Effects of digestate application depth on soil nitrogen volatilization and vertical distribution

Wang Lili[1], Li Wenzhe[1], Wang Zhongjiang[1*], Wang Zhiwu[2], Sui Chao[1], Li Yan[1]

(1. *College of Engineering, Northeast Agricultural University, Harbin 150030, China*; 2. *Occoquan Laboratory, Department of Civil and Environmental Engineering, Virginia Tech, 9408 Prince William Street, Manassas, VA 20110-5670*)

Abstract: This study investigated the effect of the digestate application depth on soil nitrogen volatilization and vertical distribution in black loam soil and sandy loam column. The contents of soil moisture, TKN (total Kjeldahl nitrogen), ammonium nitrogen, nitrate nitrogen, and the extent of ammonia volatilization were tested by applying digestate at depths of 0 cm, 2 cm, 6 cm, 10 cm, 15 cm and 20 cm, respectively. The experimental results showed that ammonia volatilization mainly occurred in the first 10 days and reduced significantly when the application depth was deeper than 10 cm. At the same application depth, compared with the black loam, the nitrogen loss in sandy loam through ammonia volatilization was less, and the penetration depth of nitrate nitrogen and ammonium nitrogen were all deeper. In the same soil, nitrate nitrogen penetrated deeper than ammonium nitrogen at all application depths.

Keywords: digestate, application depth, ammonia volatilization, black loam, sandy loam, soil nitrogen distribution

DOI: 10.3965/j.ijabe.20160905.2396

Citation: Wang L L, Li W Z, Wang Z J, Wang Z W, Sui C, Li Y. Effects of digestate application depth on soil nitrogen volatilization and vertical distribution. Int J Agric & Biol Eng, 2016; 9(5): 101－107.

1 Introduction

In recent years, many large and medium-sized anaerobic digestion (AD) facilities have been deployed across many countries[1-6]. These AD facilities can stabilize organic wastes and produce combustible gas that has the potential to replace the exhausting fossil fuel such as natural gas and coal. Besides, these AD processes also discharge nutrient-rich effluent, namely digestate. Without a proper disposal method, the digestate could become an environmental hazard that poses a threat to air and ground water quality[7]. Therefore, digestate disposal has become an urgent issue restricting the further development of AD projects[8-11]. Previous studies of Bougnom et al.[12] and Ahlgren et al.[13] suggested that the digestate was able to be a good fertilizer in terms of quick action and persistence ability, and a rational use of digestate could improve the physicochemical properties of soil, raise fertility, and increase the agricultural product yield. Although using digestate as fertilizer has these advantages, there are also some disadvantages. Moisture and nitrogen contents are usually high in digestate, which can reduce soil viscosity and make nitrogen more transferable to deep soil layers, and create a contamination threat to groundwater[14,15]. Moreover, a considerable amount of nitrogen can also be released into the air through ammonia (NH_3) volatilization, generating odor nuisance and reducing fertilizer efficiency[11,16,17].

Received date: 2016-01-24 **Accepted date:** 2016-07-17

Biographies: Wang Lili, PhD, Associate Professor, research interests: agricultural bio-environment and energy engineering, Email: wanglili22663@163.com; **Li Wenzhe**, PhD, Professor, research interests: transformation and utilization of biomass, Email: liwenzhe9@163.com; **Wang Zhiwu**, PhD, Professor, research interests: biomass energy, Email: wzw@vt.edu; **Sui Chao**, Graduate student, research interests: agricultural bio-environment and energy engineering, Email: 365208949@qq.com; **Li Yan**, PhD, Professor, research interests: wind energy, Email: liyanneau@163.com.

***Corresponding author: Wang Zhongjiang**, Professor, research interests: agricultural bio-environment and energy engineering. College of Engineering, Northeast Agricultural University, Harbin 150030, China. Tel:+86-451-55191140. Email: neauwzj@126.com.

Digestate is widely applied on the soil surface[18-20], which can easily cause ammonium nitrogen loss in the form of NH_3 volatilization[11]. It has been reported that nitrogen fertilizer applied under the soil surface could effectively reduce the loss caused by NH_3 volatilization[21], and could improve the digestate fertilizer capacity. However, deeper land application may lead to more serious penetration of nitrate nitrogen into the groundwater. The ideal application depth for digestate into farm land is still unknown.

So far, studies on the farm land application of digestate primarily focused on its effect on crop growth[11,22-24]. The effect of the application depth on nitrogen volatilization and distribution in the soil still has not been studied yet deeply and systematically. This study utilized two representative types of soil in Northeast China, black loam and sandy loam, to monitor the nitrogen transport in soil column experiment. The nitrogen volatilization and vertical distribution in the soil were mainly studied after the digestate was applied at different depth. The purpose of the study was to identify the optimum application depth of digestate to minimize the risk of groundwater contamination and NH_3 volatilization, meanwhile enhance the digestate fertilizer efficiency.

2 Materials and methods

2.1 Soil and digestate

The black loam used in this experiment was collected from an experimental field (45°42′N, 126°46′E) behind the School of Life Sciences in the Northeast Agricultural University of Heilongjiang Province, China. The sandy loam was collected from Xingfu village (45°53′N, 125°07′E) of Maoxing town located in the Zhaoyuan county of Heilongjiang Province, China. The soil was collected within the top 20 cm of the plough layer and then passed through a 2 cm sieve. The characteristics of the two types of soil are shown in Table 1.

The digestate was collected from a pilot-scale AD facility in Northeast Agricultural University, in which chicken manure had been digested as feedstock for 30 days. The initial AD concentration of total solid was 8%. The fermentation temperature was 35°C. The pH, concentration of total solid, viscosity, total Kjeldahl nitrogen (TKN), ammonium nitrogen and nitrate nitrogen of the digestate was 8.14, 3.69%, 248 mPa·s, 3331.96 mg/L, 2598.46 mg/L and 77.53 mg/L, respectively.

Table 1 Characteristics of soils used in the study

Parameters	Black loam	Sandy loam
pH	7.02	6.89
Total Solid/%	81.23	88.22
Moisture/%	18.77	11.78
Field capacity/%	21.36	18.51
Organic matter/%	8.79	5.28
TKN/mg·kg^{-1}	1658.75	959.08
Ammonium nitrogen/mg·kg^{-1}	100.58	49.75
Nitrate nitrogen/mg·kg^{-1}	1.68	4.74

2.2 Experimental design

Soil column simulation experiment was conducted at room temperature (20ºC±2ºC). The effect of different digestate application depth on the levels of moisture content, ammonium nitrogen, nitrate nitrogen and TKN along the vertical soil profile, as well as the extent of NH_3 volatilization measured at the soil surface was systematically monitored. According to the foregone nitrogen fertilizer application depth for studying NH_3 volatilization[25-27] and the root systems length of different crops[28-30], the digestate application depth was chosen as 0 cm, 2 cm, 6 cm, 10 cm, 15 cm and 20 cm respectively. The soil column used in the experiment was made of rigid polyvinyl chloride (PVC) cylinder with an inner diameter of 10 cm and a height of 50 cm. The dry quartz sand cleaned by deionized water was added to the bottom of the PVC cylinder. The soil was mixed and loaded into the column, the final volumetric density was 1.16 g/cm^3 and the height was 40 cm. One hundred milliliters digestate was injected into each column at the selected depth. Two sponges (2 cm thickness) were pre-soaked in phosphoglycerol and then placed at the top of each PVC cylinder for absorbing vaporized ammonia. The operation was repeated 3 times for each soil column. The NH_3 volatilization was determined by analyzing the absorbed ammonia in sponge at a five-day interval. The soil samples were collected at a 5 cm vertical interval along the soil column depth after the experiment.

2.3 Analytical methods

Soil pH was determined in a 1:5 soil/water suspension by using potentiometric method[31] and digestate pH was determined directly by using pH meter (Sartorius basic pH meter, Germany). The total solids (TS) of soil and digestate were measured according to the oven-dried method at (105±5)ºC for 8-12 h[31,32]. The moisture of soil was the difference in value between the original sample and TS. The field capacity of soil was measured by 100 cm^3 cutting ring according to Wilcox method[33-35]. The soil organic matter (SOM) was measured based on the loss of dry mass after sample ignition at 375ºC for 16 h[36,37]. The viscosity of digestate was measured by using digital viscometer (NDJ-9S, Hangping, China). The TKN and ammonium nitrogen contents of soil and digestate were measured by auto Kjeldahl nitrogen analysis equipment (Kjeldahl 2300, FOSS, Denmark) according to the standard method edited by Liu and Clescerl, et al.[31,32]. The nitrate nitrogen content of soil was analyzed by filtration passing through a 0.2 μm filter from oscillation extraction in a 2 mol/L KCL solution to which soil sample was added, and then measured by UV/VIS Spectrometer (Lambda 35, PerkinElmer, Singapore)[31,32]. The nitrate nitrogen content of digestate was analyzed according to the standard method of water quality-determination of nitrate-nitrogen-ultraviolet spectrophotometry[38]. Volatile ammonia was captured by sponges pre-soaked in phosphoglycerol, and then analyzed for ammonium nitrogen concentration at room temperature following oscillation extraction in 1 mol/L KCL solution according to the method used by Paramasivam et al.[39] All measurements in this study were conducted in triplicate and the average values were calculated and reported.

3 Results and discussion

3.1 Effect of the digestate application depth on NH_3 volatilization

Digestate was applied at the depth of 0 cm, 2 cm, 6 cm, 10 cm, 15 cm, and 20 cm, respectively, and the analyzed NH_3 volatilization above the soil surface is displayed in Figure 1.

As is shown in Figure 1, when the application depths were 0 cm, 2 cm, and 6 cm, NH_3 volatilized more than at 10 cm, 15 cm and 20 cm. Moreover, Figure 1 reveals that most of the NH_3 volatilization actually occurred within the first 10 days at all application depths. In sandy loam, the percent of volatile ammonia out of the total ammonia in the first 10 days were 87.48%, 67.78%, 59.59%, 53.40%, 53.70%, and 48.38% at 0 cm, 2 cm, 6 cm, 10 cm, 15 cm and 20 cm, respectively. In contrast, 100% ammonia was lost through volatilization in black loam in the first 10 days at all application depths (Figure 1). From the 10th to 20th day of the experiment, NH_3 volatilization became negligible except those with zero application depths. After 25 days, NH_3 volatilization totally stopped in all soil columns. These findings are consistent with the results reported by Chantigny et al.[19]. The reason for that is nitrogen in digestate could not be absorbed and converted by soils at the early stage of the experiment so as to escape through pore space in soils in the form of NH_3 volatilization. The NH_3 volatilization reduced after digestate application was deepened. Figure 1 also shows that there was a big difference in NH_3 volatilization when digestate application depths were the same in different soils. NH_3 volatilization rate in the 6 groups of black loam was higher than that of sandy loam, and volatilization period in the 6 groups of black loam was shorter than that of sandy loam. The reason is that the pore space in sandy loam was bigger than that in black loam and digestate could penetrate deep into soils in a shorter time than that in black loam[40].

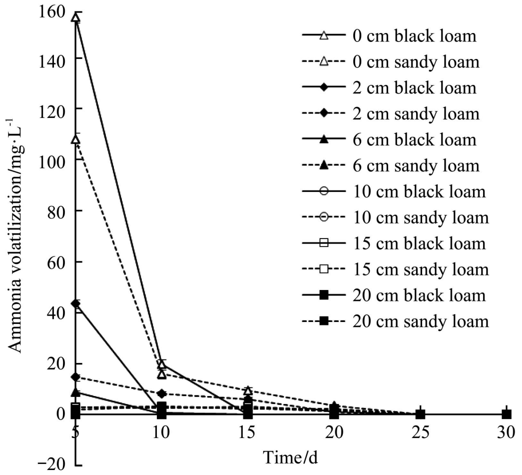

Figure 1 Effect of the digestate application depth on NH_3 volatilization in the experiment

3.2 Effect of the digestate application depth on cumulative NH_3 volatilization

The effect of the digestate application depth on cumulative NH_3 volatilization is shown in Figure 2.

It can be seen from Figure 2 that cumulative NH_3 volatilized significantly less when the application depth was 6 cm, 10 cm, 15 cm, and 20 cm than 0 cm and 2 cm. For instance, the cumulative NH_3 volatilization became negligible when the application depth was deeper than 10 cm. This result indicates that the nitrogen loss through NH_3 volatilization could be effectively controlled when the digestate was applied 10 cm under the soil surface. Again, the cumulative NH_3 volatilization in the black loam was found significantly ($p<0.01$) more than that in the sandy loam when the application depth was at 0 cm and 2 cm, respectively.

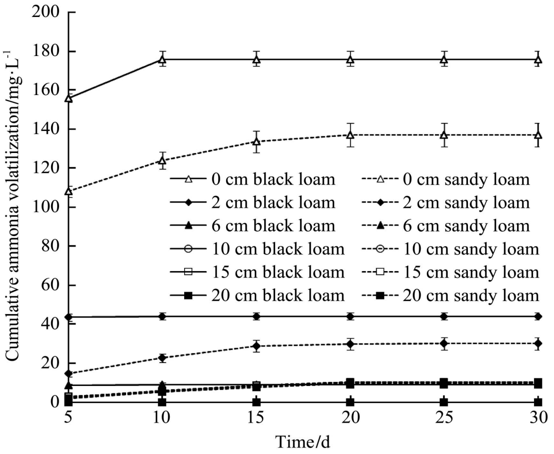

Figure 2 Effect of the digestate application depth on cumulative NH_3 volatilization

3.3 Effect of the digestate application depth on soil moisture content

The digestate application depth-dependent soil moisture content along the vertical depth of the soil is shown in Figure 3.

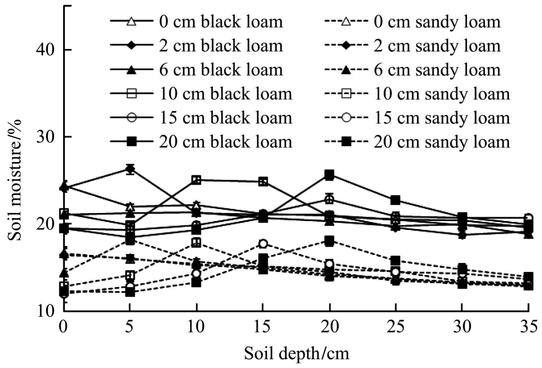

Figure 3 Digestate application depth-dependent soil moisture content along the vertical depth of the soil

As shown in Figure 3, the moisture content in the soil applied with digestate was always higher than the original soil. The profile of moisture content along the soil depth appeared to be in the shape of “7”. That is to say, the moisture content in the soil reached a maximum at fertilizer points (0 cm, 2 cm, 6 cm, 10 cm, 15 cm and 20 cm), and then it leveled down toward the upper and lower sides of the fertilizer points. The maximum moisture content in the sandy loam was much higher when digestate application depth was 6 cm, 10 cm, 15 cm and 20 cm than when it was at 0 cm and 2 cm. This result indicates that the amount of evaporation decreased significantly when the application depth was deeper.

3.4 Effect of the digestate application depth on soil nitrogen distribution

3.4.1 Effect of the digestate application depth on soil ammonium nitrogen distribution

The digestate application depth-dependent ammonium nitrogen distribution along the vertical depth of the soil is shown in Figure 4.

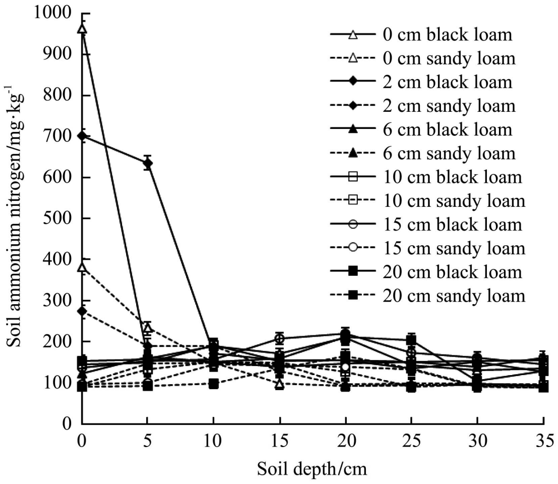

Figure 4 Digestate application depth-dependent ammonium nitrogen distribution along the vertical depth of the soil

As displayed in Figure 4, the maximum ammonium nitrogen concentration in the soil was found at the soil surface when the application depth was 0 cm and 2 cm, respectively. The ammonium nitrogen distribution in the depths deeper than 6 cm basically remained unchanged. That is to say, the ammonium nitrogen content above the fertilizer points in soils increased with the increase of soil depths, but the ammonium nitrogen content below the fertilizer points in soils decreased. Ammonium nitrogen contents below the fertilizer points decreased greatly when being closer to the fertilizer points. It also can be seen from Figure 4 that the ammonium nitrogen concentration in the black loam at all depths (0 cm, 2 cm, 6 cm, 10 cm, 15 cm and 20 cm) gradually stabilized in the range from 5 cm to 10 cm below the fertilizer points, but in sandy loam this stabilized range was from 10 cm to 15 cm below the fertilizer points. This result indicates that the ammonium nitrogen penetration in the sandy loam was much deeper than in the black loam, which is in line with the finding of Cui et al.[40] Besides, in the top 35 cm layer of the soil, the ammonium nitrogen concentration remained stable regardless of the digestate application depth.

3.4.2 Effect of the digestate application depth on the soil nitrate nitrogen distribution

The results of the vertical distribution of the nitrate nitrogen in the soil are shown in Figure 5.

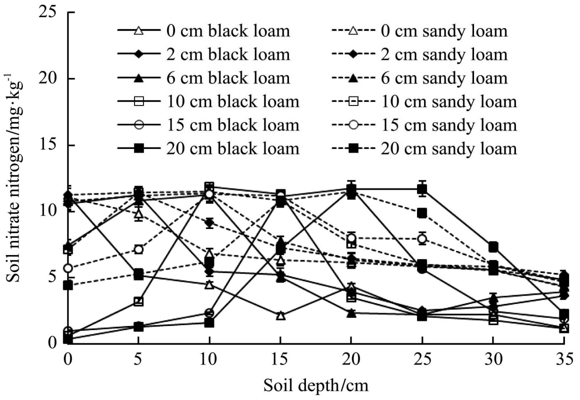

Figure 5 Digestate application depth-dependent nitrate nitrogen distribution along the vertical depth of the soil

Figure 5 illustrates that the maximum concentration of nitrate nitrogen was lower than 12 mg/kg for all application depths. There was little difference in the maximum nitrate nitrogen concentration, but great change in nitrate nitrogen concentration of all digestate application depths in soils. It can also be seen from Figure 5 that the nitrate nitrogen distribution actually followed ammonium nitrogen distribution at all depths in the soil, i.e., the maximum nitrate nitrogen concentration was measured at the fertilizer point, but relatively lower nitrate nitrogen concentration was measured in the distance further away from the fertilizer point. Although nitrate nitrogen concentration was always lower than ammonium nitrogen concentration, the nitrate nitrogen concentration at all depths (0 cm, 2 cm, 6 cm, 10 cm, 15 cm and 20 cm) in black loam was gradually stable in the area of 10 cm to 15 cm below the fertilizer points, and in sandy loam this was gradually stable. This result indicates that the nitrate nitrogen penetration in the sandy loam was much deeper than that in the black loam. It can also be seen from the comparison between Figures 4 and 5 that the nitrate nitrogen at the bottom of the experimental soil columns was still unstable and decreasing. This finding indicates that nitrate nitrogen could penetrate more easily than ammonium nitrogen. This conclusion is actually supported by the study of Svoboda et al.[41] and Mantovi et al.[42] It can be inferred from this study that the groundwater is more likely to be contaminated by nitrate nitrogen when the digestate application depth is too deep.

3.4.3 Effect of the digestate application depth on the soil TKN distribution

The digestate application depth-dependent TKN distribution along the vertical depth of the soil is shown in Figure 6.

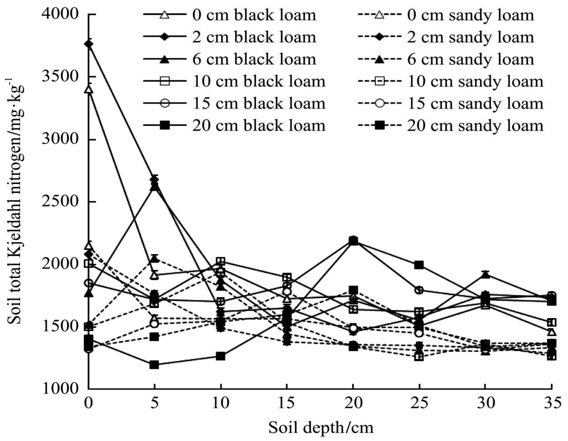

Figure 6 Digestate application depth-dependent TKN distribution along the vertical depth of the soil

The profiles of TKN distribution between black loam and sandy loam were more or less the same at all digestate application depths as shown in Figure 6. When digestate application depth was 0 cm and 2 cm, TKN concentration in soils reduced with the soils depth. When application depth was deeper than 6 cm, the distributions of TKN in the soil almost remained constant. That is to say, the maximum TKN concentration was near to the fertilizer points, but the relatively lower TKN concentration was far from above or below of fertilizer points. Likewise to the nitrate nitrogen distribution, the distribution of TKN in the soil was basically the same with that of ammonium nitrogen. The maximum TKN concentration was higher in the black loam than in the sandy loam when the application depth was 0 cm, 2 cm, and 6 cm, respectively. There was little difference in the TKN concentration between black loam and sandy loam when the application depth was 10 cm, 15 cm, and 20 cm.

4 Conclusions

NH_3 volatilization mainly occurred in the first 10 days after the land application of digestate, and it reduced significantly if deepening the application depth. For example, when the application depth was deeper than 10 cm, NH_3 volatilization reduced substantially. When the application was shallow, there was more nitrogen lost through NH_3 volatilization in the black loam than sandy loam, posing higher pollution risk to the air. The nitrate nitrogen was found capable of penetrating to deeper depth over ammonium nitrogen in the soil, and thus would more likely become a source of groundwater contamination upon digestate application on the farmland.

Acknowledgements

This project was supported by the National Natural Science Foundation of China (No. 51406032), Natural Science Foundation of Heilongjiang Province (No. E201406), Federal Funding of Heilongjiang Province (No. LBH-Z13044), and National High-tech R&D Program of China (No. 2014AA022001).

[References]

[1] Dang F, Bi Y Y, Liu Y P, Yuan H R, Li X J. Analysis of the large-and-medium-sized biogas projects in Europe and comparisons with our country. Biogas, 2014; 32(1): 79–83. (in Chinese with English abstract)

[2] Oshita K, Okumura T, Takaoka M, Fujimori T, Appels L, Dewil R. Methane and nitrous oxide emissions following anaerobic digestion of sludge in Japanese sewage treatment facilities. Bioresource Technology, 2014; 171C(1): 175–181.

[3] Mayerle S F, De Figueiredo J N. Designing optimal supply chains for anaerobic bio-digestion/energy generation complexes with distributed small farm feedstock sourcing. Renewable Energy, 2016; 90: 46–54.

[4] Li Y B, Park S Y, Zhu J Y. Solid-state anaerobic digestion for methane production from organic waste. Renewable and Sustainable Energy Reviews, 2011; 15(1): 821-826.

[5] Ge X M, Xu F Q, Li Y B. Solid-state anaerobic digestion of lignocellulosic biomass: Recent progress and perspectives. Bioresource Technology, 2016; 205: 239–249.

[6] Zarkadas I, Dontis G, Pilidis G, Sarigiannis D A. Exploring the potential of fur farming wastes and byproducts as substrates to anaerobic digestion process. Renewable Energy, 2016; 96: 1063–1070.

[7] Gioelli F, Dinuccio E, Balsari P. Residual biogas potential from the storage tanks of non-separated digestate and digested liquid fraction. Bioresource Technology, 2011; 102: 10248–10251.

[8] Chen C, Ruan Z Y, Wu J, Gao L H, S J L, Wang Y W, Xu Y S, Wei X L, Xu F H. Research progress on the comprehensive disposal and utilization of biogas slurry from large scale biogas engineering. Biogas, 2013; 31(1): 25–28. (in Chinese with English abstract)

[9] Zhang G Z, Wu S B, Wang H L, Wei S Q, Wang K Y, Long Y, Deng L W. Survey and analysis on state quo of public intention for utilizing digestate from large and medium size biogas Plants. Biogas, 2009; 28(1): 21–24. (in Chinese with English abstract)

[10] Dorno N, Feilberg A, Balsari P, Nyord, T. Nitrous oxide losses from untreated and digested slurry as influenced by soil moisture and application method. Biosystems Engineering, 2013; 115(4): 423–433.

[11] Quakernack R, Pacholski A, Techow A, Herrmann A, Taube F, Kage H. Ammonia volatilization and yield response of energy crops after fertilization with biogas residues in a coastal marsh of Northern Germany. Agriculture, Ecosystems and Environment, 2012; 160(4): 66–74.

[12] Bougnom B P, Niederkofler C, Knapp B A, Stimpfl E, Insam H. Residues from renewable energy production: their value for fertilizing pastures. Biomass Bioenergy, 2012; 39(39): 290–295.

[13] Ahlgren S, Bernesson S, Nordberg A, Hansson P A. Nitrogen fertilizer production based on biogas-energy input, environmental impact and land use. Bioresource Technology, 2010; 101(18): 7192–5.

[14] Svensson K, Odlare M, Pell M. The fertilizing effect of compost and biogas residues from source separated household waste. Journal of Agricultural Science, 2004; 142(4): 461–467.

[15] Gutser R, Ebertseder T, Weber A, Schraml M, Schmidhalter U. Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. Journal of Plant Nutrition and Soil Science, 2005; 168(4): 439–446.

[16] Gericke D. Measurement and modeling of ammonia emissions after field application of biogas slurries. Doctoral thesis. Kiel University, Germany, 2009.

[17] Mōller K, Stinner W. Effects of different manuring systems with and without biogas digestion on soil mineral nitrogen content and on gaseous nitrogen losses (ammonia, nitrous

oxides). European Journal of Agronomy, 2009; 30(1): 1–16.

[18] Terhoeven-Urselmans T, Scheller E, Raubuch M, Ludwig B, Joergensen R G. CO_2 evolution and N mineralization after biogas slurry application in the field and its yield effects on spring barley. Applied Soil Ecology, 2009; 42(3): 297–302.

[19] Chantigny M, Rochette P, Angers D, Masse D, Cote D. Ammonia volatilization and selected soil characteristics following application of anaerobically digested pig slurry. Soil Science Society of America journal, 2004; 68(1): 306–312.

[20] Bian B, Lv L, Yang D H, Zhou L J. Migration of heavy metals in vegetable farmlands amended with biogas slurry in the Taihu Basin, China. Ecological Engineering, 2014; 71(71): 380–383. (in Chinese with English abstract)

[21] Sommer S G, Hutchings N J. Ammonia emission from field applied manure and its reduction—invited paper. European Journal of Agronomy, 2001; 15(1): 1–15.

[22] Abubaker J, Risberg K, Pell M. Biogas residues as fertilisers-Effects on wheat growth and soil microbial activities. Applied Energy, 2012; 99(2): 126–134.

[23] Jothi G, Pugalendhi S, Poornima K, Rajendran G. Management of root-knot nematode in tomato *Lycopersicon esculentum*, Mill., with biogas slurry. Bioresource Technology, 2003; 89(2): 169–170.

[24] Dahiya A K, Vasudevan P. Biogas plant slurry as an alternative to chemical fertilizers. Biomass, 1986; 9(1): 67-74.

[25] Zhang Q Z, Chen X, Shen S M. Advances in studies on accumulation and leaching of nitrate in farming soil. Chinese Journal of Applied Ecology, 2002; 13(2): 233–238. (in Chinese with English abstract)

[26] Qiao Y F, Han X Z, Zhao L P, Wang S Q. Rsearches on ammonia volatilization loss characters of nitrogen fertilizer from black soil. Journal of Soil and Water Conservation, 2009; 23(1): 198–201. (in Chinese with English abstract)

[27] Yang S L, Zhu A N, Zhang J B, Chen X M, Zhu Q G. Ammonia volatilization loss and its affecting factors under different amounts and ways of N application in field. Arid Zone Research, 2010; 27(3): 415–421.

[28] Miao G Y, Yin J, Zhang Y T, Zhang A L. A study of the root systems of main crops in Northern China. Springer Netherlands, 1998; 82: 345–356.

[29] Yu Y, Loiskandl W, Kaul H P, Himmelbauer M, Wei W, Chen L D, Bodner G. Estimation of runoff mitigation by morphologically different cover crop root systems. Journal of Hydrology, 2016; 538: 667–676.

[30] Geng G, Wang J K, Yu L H, Yin B, Zheng C B, Hui F, et al. The effect of crop's roots on the content of different forms of nitrogen in black soil. Chinese Journal of Soil Science, 2010; 41(6): 1344–1348. (in Chinese with English abstract)

[31] Liu F Z, Liu X W. Quality standards and testing methods of soil and solid waste. Beijing: Chemical Industry Press, 2007. (in Chinese)

[32] Clescerl L S, Greenberg A E, Eaton A D. Standard methods for the examination of water and wastewater, 20th edition. American Public Health Association, 1999.

[33] Duan X W, Xie Y, Liu G, Gao X F, Lu H M. Field capacity in black soil region, northeast China. Chin. Geogra. Sci., 2010; 20(5): 406–413.

[34] Jiang P F, Lei T W, Liu X H, Wu Y, Li X, Wang Q J. Principles and experimental verification of capillary suction method for fast measurement of field capacity. Transactions of the CSAE, 2006; 22(7): 1–5. (in Chinese with English abstract)

[35] Xie X Q, Wang L J. Observation and analysis of water environmental factors. Beijing: Standards press of china, 1998; pp.7–9. (in Chinese)

[36] Peake L R, Reid B J, Tang X Y. Quantifying the influence of biochar on the physical and hydrological properties of dissimilar soils. Geoderma, 2014; 235–236: 182–190.

[37] Salehi M H, Beni O H, Harchegani H B, Borujeni I E, Motaghian H R. Refining soil organic matter determination by loss-on-ignition. Pedosphere, 2011; 21(4): 473–482.

[38] China National Standard. HJ/T346 — 2007 water quality-determination of nitrate–nitrogen–ultraviolet spectrophotometry. Standards Press of China, 2007. (in Chinese)

[39] Paramasivam S, Jayaraman K, Wilson T C, Alva A K, Kelson L, Jones L B. Ammonia volatilization loss from surface applied livestock manure. Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes, 2009; 44(3): 317–324.

[40] Cui M, Hu C X, Di H J, Sun X C, Tan Q L, Zhang M. Leaching and transport of nitrate in vegetable production systems in suburbs of Wuhan. Plant Nutrition and Fertilizer Science, 2012; 18(3): 637–644.

[41] Svoboda N, Taube F, Wienforth B, Klu C, Kage H, Herrmann A. Nitrogen leaching losses after biogas residue application to maize. Soil & Tillage Research, 2013; 130(6): 69–80.

[42] Mantovi P, Fumagalli L, Beretta G P, Guermandi M. Nitrate leaching through the unsaturated zone following pig slurry applications. Journal of Hydrology, 2006; 31(6): 195–212.