CHEMICAL ENGINEERING TRANSACTIONS
VOL. 63, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Jeng Shiun Lim, Wai Shin Ho, Jiří J. Klemeš

ISBN 978-88-95608-61-7; **ISSN** 2283-9216
DOI: 10.3303/CET1863059

A Review on the Impacts of Compost on Soil Nitrogen Dynamics

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With the depletion of soil quality, the increased use of inorganic fertiliser is required to cope with the increasing food demand. The increasing use of inorganic fertiliser has become a burden to both the economy and environment. The overuse of nitrogen fertiliser can cause the leaching of NO_3^- to the surrounding water source and the emissions of N_2O and NO to the atmosphere. Besides the environmental issues associated with conventional farming, more attention has been drawn to the rapid population growth and urbanisation that has led to the production of abundant municipal solid waste (MSW). To overcome these problems, composting can be an alternative option to both managing MSW and replacing inorganic fertiliser. As a biological process, composting can utilise the organic fraction of MSW as the raw material to produce compost, a stable form of organic matter that can be used as soil amendment or organic fertiliser. Although the utilisation of compost as an organic fertiliser is quite well studied, less research had focused on the nitrogen dynamic after compost application to soil. It is essential to figure out the correlation between compost application and soil nitrogen dynamic in order to prevent further nitrogen loss as a pollutant after compost application. This paper reviews the soil nitrogen cycle and the potential of nitrogen loss prevention with the application of compost. The application of compost is providing some promising effects in term of soil organic carbon and nutrients replenishment and soil microbial population enhancement. The effects of compost to soil are highly dependent on the characteristics of the raw materials for composting. The presence of high nutrient in compost is not always a good thing since it also increases the risk of nutrient loss through leaching or gas emission. The combination between nutrient rich and nutrient poor compost can be an alternative way to prevent nutrient loss. N_2O emission from soil is always associated with high nitrogen content and anaerobic condition in soil. The mitigation of N_2O emission can be achieved by compost application, and the addition of biochar during composting process can further enhance the effect.

1. Introduction

Soil degradation, an outcome of improper agricultural practices, is the physical, chemical and biological decline in soil quality, which is related to the decrease in soil organic matter, fertility, and structural condition. It had become a major environmental and agricultural concern worldwide. In order to secure the sustainable food supply that can cope with the rapid population growth and urbanisation, fertiliser application is necessary. The global demand for fertiliser nutrients (N, P_2O_5, and K_2O) for 2015 is 184.02 t and is estimated to reach 201.66 t in 2020; the demand for nitrogen fertiliser was estimated to increase from 110.03 to 118.76 t from 2015 to 2020, with an annual growth rate of 1.5 % (FAO, 2017). The intensive use of chemical fertiliser can cause severe pollution to the ecosystem. Replacement with organic amendments, such as compost, manure, or plant residues, as a nutrient source is becoming more attractive.
Composting is one of the recycling technologies that transform and stabilise organic substrates into the value-added product under aerobic condition. Mature compost can be used as a soil amendment or bio-fertiliser. As

Please cite this article as: Li Yee Lim, Chew Tin Lee, Cassendra Phun Chien Bong, Jeng Shiun Lim, Mohamad Roji Sarmidi, Jiří Jaromír Klemeš, 2018, A review on the impacts of compost on soil nitrogen dynamics, Chemical Engineering Transactions, 63, 349-354
DOI:10.3303/CET1863059

a greener and cleaner technology, composting recycles the nutrients from the municipal organic wastes and agri-food industry wastes; application of compost enhances and restores the soil organic matter. Instead of the direct application of raw organic matter via mineral fertiliser, the use of compost is preferable. Composting process pasteurises the organic waste, concentrates the nutrient content, and reduces the phytotoxicity effect of the direct application of raw organic waste. The slow nutrient release pattern of compost enhances the net primary productivity and reduces the need for constant application of fertiliser (Ryals and Silver, 2013). The presence of beneficial microbe in compost increases the resistance of plant against stress and diseases (Mehta et al., 2014). High humus content and neutral pH in compost allow the immobilisation of heavy metals from the contaminated wastes in soil (Lim et al., 2017).

Some adverse effects could occur in soil and environment during composting and post-application of compost. Improper management of composting process can lead to a higher emission of greenhouse gases (GHG), which can be avoided with the addition of several amendments such as aeration, inoculation with earthworm or microbial inoculants (Bong et al., 2017). Increased level of inorganic N, microbial available C and water in soil can lead to higher CO_2 and N_2O emissions (Chadwick et al, 2011). The repeated application of compost can lead to a high chance of N mineralisation (Willekens et al., 2014). Table 1 lists the potential negative impacts during the preparation and application of compost.

Table 1: The potential negative impacts during compost preparation and application

	Compost preparation	Compost Application
Fossil fuel consumption (GHG emission)	Transportation of organic wastes, On-site machinery (compost turning, air supply).	Transportation of mature compost.
Leaching	Compost leachate (rich in NH_3, trace elements, heavy metals, pathogen, high chemical oxygen demand).	P and N leaching might occur with the excessive application of compost.
Gas emission	CH_4, NO_x, and N_2O emissions if under poor ventilation.	NO_x, and N_2O emissions if aerobic “pocket” of soil is blocked.
Water pollution	Leaching of nutrients can pollute the surrounding water system.	Leaching of nutrients can cause underground water pollution.
Phytotoxicity	Not applicable.	Application of immature compost can be phytotoxic to the plants, the presence of pathogen in immature compost can cause disease to plants.
Water pollution	Leaching of nutrients can pollute surrounding water system.	Leaching of nutrients can cause underground water pollution.

To prevent issues listed in Table 1, proper management of the composting process and sound application of compost is essential. This paper aims to review the impacts of compost application to the environment with a brief outline of soil nitrogen dynamic and potential to mitigate the nitrogen loss during compost application.

2. Soil N dynamic

Nitrogen (N), as the main building block for proteins and nucleic acids, is one of the most important elements for living life. Although nitrogen gas (N_2) forms about 78 % of Earth’s atmosphere, this abundant reservoir cannot be accessed by most organisms. With a series of natural occurred activities, such as microbial transformation and lightning, the free flow of N falls into the ground and made available to the plants. With the N-fixing microorganisms (free-living N-fixing bacteria and mutualistic bacteria that associated with leguminous plants) account for around 90 % of the N fixation and only 1 - 5 % of N is fixed by the free-living N-fixing bacteria, the available N content in soil is not sufficient to sustain the agricultural practices. Addition of N into the soil system, including N fertilisers (solid or soluble form), compost, plant residues, manure, and cover crops, is crucial to overcome these issues. Most of the N inputs listed are in organic form (apart of the inorganic fertilisers) that requires the transformation from soil microorganisms into the plant-available form (inorganic N, NH_4^+ and NO_3^-). Soil microorganisms act as a very crucial part in soil nitrogen cycle as shown in Figure 1.

The nitrogen cycle in soil include several processes, namely nitrogen fixation, nitrogen mineralisation, nitrogen assimilation, ammonification, nitrification, and denitrification, which involves several N species, such as N_2, NH_3, NH_4^+, NO_2^-, NO_3^-, N_2O, and NO_x. The nitrogen flow is considered very efficient and effective when microorganisms is actively transforming the organic nitrogen, at the same time, plants are taking up the NH_4^+ and NO_3^- rapidly, which mean the potential for nitrogen loss is relatively low in this case. But this perfect scenario is not likely to occur in natural, especially when amendments are added into the soil system. Farmers tend to add a “more than enough” level of inorganic fertilisers or organic amendments. This lead to the N loss from the soil system especially in the form of NO_3^- leaching, which is the most concerned pollution issue when come across farming. According to Berthrong et al. (2014), addition of N fertiliser through human activity (dotted line in Figure 1) suppresses the diversity and abundance of N-fixing bacteria under the elevated atmospheric CO_2 conditions. Although more research is required to identify the actual microbial activities in soil, this finding become a major issue to solve in order to limit the effect of climate change in food production.

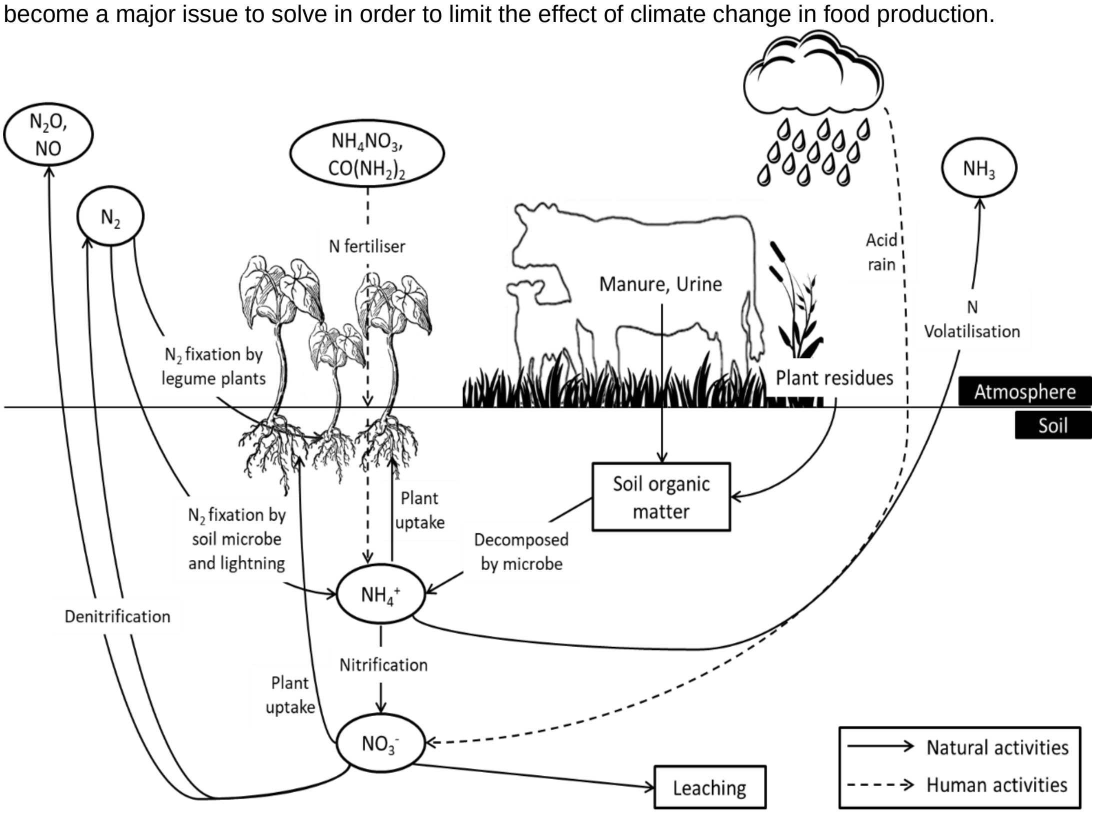

Figure 1: Nitrogen dynamic in soil (modified from Saggar et al., 2013)

The N cycle is highly affected by soil N, carbon (C), pH, temperature, oxygen supply and water content. Since the leaching of NO_3^- occurs with the oversupply of N, the possibility of its occurrence during organic farming is considerably low as the organic supply of N is relatively limited. The advantages of most of the organic amendments such as compost are based on their slow release pattern of bound nutrients. Compost is quite susceptible to N_2, N_2O and NO emissions. As an inert gas in the Earth’s atmosphere, the emission of N_2 does not cause any negative impact to the environment apart of the loss of nitrogen from soil. The emissions of N_2O and NO into environment can be a great concern. N_2O is the GHG that has a global warming potential (GWP) of 298 CO_2-eq in a 100 y horizon while NO is an air pollutant. According to Saggar et al. (2013), the increase in soil nitrogen supply, decrease in soil pH, carbon availability and water content generally increase the N_2O:N_2 ratio. The emissions of both N_2O and NO can be avoided by improving soil drainage conditions, avoiding soil compaction and pugging in wet soil conditions, avoiding over-irrigation and excessive N supply and through liming.

3. Impact of compost application on N dynamics

The creditability of compost application is dependent on its impacts toward soil, which can be either positive or negative. As mentioned in the previous section, N is the limiting elements in soils which is crucial to all living organisms, this section discusses the potential changes in the soil characteristics, notably soil N dynamic, following compost application. Table 2 present changes in soil characteristic and soil N dynamic following compost application.

Table 2: Changes in soil characteristic and soil N dynamic following compost application

Reference	Compost	Soil type & Study site	Experimental setup	Effect of compost
D'Hose et al., 2016	Plant-based farm compost	Sandy loam Merelbeke, Belgium	Plots received 2,000 kg C ha^{-1} y^{-1} by compost application	Increased microbial biomass and earthworm number and suppression of certain plant related diseases Increased soil pH and water retention Enhanced soil organic carbon (SOC) content, SOC stock and nutrient contents without noticeable P leaching Significant increase in total N and nitrate-N without noticeable N leaching
Ryals et al., 2014	Dry green waste compost	Grassland soil California	One-time amendment of ~ 1.3 cm thick compost on soil surface	Incorporation and retention of compost with soil 26 - 37 % increase in C content ~ 54 % increase in N content
Castán et al., 2016	Biosolids compost (BC), municipal compost (MC), feedlot compost (FC), poultry litter compost (PC)	Sandy soil Northeastern Argentina	Composts and mixtures were surface-applied at an equivalent rate of 40 Mg ha^{-1} (dry weight)	Higher cumulative CO_2 emissions, especially for MC alone or mixtures (FC-MC, PC-MC) compared to inorganic fertiliser Increase both soil C and N concentration Higher inorganic N during first year application, but similar reading observed after 2 y compost application NH_4^+-N is the main inorganic N form during incubation, but at the end of incubation (2 y), NO_3^--N dominate in soil
Nicholson et al., 2017	Green compost and green/ food compost	Clay loam and sandy loam England and Wales	Surface broadcast of compost at rate of 20 t ha^{-1} compost	Compost treatment gave the lowest NH_3 and N_2O emissions and lowest cumulative NO_3^- leaching losses compared to food-based digestate, cattle slurry and farmyard manure N_2O emissions factor from compost treatment was not significantly different from the background values
Yuan et al., 2017	Biochar-chicken manure co-compost (BM), chicken manure compost (M)	Loamy sand North Carolina, USA	1 % BM, 5 % BM, 4 % M	Compost addition significantly enhanced soil total C and N, inorganic and KCl extractable organic N, microbial biomass C and N, cellulase enzyme activity, N_2O-producing bacteria and fungi, and gas emissions of N_2O and CO_2 BM significantly reduced soil CO_2 and N_2O emissions by 35 % and 27 % and improve soil organic C stabilisation compared to M
Sharifi et al., 2014	Beef manure compost	Clay loam Alberta, Canada	Compost was applied with unchopped barley straw or wood chips in the rate of 13, 39, or 74 Mg ha^{-1} DM	Medium to high rates of compost amendment resulted in the increase of potential, readily and intermediate mineralisable N pools in ranges of 140 - 355 % as compared to the control and fertiliser treatment But medium to high application rate did not contribute to higher barley yield Application in the rate of 13 - 39 Mg ha^{-1} DM were recommended

As stated in Table 2, compost has the ability to improve soil organic matter content, soil water holding capacity, and nutrient availability to plant and increase soil microbial population. According to D'Hose et al. (2016), the increased in hot-water extractable C (easily mineralisable C) is beneficial to soil microorganisms. It improves the microbial biomass, microbial activity, change the microbial community structure and composition and enhance the growth of specific group of organisms such as actinomycetes and Arbuscular mycorrhiza fungi. Compared to animal slurry, compost was found to contain higher nutrient supplies (plant available potassium and extractable phosphorus) which release in time. The long-term of compost application is not suggested in order to prevent the nutrient loss to the environment, although the noticeable P and N leaching is not observed after a 4-y application.

The effect of compost application to soil might vary with the different of raw material used for composting. As reported by Castán et al. (2016), the municipal compost (MC) that contained higher $CaCO_3$ had some liming effect to the soil, which increases the microbial respiration and nitrification and thus leading to the increased in CO_2 emission upon application. Although the nutrient contents in MC is relatively low compared to poultry litter compost (PC) and biosolid compost (BC), the liming effect increase its P retention with the formation of $Ca_3(PO_4)_2$. Similar to the PC, the binding of phosphorus to Ca and Mg allow the gradual decrease of P overtime. For the case of BC, the binding of phosphorus with Al and Fe restrict the release of P while the high nitrogen content of the raw material can easily lead to nitrogen loss through leaching. The combination use of different type of compost was suggested to maintain the nutrient balance in the soil (e.g. combination use of MC, PC, and FC to reduce the risk of P leaching and the combination use of BC and MC to reduce N leaching).

The nitrogen loss through either leaching as NO_3^- or emission as gases (N_2O, NO, and NH_3) from soil are varying among different studies. High NH_3 emission as observed by Nicholson et al. (2017) was highly related to the NH_4^+-N content of the compost. The pH greater than 8 is also conducive to elevated NH_3 emission. As the nitrogen emissions (NH_3, N_2O, and NO_3^-) from green and green/food compost were relatively low, with its low risk character in terms of N losses, it can be used to build up soil long-term (organic) N reserves and to improve soil condition (Nicholson et al., 2017). Yuan et al. (2017) also showed a positive impact of compost application in reducing N_2O emission to the atmosphere, although the addition of biochar during composting process was suggested since it provided the further improvement in mitigating N_2O emission. A reduction of more than 30 % of N_2O emission had been observed by Mukumbuta et al. (2017) when manure compost was applied in an andosol soil.

The application of compost with 85 % municipal wastes, 6.5 % pruning wastes, and 8.5 % agro-industrial organic residues on sandy soil at a rate of 76.8 g fw kg^{-1} had showed the increased volume in nutrient leaching (Sorrenti and Toselli, 2016). According to a research done by Lou et al. (2017) in Zhejiang Province, China, the application of spent mushroom composts on loamy soil enhanced the mineral nitrogen content in soil with the converted of 39.4 % of input nitrogen into mineral nitrogen within 42 d of incubation. Application of compost was found to increase the amount of dissolved organic carbon and total dissolved nitrogen but the leaching of heavy metals was not observed. The addition of biochar decreases the nutrient volume being leached out.

4. Conclusions

The improvement of soil organic matter content, soil water holding capacity, and nutrient availability to plant and increment in soil microbial population can be achieved by compost application as organic amendment to soil. To avoid the nutrient leaching and unwanted gas emission (N_2O, NO, and NH_3), the application of compost with excessive nitrogen and phosphorus must be avoided. The combination of different nutrient level of compost can be an alternative to reduce the risk of nutrient leaching. Nitrogen level in compost is the major parameter that affects the occurrences of nitrogen loss. In most cases, the application of compost can mitigate the emissions of N_2O from soil by 30 % provided the soil is maintained under adequate oxygen level. The addition of biochar during the composting process can further improve the N_2O mitigation.

Acknowledgments

The authors acknowledge research grants from Universiti Teknologi Malaysia with the grant no. Q.J130000.2546.14H65; and the EU project Sustainable Process Integration Laboratory – SPIL, project No. CZ.02.1.01/0.0/0.0/15_003/0000456, funded by Czech Republic Operational Programme Research, Development and Education, Priority 1: Strengthening capacity for quality research, in collaboration agreement with the UTM.

References

Berthrong S.T., Yeager C.M., Gallegos-Graves L., Steven B., Eichorst S.A., Jackson R.B., Kuske C.R., 2014, Nitrogen fertilization has a stronger effect on soil nitrogen-fixing bacterial communities than elevated atmospheric CO_2, Applied and Environmental Microbiology, 80, 3101-3112.

Bong C.P.C., Lim L.Y., Ho W.S., Lim J.S., Klemeš J.J., Towprayoon S., Ho C.S., Lee C.T., 2017, A review on the global warming potential of cleaner composting and mitigation strategies, Journal of Cleaner Production, 146, 149-157.

Castán E., Satti P., González-Polo M., Iglesias M.C, Mazzarino M.J., 2016, Managing the value of composts as organic amendments and fertilisers in sandy soils, Agriculture, Ecosystems & Environment, 224, 29-38.

Chadwick D., Sommer S., Thorman R., Fangueiro D., Cardenas L., Amon B., Misselbrook T., 2011, Manure management: implications for greenhouse gas emissions, Animal Feed Science and Technology, 166, 514-531.

D'Hose T., Ruysschaert G., Viaene N., Debode J., Vanden Nest T., Van Vaerenbergh J., Cornelis W., Willekens K., Vandecasteele B., 2016, Farm compost amendment and non-inversion tillage improve soil quality without increasing the risk for N and P leaching, Agriculture, Ecosystem and Environment, 225, 126-139.

Food and Agriculture Organization of the United Nations (FAO), 2017, World fertilizer trends and outlook to 2020 (summary report) < www.fao.org/3/a-i6895e.pdf>, accessed 20.09.2017.

Lim L.Y., Lee C.T., Lim J.S., Klemeš J.J., Ho C.S., Abu Mansor N.N., 2017, Feedstock Amendment for the Production of Quality Compost for Soil Amendment and Heavy Metal Immobilisation, Chemical Engineering Transactions, 56, 499-504.

Lou Z., Sun Y., Zhou X., Baig S.A., Hu B., Xu X., 2017, Composition variability of spent mushroom substrates during continuous cultivation, composting process and their effects on mineral nitrogen transformation in soil, Geoderma, 307, 30-37.

Mehta A.B., Uma Palni, Franke-Whittle I.H., Sharma A.K., 2014, Compost: Its role, mechanism and impact on reducing soil-borne plant diseases, Waste Management, 34, 607-622.

Mukumbuta I., Shimizu M., Hatano R., 2017, Mitigating global warming potential and greenhouse gas intensities by applying composted manure in cornfield: a 3-year field study in an Ansosol soil, Agriculture, 7, 1-20, DOI: 10.3390/agriculture/7020013.

Nicholson F., Bhogal A., Cardenas L., Chadwick D., Misselbrook T., Rollett A., Taylor M., Thorman R., Williams J., 2017, Nitrogen losses to the environment following food-based digestate and compost applications to agricultural land, Environmental Pollution, 228, 504-516.

Ryals R., Kaiser M., Torn M.S., Berhe A.A., Silver W.L., 2014, Impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils, Soil Biology and Biochemistry, 68, 52-61.

Ryals R., Silver W.L., 2013, Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands, Ecological Applications, 23, 46-69.

Saggar A., Jha N., Deslippe J., Bolanc N.S., Luo J., Giltrap D.L., Kim D.G., Zaman M., Tillman R.W., 2013, Denitrification and N_2O:N_2 production in temperate grasslands: Processes, measurements, modelling and mitigating negative impacts, Science of the Total Environment, 465, 173-195.

Sharifi M., Zebarth B.J., Miller J.J., Burton D.L., Grant C.A., 2014, Soil nitrogen mineralisation in a soil with long-term history of fresh and composted manure containing straw or wood-chip bedding, Nutrient Cycling in Agroecosystems, 99, 63-78.

Sorrenti G., Toselli M., 2016, Soil leaching as affected by the amendment with biochar and compost, Agriculture, Ecosystem and Environment, 226, 56-64.

Willekens K., Vandecasteele B., Buchan B., De Neve S., 2014, Soil quality is positively affected by reduced tillage and compost in an intensive vegetable cropping system, Applied Soil Ecology, 82, 61-71.

Yuan Y., Chen H., Yuan W., Williams D., Walker J.T., Shi W., 2017, Is biochar-manure co-compost a better solution for soil health improvement and N_2O emissions mitigation?, Soil Biology and Biochemistry, 113, 14-25.