-L	1.29	3879	1821	118.6	4.7	0.2	1.6	182.6	16.8	5.1
RP-M	1.41	4752	1926	7.9	2.6	2.1	1.7	823.2	95.1	4.1
RP-H	1.48	5076	2613	17.5	6.7	1.6	0.9	1114	93.0	21.1

Notes: L, M, H: low, medium and high bulk density (mg/cm^3).

In experiment Ⅱ, N_2O loss in RP treatment was the highest in these treatments with same bulk density level (see Table 5) at the lst and 3rd days, meanwhile paper waste could result in more N_2O loss than lettuce residues at the first day. Maximum N_2O losses in RP treatment with low, medium, high bulk density levels were 3879, 4752, 5076 μgN/kg dry soil respectively at the first day, about 10, 9, 6-fold higher than that in R treatment with low, medium, high bulk density level respectively and 4, 4, 3-fold higher than that in P treatment with the low, medium, high density. Then N_2O emission rate declined, which was different from that in experiment Ⅰ. One explanation might be higher rate of added organic materials. e.g. paper wastes (6%) and lettuce residues (2%). Water content condition might lead in the differences (exp. Ⅱ, 13.76% and exp. Ⅰ, 20.48%). In this case increasing addition of organic material was most important regulated factor affected soil denitrification.

Table 6 Extractable NH_4^+ and NO_3^- in the Soil Samples by Different Bulk Density /mg · kg⁻¹

Treatment	NH_4^+-N				NO_3^--N			
	0	30	68	90	0	30	68	90
CK-L	1.40	0.27	0.29	0.99	2.25	2.46	3.91	3.57
CK-M		0.13	0.51	0.79		2.44	3.77	2.42
CK-H		0.18	0.15	1.08		2.46	3.71	3.41
R-L				8.65				8.97
R-M				9.38				11.28
R-H				8.98				8.12
P-L	0.35	0.26	0.35	3.49	1.99	0.02	4.61	0.58
P-M		0.19	0.30	3.87		0.05	0.94	0.53
P-H		0.21	0.51	4.07		0.04	0.29	0.80
RP-L	3.00	2.63	8.20	12.75	5.72	0.20	0.05	2.85
RP-M		1.00	5.20	12.25		0.02	1.25	1.77
RP-H		2.26	6.35	11.98		0.02	3.30	1.09

Table 7 Effects of Soil Bulk Density (g/cm^3) on Mineralization (CO_2 release) by Using Paper Waste and Lettuce Residue (mg C/kg dry soil/day)

Treatment	Soil BD	Incubation day 1	3	7	10	15	30	60	68	90
CK-L	1.29	4.45	2.88	2.23	1.75	1.82	2.05	5.54	7.78	2.34
CK-M	1.46	4.35	2.38	2.30	1.51	1.66	1.73	5.43	3.58	2.60
CK-H	1.51	5.40	2.42	2.24	1.79	1.86	2.48	4.62	2.47	2.44
R-L	1.27	101.0	45.4	25.6	12.5	4.2	9.6	8.1	4.5	4.3
R-M	1.45	97.3	42.6	27.1	13.4	5.9	4.9	8.0	4.8	3.5
R-H	1.52	47.7	35.3	30.2	15.7	6.7	9.2	9.1	13.0	6.4
P-L	1.28	50.1	44.5	39.5	39.0	25.8	27.7	18.6	11.0	7.6
P-M	1.40	40.9	43.9	37.4	39.1	31.2	25.3	16.5	11.1	6.9
P-H	1.48	54.3	38.0	42.6	41.1	24.7	39.7	18.8	14.0	9.4
RP-L	1.29	177.6	101.9	92.8	82.2	46.6	35.7	13.9	13.5	8.4
RP-M	1.41	178.6	82.7	85.7	72.9	54.2	43.4	15.6	19.4	12.8
RP-H	1.48	145.7	101.7	69.9	83.4	49.5	59.9	12.9	40.4	19.4

Before incubation, the extractable NH_4^+ and NO_3^- concentrations (see Table 6) in RP treatment were higher than those in the other treatments with same bulk density. In experiment I ,lower soil moisture (13.76%) could enhance the decomposition of organic material by increasing O_2 pressure. Table 7 demonstrated that in RP treatment the patterns of CO_2 release at low, medium density with time was in coincidence with those of N_2O fluxes. Lower ammonium content in all treatments compared to nitrate content meaned that denitrification was a dominant process in nitrogen transformation (nitrification, ammonification, immobilisation, etc.) at the beginning of incubation. After 30, 68, 90 d respectively, ammonium content increased due to enhanced mineralisation of organic matter. At the 30th, 68th days, HN_4^+ content declined with higher bulk density due to declining decomposition of organic matter by increasing anaerobic conditions and immobilisation by input of organic matters to stimulate microbial activity. NO_3^- content decreased with more compacted soil in which denitrification enhanced by anaerobic condition.

In P and RP treatments, NH_4^+ content was higher than NO_3^- content at the same bulk density. Under anaerobic condition, denitrification and ammonification were available in the incubated soil at the same time, however the predominant process was related to the ratio of nitrate to organic matter or of the nitrate to carbon of the environment. When paper wastes and lettuce residues were added into soil, the ratio of NO_3^-/C lessened, microorganisim flora tended to break up organic matters, release and accumulate NH_4^+-N. Tiedje et al. (1982, 1988) hypothesised that the partitioning of nitrate reduction between dissimilatory nitrate reduction of ammonium (DNRA) and denitrification is dependent on the nitrate-to-carbon ratio of environment, where DNRA is favoured when the ratio is low and denitrification is favoured when the nitrate-to-carbon ratio is high. In our experiment Ⅱ, the ratio of C/N in paper wastes was over 25 (see Table 1), so NH_4^+ content in P treatment were higher than NO_3^- concentrations, however this results were not investigated in R treatment.

From Table 8, ^{15}N losses in the RP treatment were lower than that in the R treatment at low bulk density, but it was higher at medium and high bulk density.

In experiment Ⅱ, there were two peaks of N_2O release in R treatments with different bulk density levels (see Table 5). Like the experiment Ⅰ the first peak on the first day after incubation, however, a different point was that great increase of N_2O release (second peak) was at the 7th day. The results showed that after the incorporation of easily decomposable organic matter like lettuce residues, considerable N_2O losses of 0.84 and 0.69 mg N/kg dry soil with high density, 0.55 and 0.57 mg N/kg dry soil with medium bulk density and 0.37 and 0.67 mg N/kg dry soil with low bulk density could occur even at a lower soil water content on the 1st and 7th day after incubation. Statistical analysis demonstrated that variance of N_2O emission between different treatments were significant.

Table 8 ^{15}N Losses from Soil (Exp. Ⅱ) on the 90th Day*

Treatment	Bulk density g/cm³		^{15}N% mean	SD	Total N% mean	SD	^{15}N mg/kg dry soil	Losses ^{15}N mg/kg dry soil
CK	L	1.29	0.3735	(0.001)	0.13	(0)	5.51	
	M	1.46	0.3863	(0.011)	0.13	(0)	5.71	
	H	1.51	0.3723	(0.002)	0.126	(0.005)	5.33	
R	L	1.27	2.180	(0.065)	0.15	(0.008)	37.16	94.33
	M	1.45	2.144	(0.063)	0.14	(0)	34.12	91.59
	H	1.52	2.189	(0.020)	0.146	(0.005)	36.33	89.00
P	L	1.28	0.4006	(0.021)	0.15	(0)	6.83	
	M	1.40	0.3738	(0.006)	0.143	(0.005)	6.08	
	H	1.48	0.3749	(0.001)	0.153	(0.009)	6.53	
P+R	L	1.29	1.8632	(0.037)	0.163	(0.005)	34.53	90.98
	M	1.41	1.8306	(0.118)	0.16	(0.008)	33.29	92.42
	H	1.48	1.8374	(0.106)	0.167	(0.009)	33.48	90.36

* $n=3$ for St Dev

2.2 Effects of soil bulk density (BD) on denitrification

Effects of BD on denitrification by using lettuce residues and paper mills were studied in our experiment, the effects of soil BD on N_2O emission were illustrated in Table 5. In the first 10 days after incubation, N_2O emission was highest in the CK treatment with low BD than those in the treatments with medium and high BD, however, analysis of variance of N_2O emission in different BD levels in CK treatment is not significant ($P > 0.05$). In this treatment, effects of BD on N_2O emission were ignored. In the other treatments, N_2O emission were stimulated by high BD (see Table 5). In RP treatment, the maximum rate of N_2O emission with high BD at the first day afterincubationis 5.08 mg N/kg dry soil/day, which is 1.07-fold than that in the samples with medium BD and 1.31-fold of that in the samples with low BD. In the P treatment, the maximum rate of N_2O emission with high BD at the first day is 1.90 mg N/kg dry soil/day, which is 1.53-fold of the samples with medium BD and 1.92-fold of the samples with low BD. In R treatment there are two peaks of N_2O emission, the first with high BD on first day is 0.84 mg N/kg day soil/day, which is 1.52-fold of that in the samples with medium BD and 2.25-fold of the samples with low BD. The second peak of N_2O emission on the 7th day with high BD is 0.69 mg N/kg dry soil/day, which is 1.22-fold of the samples with medium BD and 1.00-fold of the samples with low BD.

The changes of soil BD by compaction could result in changes of soil porosity. With constant water content, soil BD might change soil air volume, ratio of air volume to water volume in soil (see Table 9), which affected the activity of soil microorganism and nitrogen transformation in soil, especially the processes of denitrification, nitrification and ammonification. Denitrification required anaerobic condition, hence the rate of denitrification decreased and was eventually inhibited in the presence of O_2. Reduction of N_2O to N_2 is more prone to be inhibited by O_2 than reduction of NO_3^- to N_2O, thus the N_2O/N_2 ratio decreased with low O_2 concentration. Nitrification is an aerobic process producing N_2O and NO_3^-, the process rate decreased and the production ratio N_2O/NO_3^- increased as the O_2 supply went down. Thus, in both processes, N_2O is product favoured at intermediate aeration (Khdyer and Cho, 1983).

In our experiments, the volumes of air were changed from 53.77 cm^3 to 39.17 cm^3 and 31.75 cm^3 with the changes of soil BD from about 1.29 g/cm^3 to about 1.41 g/cm^3 and 1.48 g/cm^3, the ratio of air volume and water volume were also changed from 1.57 to 1.14 and 0.93 in RP treatment. These changes by increasing bulk density supplied an anaerobic conditions, which enhanced denitrifcation process, thus the N_2O emission in the most samples increased by increasing of bulk density.

Table 9 Effect of Bulk Density on the Change of Volume of Air

Treatment	Bulk density g/cm³		V_{air} cm³	V_{air}/V_{water}	V_{air}/V_{soil} · /100%
CK	L	1.29	53.77	1.57	31.35
	M	1.46	33.79	0.98	65.58
	H	1.51	28.92	0.84	19.74
R	L	1.27	56.47	1.64	32.54
	M	1.45	34.84	1.02	22.84
	H	1.52	27.82	0.81	19.11
P	L	1.28	55.11	1.61	31.31
	M	1.40	40.25	1.18	25.47
	H	1.48	31.75	0.93	21.24
RP	L	1.29	53.77	1.57	31.35
	M	1.41	39.17	1.14	24.96
	H	1.48	31.75	0.93	21.24

Where, V_{air} = Volume of air; V_{water} = Volume of water; V_{soil} = Volume of soil, including V_{solid}, V_{water} and V_{air}.

Soil texture, water content and management (tillage, tractor compacting) could affect diffusion of soil gases, high BD might retard N_2O and O_2 diffusion rate in soil. These might lead to a reserve result that N_2O emission decreased with high BD in 30% of samples. Although soil water content is low (13.7%) in the experiment, amounts of organic matters was added into soil, which stimulated microbiological activity and increased available NH_4^+ concentrations in most samples compared to CK treatment with same bulk density (see Table 6).

It was very interesting that extractable NH_4^+ and NO_3^- concentration were affected by bulk density. In the most samples, NH_4^+ concentration was reduced by increasing bulk density, especially in RP treatment. When the bulk density was increased from 1.29 to 1.48 g/cm³, the NH_4^+ concentrations decreased from 2.63, 8.20, 12.75 mg/kg to 2.26, 6.35, 11.98 mg/kg at the 30th, 68th, 90th days. This was possibly related to adsorption of NH_4^+ ion by soil colloids with negative electronic charges, and input of organic matter could increase negative electronic charges in soil colloids. However, with shortage of organic matter in soil, NH_4^+ concentration in R and P treatments increased by high BD at the 68th, 90th days, because improved anaerobic conditions by increasing bulk density enhanced ammonification process, which was more important than adsorption of NH_4^+ ions in that case, increasing of NH_4^+ concentration enhanced nitrification, ammonium oxidiser may use the intermediate NO_3^- as an alternative electron acceptor. N_2O is formed in this case.

Effect of BD on NO_3^- concentration was quite different. In the R treatment, NO_3^- concentration increased from 8.97 to 11.28 mg/kg with high BD from 1.27 to 1.45 g/cm^3 on the 90th day, then it was reduced to 8.12 mg/kg at the bulk density of 1.52 g/cm^3, indicating that very high bulk density did not limit the increase of NO_3^- concentration in added easily composed organic matters. But the interesting phenomenon is that very high bulk density also caused N_2O emission increase due to the same increase of NH_4^+ concentration in the same case. Because NH_4^+-N could enhance soil nitrification related to N_2O form. However, NO_3^- and NH_4^+ concentration affected denitrification, but improved anaerobic conditions is most important one of the reasons of affecting denitrification by increasing bulk density. For example, in the treatment added residues and paper residue, though both of NH_4^+ and NO_3^- concentrations were reduced by increasing bulk density from 1.28 to 1.48 g/cm^3 on the 90th day (see Table 6), N_2O emission also obviously increased from 0.0051 to 0.0211 mg N/kg dry soil (see Table 5). Here aeration is limiting factor for denitrification in the plenty added organic materials.

Mathematical analysis described the relationship between bulk density and concentration of NO_3^- or NH_4^+. There were negative relationships in the 63% of all samples of different treatments for NO_3^- or NH_4^+. The regression coefficient R^2 of the most samples were high, for example, in the treatment added only paper wastes on the 68th day, the cogression coefficient $R^2=0.98$ by formula $y=ax+b$, $R^2=0.983$ by formula $y=a\log x+b$. (where, $x=$ bulk density, $y=NO_3^-$ concentration). For increasing the gradient of concentration NO_3^- by reducing bulk density a is -18.18 or -58.28. In the treatments added mixed residues and paper wastes there were high regression coefficient of concentration NO_3^- by bulk density at the 30th, 68th, 90th days.

Statistical analysis show that significant test of N_2O emission between different bulk density was small or no significant, especially between medium and high bulk density by t-test. But it did not alter and affect above analysis and conclusion, because gas samples were measured and collected with so many difficulties, which may caused errors was beyond the range of discussion here.

2.3 Effects of added lettuce residue and paper wastes on mineralisation

The CO_2 emission of gases in soil samples from treatments added only lettuce residues, only paper wastes and mixture of both were measured for 107 d. The dynamic effects of different organic materials added on CO_2 emission are shown in Table 10 for first experiment. The general change trends of CO_2 concentration were declining and tend to same level as that at the 107th day. In the treatment added mixed residues and paper wastes, the released CO_2 quantities were higher than that in other treatments every day. Its maximum released CO_2 quantity was 79 mg C/kg dry soil/day, which is 2.16 times higher than that in the control treatments. 0.46 times higher than in the treatments added only residues, 1.02 times higher than that in the treatments added only paper wastes on the 2nd day after incubation. Then it was dealing with faster rate than in other treatments, because plenty of organic matters (added residue 0.5%, paper wastes 2.5%) were applied in the soil, which has appropriate ratio of C/N 25 : 1 (see Table 1) for micro-organism activity. If we assumed CO_2 emission quantity in the control treatments is caused by the "soil respiration", input of residues and paper wastes could increase microbiological respiration 54, 23, 14, 13, 6, 4, 7, 0 mg C/kg dry soil/day respectively at the 2nd, 3rd, 8th, 14th, 21st, 30th, 63rd, 107th days (see Table 10), and increase of N_2O emission compared with control treatment were 70, −16, 2, 0 mg N/kg dry soil respectively at the 1st, 2nd, 3rd, 8th days after incubation (see Table 2). But an interesting phenomenon was that N_2O emission quantity was lower in the treatment added residues and paper wastes than that in the treatment only added residues in the same day (see Table 3). From Table 3 we can know that increased N_2O emission quantity in the added only residue compared with the treatment added residue and paper wastes was 27, 47, 6, 0 μg N/kg dry soil/day respectively at the 1st, 2nd, 3rd, 8th days. This phenomenon can be explained as that the input of mixed residues and paper wastes enhanced the reverse process of mineralisation of organic matters immobilisation, by which a net incorporation of mineral nitrate, usually NH_4^+, into organic forms, especially into microbial tissue during the decomposition process.

In the first experiment another interesting phenomenon was found. From the 14th day release of CO_2 in the treatment using only paper waste exceeded in the treatment using only the residues (see Table 10). It means that the quality of the added organic matters is very important factor. Lettuce residue is more easily decomposed than the paper waste by micro-organism, therefore on the first 14 days, in the treatment added only residues more NH_4^+ and NO_3^- (Table 3) was released and more micro-organic activity and respiration was stimulated than in the treatment added only paper waste. But after 14 d, in the treatment added only residue, the organic matter was decomposed and fully consumed by micro-organism. Though paper wastes are difficult to decomposed, the input amount (2.5%) was higher than that of added residues, it can be slowly decomposed and supply nutrients and energy for micro-organism. The major factor was quality of input of organic matters for micro-organic activity on the first 14 days after incubation, after then major factor of affecting mineralisation was quantity of input of organic matter in this case.

Table 10 The Release of CO_2 (mg C · kg^{-1} · d^{-1}) from Soils Incubated at 15 ℃ with Paper Waste and Crop Residue***

d	CK		R*		P**		RP	
	mean	SD	mean	SD	mean	SD	mean	SD
2	25	(2.84)	54	(4.65)	39	(0.62)	79	(6.28)
3	16	(0.26)	34	(3.36)	23	(2.63)	39	(1.45)
9	13	(0.95)	24	(0.68)	19	(0.62)	27	(0.75)
14	15	(0.63)	20	(0.82)	20	(0.39)	28	(2.50)
21	15	(1.07)	14	(0.92)	10	(0.52)	21	(1.88)
30	10	(1.52)	9	(0.75)	12	(2.40)	14	(1.71)
63	8	(0.82)	7	(0.30)	13	(2.91)	15	(2.87)
107	2	(0.08)	2	(0.07)	2	(0.06)	2	(0.25)

*Crop residue added at a rate of 0.6 g · kg^{-1} soil dry weight;

**Paper waste added at a rate of 11.1 g · kg^{-1} soil dry weight;

***$n=3$ for St Dev.

From first experiment it could be concluded that lettuce residue had a significant effect on microbial activity. During a 107 day's incubation at 15 ℃ the application of both paper waste and residue increased soil respiration significantly ($P<0.01$). The highest respiration rate was observed in the residue plus paper waste treatment. About 12% of the extra C from the paper waste was respired during the incubation. Lettuce residues were also found to cause a substantial increase in denitrification during the early part of incubation. Only using paper waste could not increase N_2O emission at the early time in this case.

Each successive cycle resulted in a slightly smaller release of respired CO_2 and mineralised nitrogen. The first experiment results showed that the best cycle of nitrogen appeared in the treatment added residue in a short time (two weeks) and after two weeks it appeared in the treatment added only paper or added both of residues and paper wastes.

2.4 Effects of soil bulk density on mineralisation

Table 7 described the effects of bulk density on CO_2 emission and showed the effects of input of only residues, only paper wastes and both of residues and paper wastes on the CO_2 emission in the different bulk densities, including the low (1.27 ~ 1.29 g/cm^3), medium (1.40~1.46 g/cm^3) and high (1.48~1.52 g/cm^3) groups of bulk density.

In the treatment added mixed paper wastes and residues, maximum of CO_2 emission increase was 173.15 mg C/kg dry soil with low bulk density compared with control on the first day after incubation, and its maximum increase with medium bulk density was 174.2 mg C/kg dry soil and with high density was 140.30 mg C/kg dry soil also on the first day after incubation. In the treatments added only residues with low bulk density, maximum CO_2 emission increasing is 96.55 mg C/kg dry soil compared with control on the first day after incubation. With medium and high bulk density, its maximum increasings were 92.95 and 42.30 mg C/kg dry soil respectively on the first day after incubation. In the treatment only added paper wastes with low, medium and high bulk density, the maximum increasings were 45.65, 36.55, 48.90 mg C/kg dry soil respectively on the first day after incubation. After the first day, rates of released CO_2 in all of the treatments were declining by different gradients (see Table 7) but with high bulk density there were two or three peaks of CO_2 emission in the different treatments, where any CO_2 emission peaks after first day cannot be consistent with peaks of N_2O emission. This phenomenon may be explained as weak relationship and no relationship between N_2O and CO_2 emission.

Hansen et al. (1993) demonstrated that the N_2O emission was either weakly correlated or not correlated with concentrations of CO_2 in soil air, but N_2O concentrations in soil air were more strongly correlated with CO_2 concentration. The air-filled porosity was negatively correlated with both N_2O parameters in the uncompacted soil, in contrast to compacted soil where no significant correlation was found.

Different changes of CO_2 emission in the same treatment from the second experiment were found. Both the quantity and quality of added organic matter affected mineralisation, but which of them is dominant factor or limiting factor? It is found that in the group with low bulk density, CO_2 emission-quantity were higher (50.9, 0.9 mg C/kg dry soilday in the treatment added only residues than that in the treatment added only paper wastes at the 1st and 3rd days, eg. CO_2 emission in the treatment added only paper waste exceeded in the treatment added only residue with low bulk density at the 7th day. With the medium bulk density the above exceeding was on the 3rd day and with the high bulk density this exceeding was on the first day after incubation, showing the exceeding shift to an earlier time with increasing bulk density. Because increasing bulk density reduced volume of air and increased volume of water in the soil samples, changes of N_2O emission were coincided with above change of CO_2 emission. The rate of mineralisation from soil organic matter generally increased with increasing moisture content between permanent wilting point (−1.5 M Pa) and field capacity (−5～ −10 KPa). This effects was well illustrated by the results of Stanford and Epstein (1974), who found a two-and-a-half-fold increase in the amount of mineral nitrogen accumulating over a two-week period of incubation, as the soil moisture content was increased from < 5 to about 35 g/100g. As the soil moisture content was raised above field capacity, however, mineralisation rates fall because of restricted aeration. Though in our experiments the volumes of moisture were increased, the conditions of the sample were within aerobic range (moisture=13.7%). The rate of decomposition by aerobial bacteria was much greater than that brought about by anaerobic bacteria, because the former are more energy efficient. Decomposition by fungi and actinomycetes was also predominantly an aerobic process, and thus inhibited by lack of oxygen (A J A Vinten and K A Smith, 1993). Therefore on the first short days after incubation, quality of organic matters (for example: easily decomposed lettuce residue) was major factor to affect mineralisation, especially for treatment with low bulk density. By the delaying the time after incubation and increasing bulk density eg. increasing anaerobic condition, instead of its quality the quantity of input organic matter became a dominant factor to affect mineralisation. Increasing bulk density made this exceeding earlier.

Statistical analysis described relationship between the bulk density and CO_2 emission by formula $y=ax+b$ and $y=a \log x+b$ (where, x=bulk density, y=CO_2 emission). The gradients of CO_2 emissin by increasing bulk density were negative in more 30% of the samples, especially on the beginning short days after incubation. Because reducing volume of air in the soil by increasing bulk density could result in the anaerobial condition, which could reduce decomposition of organic matter and increased denitrification, but in our experiments the constant moisture was kept. This moisture content (13.7%) was far from anaerobic conditions, therefore O_2

was not limiting factor for mineralisation or biological respiration. In the soil the environmental factors always interacted with each other, hence changes of CO_2 emission by increasing bulk density were quite different in the different treatments.

3 CONCLUSIONS

(1) Input of lettuce residue (0.5%) had a significant effect on microbial activity, and N_2O emission by denitrification at the short time (8 d). The maximum N_2O emission was 15-fold. Increasing micro-organic respiration is 2.1-fold higher than control on the 1st day after incubation. Increasing input rate of lettuce residue (2%), 2 peaks of N_2O emission in 90 d were reached. The maximum of N_2O emission increasing (0.373 and 0.638 mg N/kg dry soil/day) was 373 and 297-fold higher than control respectively on the 1st and 7th days. The lettuce residue can improve N_2O emission on the 68 day. CO_2 emission by added lettuce residue was higher than control, but lower than that in the treatments added only paper waste (except the 1st and 3rd days) and added mixture of residue and paper waste, on the full-time incubation (90 d).

(2) With input of 2.5% paper waste into the soil samples, paper waste had no effect on N_2O emission in the first 8 days, but with input of 6% paper waste and moisture of 13.7%, denitrification was improved. The maximum N_2O emission was 0.993 mg N/kg dry soil/day on the first day of incubation, which was 993, 2.66-fold higher than those in control and the traeatment added only residue, then the paper waste enhanced microbial immobilisation of nitrogen, therefore reduced N_2O emission compared with that in the treatment only using residues. We suggest that this type of paper waste be applied to agricultural land for increasing organic matter and immobilisation of nitrogen and reducing N_2O losses.

(3) Application of both lettuce residue (0.5%) and paper waste (2.5%) can improve decomposition of organic matter, microbic respiration, denitrification and immobilisation of nitrogen, compared with control treatment, added only residue or only paper waste in the 1st experiments. The maximum of N_2O emission with input of 2% residue and 6% of paper waste was 3.879 mg N/kg dry soil/day, which is 3879, 10.4, 3.9-fold higher than those in control the treatments, added only residue and added only paper waste on the first day respectively. The maximum CO_2 emission in the treatment added mixed residue and paper wastes was 177.6 mg C/kg dry soil/day, which is respectively 39.9, 1.8, 3.5-fold higher than those in control treatments, added only residue and added only paper waste. But input of

0.5% residue and 2.5% of paper waste can reduce denitrification and atmosphere pollution by N_2O compared with added only residue in the first treatment. We suggest that it is better to apply mixture of plant residue and paper waste for cooperative integrating readily available and slow-released nutrients supplement in the agricultural land.

(4) Different bulk density by respective compacting 2, 6, 16 kg per ring bulk density with 209 cm^3 affected N_2O emission and CO_2 emission. In the about 70% of samples relationships between bulk densities and N_2O or CO_2 emission were positive. Increasing bulk density can enhance microbial respiration. When bulk density was increased from 1.28 to 1.40 then 1.48 g/cm^3, exceeding of CO_2 emission in the treatment added only paper wastes were earlier respectively on the 7th, 3rd, 1st days than in the treatment added only lettuce residue due to improved decomposition of organic matters with increasing water volume by increasing bulk density on short time. In general trend, N_2O and CO_2 emission were increased by increasing bulk density, but significant tests on them were weak or no observatinal, especially between medium and high bulk density. We suggest to use light machines on the agricultural soil to reduce N_2O losses and pollution of the atmosphere by N_2O.

(5) Input of different quantity and quality of organic matters with different bulk density affected NO_3^- and NH_4^+ concentration, denitrification, nitrification and immobilisation processes in the soil.

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