ISSN: 2688-8645

Research Progress on Soil Nitrogen Loss Pathways in Tea Plantation Ecosystems

Qianyu Zhao[1, 2, 3, 4, 5], Ziru Niu[1, 2, 3, 4, 5]

[1]Shaanxi Agricultural Development Group Co., China

[2]Shaanxi Land Construction Land Engineering Technology Research Institute Co., LTD, China

[3]The Key Laboratory of the Degeneration and Unused Land Consolidation Project of the Ministry of Natural Resources, China

[4]Shaanxi Province Land consolidation Engineering Technology Research Center, China

[5]The Land Engineering Technology Innovation Center of the Ministry of Natural Resources, China

Abstract

Nitrogen is an essential nutrient for the growth and development of the tea tree, and is important for the formation of yield and quality. The application of large amounts of nitrogen fertilizer in tea gardens is prone to waste of fertilizers and at the same time has a negative impact on the environment. This paper discusses the current research status of tea garden nitrogen and the characteristics of tea garden soil nitrogen migration and transformation, with a view to providing a research direction and foundation for future research on the blocking and control of soil nitrogen loss and the efficient utilization of nitrogen in tea gardens.

Keywords

Tea Plantation; Fertilization; Nitrogen Transport and Transformation; Research Progress.

1. Introduction

Tea tree is suitable for growing in acidic soil with pH 4.5-5.5. In the long-term planting of tea tree soil has desilica-rich aluminum, polyphenolic substances, acidification and other characteristics. quality enrichment, acidification and other characteristics, thus forming a unique soil chemical environment. The soil chemical environment is unique. In the past, it was believed that under acidic soil conditions, the nitrogen transformation process was slow, and the nitrogen conversion process of tea plantation soil was slow. The research on the nitrogen transformation process of tea garden soil found that the nitrogen mineralization rate of tea garden soil is indeed higher than that of acidic soil. Nitrogen mineralization rate of tea plantation soil is indeed much lower than that of forest soil [1]. However, under the fertilization fertilizer conditions, even if the pH value of 2.9 of the tea garden soil can still occur Nitrification [2]. Some studies have shown that this is mainly due to the long-term application of nitrogen fertilizer can promote the size and activity of ammonia-oxidizing microorganisms, which can alleviate the effects of soil acidification on and activity of ammonia-oxidizing microorganisms by long-term application of nitrogen fertilizer [3-5]. In addition, acidic tea plantation soils, compared to neutral farmland soils, have a higher N2O emission capacity [6-7], and it can also be hypothesized that, compared with naturally acidified soils, it can also be speculated that tea garden soils with fertilizers applied have a faster nitrogen cycling transfer rate, so the study of soil nitrogen fate in tea plantation ecosystems is of great importance. Therefore, the study of soil nitrogen fate in tea plantation ecosystems is of great significance.

China is the world's largest tea producer, tea plantations account for about two-thirds of the global tea plantation area [8-9], and tea is an important economic crop in China. Nitrogen is an essential nutrient for the growth and development of tea plant. Nitrogen is an essential nutrient for the growth and development of tea tree, but nitrogen has strong mobility in the soil, and the mineral nitrogen in the soil is difficult to meet the demand of plants. Mineral nitrogen in the soil is difficult to meet the demand of plants, so fertilization is a necessary agricultural measure to stabilize and improve the yield and quality of tea. Therefore, fertilization is a necessary agronomic measure to stabilize and improve the yield and quality of tea. Nitrogen fertilizer applied to soil soil, in addition to being absorbed and utilized by plants, it will also be absorbed by leaching, runoff, ammonia volatilization, nitrous oxide, and other organic pollutants. ammonia volatilization, nitrous oxide emission and other pathways, thus increase the N load in terrestrial and aquatic ecosystems [10-11]. How to rational application of nitrogen fertilizer, improve the utilization rate of nitrogen fertilizer, reduce nitrogen loss, and solve the resulting environmental problems has become a major issue in the control of agricultural surface pollution. control of agricultural surface pollution has become a major topic of research, but the quantification of soil nitrogen loss in tea plantations is still scarce. However, comprehensive research on the quantification of soil nitrogen loss in tea plantations is still scarce. Based on the published literature, this paper summarizes the characteristics of soil nitrogen migration and transformation in tea plantations, with a view to providing a theoretical basis for the efficient use of nitrogen in tea plantations and the control of agricultural surface pollution.

Tea garden soil nitrogen migration and transformation is a complex process, subject to soil properties, climatic conditions, biological characteristics of the tea tree and the integrated impact of management measures. The following are its main features:

1. Soil acidification inhibits nitrification

Characteristics: Tea plantation soils are usually acidic (pH 4.0~5.5), which inhibits nitrifying bacteria activity, resulting in weaker nitrification (ammonium nitrogen → nitrate nitrogen) and a higher proportion of ammonium nitrogen (NH_4^+) accumulation.

Impact: Tea tree prefers to absorb ammonium nitrogen, and the acidic environment is favorable for its growth, but the low proportion of nitrate nitrogen may limit the nitrogen effectiveness of the deep soil.

2. Active organic nitrogen mineralization

Characteristics: Higher organic matter content of tea plantation soils (especially after application of organic fertilizers), stronger microbial-driven mineralization (organic N → ammonium N).

Seasonal variations: mineralization is accelerated by high temperature and humidity in the rainy season and slowed down in the dry season; long-term fertilization may lead to excessive mineralized N, exacerbating the risk of leaching or volatilization.

3. Nitrification and Nitrogen Loss

Conditions: In acidic soils, anaerobic environments (e.g. waterlogging) promote denitrification (nitrate N → N_2O or N_2), especially significantly during the rainy season or after irrigation.

Environmental effects: denitrification is an important source of the greenhouse gas N_2O, and tea plantations may be a potential source of emissions.

4. Significant ammonia volatilization

Causes: Frequent application of urea or ammonium nitrogen fertilizers is easily converted to NH_3 volatilization under alkaline conditions (e.g., localized elevation of topsoil pH).

Management implications: surface spreading of fertilizers exacerbates volatilization, deeper application or mulching reduces losses.

5. High risk of nitrogen leaching

ISSN: 2688-8645

Reason: Nitrate nitrogen in rainy areas (e.g. southern tea gardens) tends to seep down to the deeper layers with water, while the root system of tea trees is shallow (mostly distributed in 0~40 cm), leading to leaching.

Pollution risk: Nitrate nitrogen leaching may pollute groundwater, especially after excessive fertilization or heavy rainfall.

6. Tea tree uptake preferences and root system effects

Absorption characteristics: Tea tree preferentially absorbs ammonium nitrogen, and organic acids (e.g. oxalic acid) secreted by the root system may further acidify the inter-root soil and inhibit nitrification.

Root distribution: The shallow root system concentrates on absorbing surface nitrogen, and the deeper nitrogen is easily lost without being utilized.

7. Regulation of nitrogen cycle by fertilizer management

Excessive fertilization: Tea farmers are accustomed to high nitrogen inputs (especially chemical nitrogen fertilizers), which leads to soil nitrogen saturation and exacerbates volatilization, leaching and denitrification.

Organic fertilizer substitution: organic fertilizers (e.g., rapeseed cake) slow-release nitrogen, reducing short-term leaching, but long-term mineralization may increase late nitrogen release.

8. Influence of climate and topography

Rainfall: heavy rainfall exacerbates nitrogen leaching and runoff, and soil erosion in sloping tea plantations further leads to nitrogen migration.

Temperature: high temperature promotes microbial activity and accelerates mineralization and nitrification, but may shorten the residence time of N in the soil.

9. Microbial community adaptation

Community structure: acid-tolerant microorganisms (e.g. some fungi) dominate nitrogen transformation in acidic soils, and nitrifying bacteria are less diverse.

Functional genes: abundance of nitrification-related genes (e.g. amoA) may be reduced, limiting nitrification rates.

10. Nitrogen Accumulation Effect of Long-term Continuous Cropping

Continuous cropping effects: multi-year cropping leads to imbalance of soil nitrogen balance, surface nitrogen enrichment and deep layer depletion, exacerbating environmental risks.

Acidification accumulation: Continuous application of physiologically acidic fertilizers (e.g. ammonium sulphate) aggravates soil acidification and further inhibits nitrification.

Heavy application of nitrogen fertilizer is the main reason for the high annual N_2O emissions from tea plantation soils. Early observation of Japanese tea gardens found that the annual nitrogen fertilizer use of 510kg·hm-^{2} tea gardens, N_2O emissions of 10.6-14.8kg·hm-^{2}, if the annual nitrogen application of more than 1,000kg-kg·hm-^{2}10.6-14.8 kg·hm-^{2}, if the annual nitrogen application exceeds 1000 kg·hm-^{2}, the emission potential of N_2O in acidic tea plantation soils will be significantly increased, and when the amount of nitrogen fertilizer is cut from 1200 kg·hm-^{2} to 600 kg·hm-^{2} per year, the annual N_2O emission in tea plantations will be higher than that in other tea plantations. When the amount of nitrogen fertilizer is cut from 1200kg·hm-^{2} to 600kg·hm-^{2} per year, the N_2O emission of tea plantation can be reduced by 85% [12-13]. In addition, the type of fertilizer also affects the soil N_2O emission in tea plantations, and studies have shown that the application of potassium nitrate has the highest soil N_2O emission, followed by ammonium nitrate, and urea and ammonium sulfate have the lowest N_2O emissions were the lowest [14], which may be related to pH, which was found to be a key factor in regulating the N_2O production pathway in dryland acidic soils, and denitrification was the main source of soil N_2O when pH＜4.4, while denitrification was the main source of soil N_2O

when pH＞4.4.When pH＜4.4, denitrification is the main source of soil N_2O, while when pH＞4.4, nitrification is the main pathway of N_2O production [15-16].

N_2O emissions from tea plantations have strong spatial heterogeneity, and because nitrogen fertilizers in tea plantations are mainly ditch applied between the rows of tea trees, the soil N_2O emissions between the rows of tea plantations are higher. Some monitoring results show that although the annual emission of N_2O in tea plantations is 39-45 $kg·N·hm^{-2}$, the emission of soil N_2O between rows can be as high as 116-134 $kg·N·hm^{-2}·y^{-1}$ [17]. Soil N_2O emissions below the tea tree canopy should not be ignored, and its total emissions account for about 35% of the total emissions of the entire tea garden [18]. Therefore, reasonable selection of fertilizer location, fertilizer type, can reduce the emission of N_2O in tea plantations to a certain extent.

Regarding the future progress of soil nitrogen research in tea plantations, taking into account the current research status and challenges, suggestions and directions can be made in the following areas:

2. Optimizing Nitrogen Management and Fertilization Technology Innovation

Fertilizer application and slow-release technology: Research shows that slow-release fertilizers (SF) can significantly reduce nitrate nitrogen leaching (44.86-62.39%), and the “SF + 30% reduction in fertilizer application” program is optimal in terms of the environment and the economy. In the future, it is necessary to further develop intelligent controlled-release fertilizers for different types of tea plantations, and combine them with real-time soil nitrogen monitoring technologies (e.g., Internet of Things sensors) to achieve precise fertilization and reduce the risk of acidification and leaching caused by excessive nitrogen inputs.

Biochemical regulation to inhibit nitrogen loss: for the N_2O emission generated by denitrification in tea plantations, develop a composite formula of nitrification inhibitors (e.g., dicyandiamide) and urease inhibitors to improve nitrogen utilization by slowing down the rate of nitrogen conversion.

3. The Physiological and Molecular Mechanism of Efficient Nitrogen Utilization of Tea Tree

Nitrogen uptake and redistribution mechanism:The nitrogen redistribution mechanism regulated by the CsDof16-CsGS1.1 module in the mature leaves of tea tree provides a new idea to improve the quality of spring tea. In the future, it is necessary to analyze the molecular network of nitrogen transport in different reproductive stages of tea tree, and to improve the nitrogen transport efficiency in a targeted manner by gene editing technology (e.g. CRISPR).

Selection and breeding of nitrogen-efficient varieties: Aiming at the spatial heterogeneity of soil nitrogen in tea plantations, we should screen nitrogen-efficient varieties that prioritize the development of secondary root systems and efficiently transport amino acids (e.g., theanine and glutamic acid), and accelerate the improvement of varieties through gene marker-assisted breeding.

4. Multi-scale Simulation and Intelligent Decision-Making of Nitrogen Cycling in Tea Plantations

Model development and scenario prediction:Based on biogeochemical models (e.g., DNDC, HSW-2D), integrate multi-source data such as climate, soil, management measures, etc., simulate nitrogen transport pathways and environmental risks under different fertilization programs, and provide theoretical support for dynamic regulation. Combined with machine learning algorithms, an early warning system for nitrogen loss in tea gardens will be constructed to identify “hot spots” and key time periods (e.g., rainy season) for nitrogen loss, and optimize fertilizer application and irrigation schedules.

Integration of cross-scale ecological engineering: Promote the technology chain of “source reduction, process interception and end treatment” in tea plantations on sloping land.

5. Long-term Localization Study and Sustainable Management Strategy

Evaluation of the ecological effects of long-term fertilization: Long-term nitrogen application leads to soil acidification and decreased phosphorus effectiveness, so it is necessary to study the mechanism of nitrogen-phosphorus interactions through long-term positioning experiments, and formulate a balanced fertilization program to avoid nutrient imbalance.

Policy support and farmers' behavioral intervention:Establish a certification system for nitrogen management in tea plantations, promote green fertilization technology (e.g. organic fertilizer substitution, ecological interception project) through subsidy policy, and strengthen farmers' training to enhance environmental awareness.

6. Multidisciplinary Intersection and Integration of Emerging Technologies

Microbiome and synthetic biology applications:Using macro-genome technology to analyze the interaction network of nitrification-denitrification functional microorganisms in tea garden soil, and design synthetic flora to regulate nitrogen transformation pathways in a targeted manner.

Intelligent Tea Plantation and Digital Twin: Combining UAV remote sensing and ground sensor network, we will build a nitrogen dynamic digital twin platform for tea plantation, monitor soil nitrogen distribution in real time and generate fertilizer prescription maps, so as to promote the transformation of tea plantation management into intelligence.

Acknowledgments

Funded projects: Community structure and metabolic footprints of soil nematodes in the Qinba Mountains in response to the northward movement of southern tea (DJNY2024-32).

References

[1] Niu Siyun, Ni Kang, Yi Xiaoyun, et al. Research progress of soil nitrogen loss pathway in tea garden ecosystem [J]. Chinese Journal of Tea, 2020, 61(1):5.DOI:CNKI:SUN:CYKJ.0.2020-01-002.

[2] Tea planting affects soil acidification and nitrogen and phosphorus distribution in soil[J]. Peng Yan;;Chen Shen;;Lichao Fan;;Xin Li;;Liping Zhang;;Lan Zhang;;Wenyan Han.Agriculture, Ecosystems and Environment.2018

[3] Manipulation of nitrogen leaching from tea field soil using a Trichoderma viride biofertilizer[J]. Shengjun Xu;;Sining Zhou;;Shuanglong Ma;;Cancan Jiang;;Shanghua Wu;;Zhihui Bai;;Guoqiang Zhuang;;Xuliang Zhuang.Environmental Science and Pollution Research, 2017 (36)

[4] Soil pH is a good predictor of the dominating N2O production processes under aerobic conditions[J]. Yi Cheng;;Jin-Bo Zhang;;Jing Wang;;Zu-Cong Cai;;Shen-Qiang Wang.Journal of Plant Nutrition and Soil Science.2015

[5] Conversion of open lands to short-rotation woody biomass crops: site variability affects nitrogen cycling and N2O fluxes in the US Northern Lake States[J]. Marin M. Palmer;;Jodi A. Forrester;;David E. Rothstein;;David J. Mladenoff.GCB Bioenergy.2014

[6] Tea plantation destroys soil retention of NO 3 − and increases N 2 O emissions in subtropical China[J]. Tongbin Zhu;;Jinbo Zhang;;Tianzhu Meng;;Yanchen Zhang;;Jiajia Yang;;Christoph Müller;; Zucong Cai.Soil Biology and Biochemistry.2014

[7] Estimation of N2O emission from tea garden soils, their adjacent vegetable garden and forest soils in eastern China[J]. Wenyan Han;;Jianming Xu;;Kang Wei;;Yuanzhi Shi;;Lifeng Ma.Environmental Earth Sciences.2013

[8] Atmospheric dry and wet nitrogen deposition on three contrasting land use types of an agricultural catchment in subtropical central China[J]. Jianlin Shen;;Yong Li;;Xuejun Liu;; Xiaosheng Luo; Hong Tang;;Yangzhu Zhang;;Jinshui Wu.Atmospheric Environment.2013

[9] Annual dynamics of N2O emissions from a tea field in southern subtropical China[J]. Fu X.Q.;; Li Y.;; Su W.J.;; Shen J.L.;; Xiao R.L.;; Tong C.L.;; Wu J..Plant, Soil and Environment.2012

[10] Effects of rainfall and fertilizer types on nitrogen and phosphorus concentrations in surface runoff from subtropical tea fields in Zhejiang, China[J]. Zong'an Liu;;Jingping Yang;;Zhengchao Yang;;Junliang Zou.Nutrient Cycling in Agroecosystems.2012

[11] Nitrous oxide emissions from green tea fields in Japan: contribution of emissions from soil between rows and soil under the canopy of tea plants[J]. Yuhei Hirono;;Kunihiko Nonaka.Soil Science and Plant Nutrition,2012(3)

[12] Nobuharu,KIHOU,Kouichi,et al.Vertical Distribution of Nitrate Nitrogen in Soil Water under Tea Gardens and the Adjacent Forests[J].Japanese Journal of Soil Science and Plant Nutrition, 1991, 62(2):156-164.DOI:10.20710/dojo.62.2_156.

[13] Tokuda, Shin Ichi , and M. Hayatsu . "Nitrous oxide emission potential of 21 acidic tea field soils in Japan." Soil Science and Plant Nutrition 47.3(2001):637-642.

[14] Huang Ying, Li Yaying, YAO Huaiying. Changes of N2O release from strong acid tea garden soil after adding different fertilizer nitrogen [J]. Plant Nutrition and Fertilizer Journal, 2013, 19(6):6. DOI:10. 11674/ zwyf.2013.0631.

[15] Cheng Y , Zhang J B , Wang J ,et al.Soil pH is a good predictor of the dominating N2O production processes under aerobic conditions[J].Journal of Plant Nutrition and Soil Science = Zeitschrift fuer Pflanzenernaehrung und Bodenkunde, 2015, 178(3):370-373.DOI:10. 1002/jpln. 201400577.

[16] Shin-Ichi T , Masahito H .Nitrous Oxide Flux from a Tea Field Amended with a Large Amount of Nitrogen Fertilizer and Soil Environmental Factors Controlling the Flux (Environment) [J].Soil science and plant nutrition, 2004.

[17] Hirono,Nonaka.Nitrous oxide emissions from green tea fields in Japan: contribution of emissions from soil between rows and soil under the canopy of tea plants[J].SOIL SCI PLANT NUTR, 2012, 2012,58(3)(-):384-392.DOI:10.1080/00380768.2012.686434.