

CNIC-01195

CSANS-0114

# 中国核科技报告

## CHINA NUCLEAR SCIENCE AND TECHNOLOGY REPORT

$^{15}\text{N}$  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  
 $^{15}\text{N}$  LABELLED LETTUCE RESIDUE AND PAPER WASTES



中国核情报中心  
原子能出版社

China Nuclear Information Centre  
Atomic Energy Press

### 图书在版编目 (CIP) 数据

中国核科技报告 CNIC-01195 CSNAS-0114:  $^{15}\text{N}$  标记的苜蓿残体、废纸浆及容重对土壤反硝化及矿化作用的动态影响/华珞等著. —北京: 原子能出版社, 1997. 10  
ISBN 7 5022 1727-4

I. 中… II. 华… III. 核技术-研究报告-中国 IV. TL

2

中国版本图书馆 CIP 数据核字 (97) 第 18136 号

### $^{15}\text{N}$ 标记的苜蓿残体、废纸浆及容重 对土壤反硝化及矿化作用的动态影响

华珞等著

©原子能出版社, 1997

原子能出版社出版发行

责任编辑: 郭向阳

社址: 北京市海淀区阜成路 43 号 邮政编码: 100037

中国核科技报告编辑部排版

核科学技术情报研究所印刷

开本 787×1092 1/16·印张 1·字数 22 千字

1997 年 10 月北京第一版·1997 年 10 月北京第一次印刷

定价: 5.00 元

## $^{15}\text{N}$ 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 璐 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 $^{15}\text{N}$  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 $\text{N}_2\text{O}$  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 $\text{N}_2\text{O}$  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 $\text{N}_2\text{O}$  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。 $\text{CO}_2$  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 $\text{CO}_2$  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 $\text{N}_2\text{O}$  与 $\text{CO}_2$  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 $\text{NO}_3^-$  与 $\text{NH}_4^+$  浓度。

# **Dynamic Effects of Soil Bulk Density on denitrification and Mineralisation by <sup>15</sup>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 (<sup>15</sup>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 °C for 107 and 90 days, respectively. The results showed that the changes of N<sub>2</sub>O, CO<sub>2</sub> emission rates, inorganic nitrogen (NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>), total N and <sup>15</sup>N abundance 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<sub>2</sub>O emission was 15 times higher than that in soil without any additive. However, paper wastes did not increase N<sub>2</sub>O emission in the first 8 days compared with other treatments, mixed residue and paper wastes could promote soil microbial activity, but N<sub>2</sub>O 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<sub>2</sub> 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<sub>2</sub> quantities were higher than those in other treatments every day. Effect of different bulk density on N<sub>2</sub>O and CO<sub>2</sub> emission were response to the change of bulk density, it seems that N<sub>2</sub>O and CO<sub>2</sub> emission increased with bulk density. High bulk density could affect decomposition of paper wastes and NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup> concentration.

---

\* The research program supported by EC, State of Sciences and Technology of China and State Education Commission of China.

## INTRODUCTION

$\text{N}_2\text{O}$  is one of the major greenhouse gases, absorbing infrared radiation 250 times more than  $\text{CO}_2$  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  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  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 (Klemmedtsson et al., 1987; Christensen et al., 1990), the activity of plant roots consumes  $\text{O}_2$  (Cribbs and Mills, 1979; Klemmedtsson et al., 1987) and soil pH change (Marschner et al., 1986) also affect soil microbial process related to denitrification and  $\text{N}_2\text{O}$  emission. Input of organic material to soil could stimulate microbial activity and create favourable conditions for  $\text{N}_2\text{O}$  formation. Mechanical disturbance can increase aeration and  $\text{N}_2\text{O}$  emission for a short period of time due to release of soil air enriched in  $\text{N}_2\text{O}$  (Matthias et al., 1980; Bremner and Blackmer, 1980b). Soil compaction can increase both denitrification rate (Torbert and Wood, 1992) and  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  and promoting biological immobilisation. It is postulated that the amount of immobilisation, total denitrification and  $\text{N}_2\text{O}/\text{N}_2$  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  $\text{N}_2\text{O}$  and  $\text{CO}_2$  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 characteristics 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 <sub>2</sub> O <sub>5</sub> %
35	6.9	0.48	11.8	25 : 1	6.25

## 1.3 Methods

Experiment 1 :

100 g fresh soil was mixed well with two kinds of organic matter and incubated in a 570 cm<sup>3</sup> flask according to the treatments; (1) Control (CK); (2) 0.5 g <sup>15</sup>N labelled (abundance, 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 °C and air-proofed conditions.

N<sub>2</sub>O 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<sub>2</sub>O determination, the flasks were flushed for 2 h, and 10% acetylene (C<sub>2</sub>H<sub>2</sub>) was filled into flask for 24 h. CO<sub>2</sub> 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  $^{15}\text{N}$  abundance 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,  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -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  $209\text{ cm}^3$ , and compacted to three BD levels by oedometer. The soil at constant moisture was incubated at  $15^\circ\text{C}$  and air-proofed bottles of  $665\text{ cm}^3$ . 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%  $^{15}\text{N}$  abundance (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.

$\text{N}_2\text{O}$ ,  $\text{CO}_2$  concentrations in vessel were measured at the 0, 1, 3, 5, 10, 15, 30, 68, 90 days, 10%  $\text{C}_2\text{H}_2$  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  $15^\circ\text{C}$ . Extractable  $\text{NO}_3^-$  and  $\text{NH}_4^+$ , total N and  $^{15}\text{N}$  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,  $\text{N}_2\text{O}$  emission was over 15 times higher than that in CK treatment (with-out 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,  $\text{N}_2\text{O}$  release in R treatment declined to that in CK treatment. Paper wastes did not stimulate  $\text{N}_2\text{O}$  emission, however the mixture of lettuce residue and paper waste also increased  $\text{N}_2\text{O}$  emission, this effect was less than that in R treatment (see Table 2).

**Table 2**  $\text{N}_2\text{O}$  Emission from Soils Incubated at 15 °C with 10% Acetylene  
( $\mu\text{g N/kg dry soil day}$ )

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  $0.6 \text{ g} \cdot \text{kg}^{-1}$  soil dry weight;

\*\* Added at a rate of  $11.1 \text{ g} \cdot \text{kg}^{-1}$  soil dry weight.

The results in Table 3 indicated that when incubation started in experiment 1, relative high nitrate content in RP treatment as compared with ammonium could provide enough substrate for strong denitrification on the first day and  $\text{N}_2\text{O}$  emission was the highest in R treatment during the first 8 day. This phenomenon that denitrification rate was increased affected by  $\text{NO}_3^-$  addition was similar to those from other researches (Ryden, 1983; Vinther, 1984; Colbourn and Harper, 1987; Samson et al., 1990; Ambus and Lowrance, 1991).

**Table 3** Extractable  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$  Content ( $\mu\text{g/g fresh soil}$ )

Treatment	d	$\text{NH}_4^+\text{-N}$	$\text{NO}_3^-\text{-N}$
Soil (S)	0	0.21	1.07
Paper (P)	0	0.23	1.07
Residue (R)	0	3.97	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	10.60
S+RP	107	0.52	20.96

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

At the 30th day,  $\text{NH}_4^+$  content increased to  $6.00 \mu\text{g/g FW}$  in RP treatment, but  $\text{NO}_3^-$  content decreased to  $0.2 \mu\text{g/g FW}$  due to mineralization of lettuce residue and paper waste and ammonification for 30 days, active denitrification could lead to decrease of  $\text{NO}_3^-$  content. At the 63rd and 107th days nitrate content increased with  $\text{NH}_4^+$  content decline.

In experiment 1, 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  $^{15}\text{N}$  loss in Table 4 could explain this losses of  $^{15}\text{N}$  in R and RP treatments occurred during investigating time. Although paper waste also contained high total N (see Table 4), N decomposition 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  $\text{N}_2\text{O}$  loss, on the contrary, added mixture of lettuce residues and paper wastes could increase  $\text{N}_2\text{O}$  loss compared to CK treatment (see Table 2).

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

Treatment	Incubation day	$^{15}\text{N}\%$	Total N%	$^{15}\text{N}$ mg/kg dry soil	Losses $^{15}\text{N}$ 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 ( $\text{g}/\text{cm}^3$ ) on Denitrification by Using Paper Waste and Lettuce Residue ( $\mu\text{g N}/\text{kg dry soil}/\text{day}$ )

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 ( $\text{mg}/\text{cm}^3$ ).

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 1st 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  $\mu\text{gN/kg}$  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  $\text{NH}_4^+$  and  $\text{NO}_3^-$  in the  
Soil Samples by Different Bulk Density / $\text{mg} \cdot \text{kg}^{-1}$

Treatment	$\text{NH}_4^+ \text{ N}$				$\text{NO}_3^- \text{ N}$			
	0	30	68	90	0	30	68	90
CK-L	1.40	0.27	0.29	0.99	2.25	2.46	3.91	3.77
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	6.58
P-M		0.19	0.30	3.87		0.05	6.94	6.53
P-H		0.21	0.51	4.07		0.04	6.29	6.80
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 ( $\text{g}/\text{cm}^3$ ) on Mineralization ( $\text{CO}_2$  release) by Using Paper Waste and Lettuce Residue ( $\text{mg C}/\text{kg dry soil}/\text{day}$ )**

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  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations (see Table 6) in RP treatment were higher than those in the other treatments with same bulk density. In experiment 1, lower soil moisture (13.76%) could enhance the decomposition of organic material by increasing  $\text{O}_2$  pressure. Table 7 demonstrated that in RP treatment the patterns of  $\text{CO}_2$  release at low, medium density with time was in coincidence with those of  $\text{N}_2\text{O}$  fluxes. Lower ammonium content in all treatments compared to nitrate content meant 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,  $\text{HN}_4^+$  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.  $\text{NO}_3^-$  content decreased with more compacted soil in which denitrification enhanced by anaerobic condition.

In P and RP treatments,  $\text{NH}_4^+$  content was higher than  $\text{NO}_3^-$  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  $\text{NO}_3^-/\text{C}$  lessened, microorganism flora tended to break up organic matters, release and accumulate  $\text{NH}_4^+-\text{N}$ . 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  $\text{NH}_4^+$  content in P treatment were higher than  $\text{NO}_3^-$  concentrations, however this results were not investigated in R treatment.

From Table 8,  $^{15}\text{N}$  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  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  release (second peak) was at the 7th day. The results showed that after the incorporation of easily decomposable organic matter like lettuce residues, considerable  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  emission between different treatments were significant.

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

Treatment		Bulk density g/cm <sup>3</sup>	$^{15}\text{N}\%$		Total N%		$^{15}\text{N}$ mg/kg dry soil	Losses $^{15}\text{N}$ mg/kg dry soil
			mean	SD	mean	SD		
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)	5.83	
	M	1.40	0.3738	(0.006)	0.143	(0.005)	5.08	
	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 after incubation is  $5.08 \text{ mg N/kg dry soil/day}$ , 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  $1.90 \text{ mg N/kg dry soil/day}$ , 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  $0.84 \text{ mg N/kg dry soil/day}$ , 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  $0.69 \text{ mg N/kg dry soil/day}$ , 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  $53.77 \text{ cm}^3$  to  $39.17 \text{ cm}^3$  and  $31.75 \text{ cm}^3$  with the changes of soil BD from about  $1.29 \text{ g/cm}^3$  to about  $1.41 \text{ g/cm}^3$  and  $1.48 \text{ g/cm}^3$ , 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 denitrification 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 $\frac{g}{cm^3}$	$\frac{V_{air}}{cm^3}$	$V_{air}/V_{water}$	$V_{air}/V_{soil} \cdot 100\%$
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  $g/cm^3$ , 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  $\text{NH}_4^+$  concentration enhanced nitrification, ammonium oxidiser may use the intermediate  $\text{NO}_3^-$  as an alternative electron acceptor.  $\text{N}_2\text{O}$  is formed in this case.

Effect of BD on  $\text{NO}_3^-$  concentration was quite different. In the R treatment,  $\text{NO}_3^-$  concentration increased from 8.97 to 11.28 mg/kg with high BD from 1.27 to 1.45 g/cm<sup>3</sup> on the 90th day, then it was reduced to 8.12 mg/kg at the bulk density of 1.52 g/cm<sup>3</sup>, indicating that very high bulk density did not limit the increase of  $\text{NO}_3^-$  concentration in added easily composed organic matters. But the interesting phenomenon is that very high bulk density also caused  $\text{N}_2\text{O}$  emission increase due to the same increase of  $\text{NH}_4^+$  concentration in the same case. Because  $\text{NH}_4^+$ -N could enhance soil nitrification related to  $\text{N}_2\text{O}$  form. However,  $\text{NO}_3^-$  and  $\text{NH}_4^+$  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  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations were reduced by increasing bulk density from 1.28 to 1.48 g/cm<sup>3</sup> on the 90th day (see Table 6),  $\text{N}_2\text{O}$  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  $\text{NO}_3^-$  or  $\text{NH}_4^+$ . There were negative relationships in the 63% of all samples of different treatments for  $\text{NO}_3^-$  or  $\text{NH}_4^+$ . 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 regression 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,  $y$  =  $\text{NO}_3^-$  concentration). For increasing the gradient of concentration  $\text{NO}_3^-$  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  $\text{NO}_3^-$  by bulk density at the 30th, 68th, 90th days.

Statistical analysis show that significant test of  $\text{N}_2\text{O}$  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  $\text{CO}_2$  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  $\text{CO}_2$  emission are shown in Table 10 for first experiment. The general change trends of  $\text{CO}_2$  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  $\text{CO}_2$  quantities were higher than that in other treatments every day. Its maximum released  $\text{CO}_2$  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  $\text{CO}_2$  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  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  emission quantity in the added only residue compared with the treatment added residue and paper wastes was 27, 47, 6, 0  $\mu\text{g}$  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  $\text{NH}_4^+$ , 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  $\text{CO}_2$  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  $\text{NH}_4^+$  and  $\text{NO}_3^-$  (Table 3) was released and more micro-organic activity and respiration was stimulated than in the treat-



ment 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<sub>2</sub> (mg C · kg<sup>-1</sup> · d<sup>-1</sup>) from Soils Incubated at 15 °C with Paper Waste and Crop Residue\*\*\***

d	CK		R*		P**		RP	
	mean	SD	mean	SD	mean	SD	mean	SD
2	25	(2.84)	34	(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<sup>-1</sup> soil dry weight;

\*\* Paper waste added at a rate of 11.1 g · kg<sup>-1</sup> 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 °C 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<sub>2</sub>O emission at the early time in this case.

Each successive cycle resulted in a slightly smaller release of respired CO<sub>2</sub> 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