

Estimation and Distribution Characteristics Analysis of Ammonia Emissions from Nitro- gen Fertilizer Application in Tianjin Farmland: Postprint

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Abstract

Nitrogen is an essential nutrient element for crop growth. During nitrogen fertilizer application, ammonia volatilization occurs, and ammonia is an important precursor for the formation of inhalable particulate matter. To understand ammonia emissions from nitrogen fertilizer application in Tianjin's farmland and provide technical support for air pollution control in Tianjin, this study estimated ammonia emissions and analyzed their temporal and spatial distribution characteristics during nitrogen fertilizer application in Tianjin's farmland by obtaining the application rates of different nitrogen fertilizer types for different crops in Tianjin, based on the emission factor method recommended by the Ministry of Environmental Protection and the annual average temperature of Tianjin. The results showed that in 2014, ammonia emissions from nitrogen fertilizer application in Tianjin's farmland were 17,999.91 t, with an emission intensity of $3.27 \text{ t} \cdot \text{km}^{-2}$. In terms of nitrogen fertilizer types, urea was the largest emission source, contributing 83.13%, followed by ammonium bicarbonate (13.83%), with other nitrogen fertilizers accounting for 3.04%. Regarding crop types, vegetables were the largest emission source, contributing 38.91%, followed by corn (29.43%) and wheat (19.66%), with other crops accounting for 12.00%. The ammonia emission coefficient exhibited distinct temporal characteristics: high at noon and low at night; highest in August and lowest in January. Among the districts and counties, Wuqing District had the largest ammonia emissions, contributing 27.06%; Jinnan District had the smallest ammonia emissions, contributing 1.14%. Additionally, Baodi District and Ji County also had relatively high ammonia emissions, contributing 20.71% and 17.86%, respectively. Ammonia exhibited strong spatial distribution heterogeneity, with higher emissions in farmland where nitrogen fertilizer was applied and lower emissions in other areas.

Therefore, in controlling ammonia emissions from nitrogen fertilizer application in Tianjin's farmland, scientific application of urea should be strengthened during vegetable cultivation from June–August in districts such as Wuqing, Baodi, and Ji County. The temporal and spatial distribution characteristics of farmland ammonia can provide a scientific basis for the prevention and control of air pollution in Tianjin.

Full Text

Emission and Distribution Characteristics of Ammonia from Nitrogen Fertilizer Application in Tianjin Farmland

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Abstract

Nitrogen is an essential nutrient for crop growth, but its application leads to ammonia volatilization, which is an important precursor to inhalable particulate matter. To understand ammonia emissions from nitrogen fertilizer application in Tianjin and provide technical support for air pollution control, this study estimated ammonia emissions and analyzed their temporal and spatial distribution characteristics based on nitrogen fertilizer usage data for different crops in Tianjin, using the emission factor method recommended by China's Ministry of Environmental Protection and Tianjin's annual average temperature. Results showed that in 2014, ammonia emissions from nitrogen fertilizer application in Tianjin farmland totaled 17,999.91 t, with an emission intensity of $3.27 \text{ t} \cdot \text{km}^{-2}$. By fertilizer type, urea was the largest emission source (83.13%), followed by ammonium bicarbonate (13.83%) and other nitrogen fertilizers (3.04%). By crop type, vegetables were the largest emission source (38.91%), followed by maize (29.43%) and wheat (19.66%), with other crops accounting for 12.00%. Ammonia emission coefficients showed distinct temporal characteristics: higher at noon and lower at night, peaking in August and reaching their minimum in January. Among districts/counties, Wuqing District had the highest emissions (27.06%), while Jinnan District had the lowest (1.14%). Baodi District and Jixian County also showed relatively high emissions, with contribution rates of 20.71% and 17.86%, respectively. Ammonia emissions exhibited strong spatial variability, with higher emissions in farmland receiving nitrogen fertilizer and lower emissions in other areas. Therefore, controlling ammonia emissions from farmland nitrogen fertilizer application in Tianjin should focus on the scientific application of urea during vegetable cultivation in Wuqing, Baodi, and Jixian districts during June–August. The spatiotemporal distribution characteristics of ammonia emissions can provide a scientific basis for air pollution prevention in Tianjin.

Keywords: Ammonia emission; Emission factor; Emission inventory; Agricultural sources; Nitrogen application; Fertilizer type; Crop

Introduction

Nitrogen is an essential nutrient for crop growth and plays an irreplaceable role in ensuring stable and increased agricultural production [1], with different nitrogen application levels affecting crop production [2-3]. However, nitrogen is highly mobile, not easily adsorbed by soil, and prone to loss via water and soil erosion. Studies have shown that the nitrogen use efficiency for grain crops in China is only about 30% [4]. Due to high nitrogen fertilizer input and substantial losses in China [5-6], large amounts of ammonia volatilize into the atmosphere during farmland nitrogen fertilizer application. As a crucial alkaline gas in the atmospheric environment, ammonia plays an important role in atmospheric chemical reactions and aerosol formation. Ammonia is one of the most important precursors to PM_{2.5} [7], and its oxidation can generate secondary pollutants. Additionally, ammonia is a major component of atmospheric acid deposition, causing soil acidification and water eutrophication, which seriously threaten ecological and environmental health.

Foreign studies have shown that nitrogen fertilizer application is an important source of ammonia emissions [8-10]. In China, farmland nitrogen fertilizer application is also a significant ammonia emission source. Dong et al. [11] established a national atmospheric ammonia emission inventory based on emission factors and provincial activity levels from livestock breeding, chemical fertilizer application, chemical production, human respiration and excretion, finding that chemical fertilizer application accounted for 53.53% of total ammonia emissions, making it the largest emission source. After nitrogen fertilizer is applied to farmland, ammonia is emitted to the atmosphere through microbial action or self-decomposition, with major nitrogen fertilizers related to ammonia emissions including urea, ammonium bicarbonate, ammonium chloride, ammonium sulfate, ammonium nitrate, compound fertilizer, and ammonia water. Zhang et al. [12] studied agricultural ammonia emissions in Chongqing's main urban area using locally modified emission factors, finding that fertilizer application was the largest emission source (66.7%), with emissions of 5,660 t and an emission intensity of $1.04 \text{ t} \cdot \text{km}^{-2}$, mainly involving urea, compound fertilizer, and other fertilizers. Dong et al. [13] estimated ammonia emissions for 16 cities in the Yangtze River Delta region, reporting total emissions of 470,700 t, with nitrogen fertilizer application contributing 227,300 t (49.3%) as the largest source, primarily from urea, ammonium bicarbonate, ammonium nitrate, ammonium sulfate, and other fertilizers. Liu et al. [14] established an anthropogenic ammonia emission inventory for Nanjing using the emission factor method, showing that nitrogen fertilizer application was the second-largest source, accounting for 25.98% of total emissions. Numerous scholars have also studied nitrogen fertilizer application in Guiyang [15], Nantong [16], Sichuan Province [17], and other regions.

Research on ammonia emissions from nitrogen fertilizer application can provide theoretical support for controlling air pollution caused by such emissions. However, few studies have focused on ammonia emissions from nitrogen fertilizer application in Tianjin. This study uses the emission factor method, referencing the emission factors and activity level calculation methods specified in the *Technical Guidelines for Compilation of Atmospheric Ammonia Source Emission Inventories (Trial)* issued by the Ministry of Environmental Protection, to estimate ammonia emissions from Tianjin farmland in 2014 and analyze their temporal and spatial characteristics. The results provide a scientific basis for preventing secondary PM_{2.5} formation from ammonia volatilization and offer important technical support for Tianjin's air pollution control efforts.

1.1 Study Area Overview

The study area encompasses the entire Tianjin municipality, including 15 districts (one sub-provincial) and one county, comprising 240 township-level administrative divisions. Tianjin's agriculture is suburban-oriented, primarily distributed in the mountainous and hilly areas of Jixian County in the north and the alluvial plains in front of the mountains, where grain crops and fruit forests are mainly planted. The central-northern alluvial plain region primarily grows dryland grains such as wheat (*Triticum aestivum*) and maize (*Zea mays*). The main nitrogen fertilizers applied include urea, ammonium nitrate, ammonium bicarbonate, and ammonium sulfate. Tianjin has a warm temperate semi-humid monsoon climate with distinct seasons, an annual average temperature of approximately 14 °C, with July and August being the hottest months and January the coldest. Based on the Lambert projection, the entire Tianjin municipality was used as the study area, and a 3 km × 3 km grid was established using ArcMAP. Each grid was identified by the latitude and longitude coordinates of its center point, with the study area containing 1,409 grids.

1.2 Calculation Methods

The emission factor method was used to calculate ammonia emissions from nitrogen fertilizer application, where total ammonia emissions equal the product of activity level and emission factor. The calculation formula is as follows:

Where i represents region (county/district), j represents emission source, y represents year, $E_{i,j,y}$ is the emission from source j in region i in year y , A is the activity level, and f_E is the emission coefficient. Nitrogen fertilizer types (i) mainly include five categories: urea, ammonium bicarbonate, ammonium nitrate, ammonium sulfate, and other nitrogen fertilizers, i.e., $E_{\text{nitrogen fertilizer}} = E_{\text{urea}} + E_{\text{ammonium bicarbonate}} + E_{\text{ammonium nitrate}} + E_{\text{ammonium sulfate}} + E_{\text{other}}$.

Ammonia emissions from nitrogen fertilizer application are closely related to fertilizer application rate, farming practices, and environmental factors. This study used the empirical formula from Shen [18] (Equation 2) to analyze hourly and monthly variation coefficients of ammonia emissions from nitrogen fertilizer

application in Tianjin.

1.3 Emission Factor Data Acquisition

The nitrogen fertilizer emission factor is defined as the mass of ammonia emitted to the atmosphere per unit mass of nitrogen fertilizer applied, expressed in $\text{kg}(\text{NH}_3) \cdot \text{kg}^{-1}$ (nitrogen fertilizer). Due to variations in application rate and method, actual emission factors are typically corrected based on baseline emission coefficients: Actual emission factor = Baseline emission factor \times Application rate correction factor \times Application method correction factor. Baseline emission factors are shown in . For areas with fertilizer application rates exceeding $195 \text{ kg}(\text{N}) \cdot \text{hm}^{-2}$ (converted based on nitrogen contents of 0.47 kg, 0.35 kg, 0.17 kg, and 0.21 kg per kilogram of urea, ammonium nitrate, ammonium bicarbonate, and ammonium sulfate, corresponding to application amounts of 27.66 kg, 37.14 kg, 67.14 kg, 74.47 kg, and 61.90 kg, respectively), the application rate correction factor is 1.18; for other areas, it is 1.0 [11-13,15,17]. Application methods include surface broadcasting and deep incorporation with soil covering. Basal fertilizer application typically uses deep incorporation, while topdressing uses surface broadcasting. The application method correction factor is 0.32 for deep incorporation and 1.0 for surface broadcasting [14-16]. In this study, basal fertilizer application was assumed to use deep incorporation and topdressing used surface broadcasting. Specific emission factors are shown in , sourced from the *Technical Guidelines for Compilation of Atmospheric Ammonia Source Emission Inventories (Trial)* issued by the Ministry of Environmental Protection.

1.4 Activity Level Data Acquisition

Activity level refers to the quantity of production or consumption activities related to atmospheric pollutant (NH_3) emissions within a defined area and time period. The activity level data obtained mainly include nitrogen fertilizer application amounts and annual average temperature. Based on field surveys and the 2014 Tianjin Statistical Yearbook and Environmental Statistics Yearbook, nitrogen fertilizer application amounts were obtained for eight major local crops: soybean (*Glycine max*), rice (*Oryza sativa*), peanut (*Arachis hypogaea*), cotton (*Gossypium* sp.), vegetables, tubers, wheat, and maize, with annual application amounts of $3,503.27 \text{ t} \cdot \text{a}^{-1}$, $9,805.12 \text{ t} \cdot \text{a}^{-1}$, $16,975.32 \text{ t} \cdot \text{a}^{-1}$, $582.09 \text{ t} \cdot \text{a}^{-1}$, $100,919 \text{ t} \cdot \text{a}^{-1}$, $258.67 \text{ t} \cdot \text{a}^{-1}$, $51,006.48 \text{ t} \cdot \text{a}^{-1}$, and $76,328.01 \text{ t} \cdot \text{a}^{-1}$, respectively. Nitrogen fertilizers were categorized into five types: urea, ammonium nitrate, ammonium bicarbonate, ammonium sulfate, and others. The annual average temperature from the 2015 Tianjin Statistical Yearbook was used in emission calculations.

2.1 Ammonia Emissions from Different Nitrogen Fertilizers by District/County in Tianjin

The 2014 ammonia emission inventory from nitrogen fertilizer application in Tianjin districts/counties is shown in . Total ammonia emissions from farmland nitrogen fertilizer application were 17,999.91 t, comprising 14,944.95 t from urea, 2,489.32 t from ammonium bicarbonate, 57.52 t from ammonium nitrate, 313.16 t from ammonium sulfate, and 194.96 t from other nitrogen fertilizers. Urea application was the primary emission source, followed by ammonium bicarbonate. This is mainly because urea application amounts were largest: 101,943.71 t of urea, 35,920.93 t of ammonium bicarbonate, 14,379.78 t of ammonium nitrate, 22,368.57 t of ammonium sulfate, and 84,765.28 t of other nitrogen fertilizers. Although ammonium bicarbonate application was not the highest, its emission factor is relatively large, resulting in greater ammonia volatilization under the same conditions. By district/county, ammonia emissions were 3,727.27 t in Baodi, 782.45 t in Beichen, 544.09 t in Binhai, 288.71 t in Dongli, 3,214.12 t in Jixian, 205.61 t in Jinnan, 1,938.42 t in Jinghai, 1,230.43 t in Ninghe, 4,870.42 t in Wuqing, and 1,198.38 t in Xiqing. Wuqing District had the highest emissions, followed by Baodi District and Jixian County, primarily due to their extensive farmland areas.

2.2 Contribution Rates of Different Nitrogen Fertilizer Types and Crops

[Figure 1: see original paper] shows the contribution rates of ammonia emissions by district/county, nitrogen fertilizer type, and crop. Wuqing District, Baodi District, and Jixian County had the highest contribution rates at 27.06%, 20.71%, and 17.86%, respectively. By fertilizer type, urea contributed the most (83.03%), followed by ammonium bicarbonate (13.83%). By crop type, vegetables, maize, and wheat were the largest contributors at 38.91%, 29.43%, and 19.66%, respectively. These results indicate that controlling ammonia emissions from nitrogen fertilizer application in Tianjin should focus on urea application to vegetables, maize, and wheat in the peri-urban districts of Wuqing, Baodi, and Jixian.

2.3 Daily and Monthly Variation of Ammonia Emissions from Nitrogen Fertilizer Application

The hourly variation coefficients of ammonia emissions on the 15th day of each month are shown in [Figure 2: see original paper]. Although daily variation coefficients differ slightly across months, they generally show higher coefficients at midday and lower coefficients at night, suggesting that ammonia emissions from nitrogen fertilizer application are strongly influenced by temperature. Therefore, implementing ammonia emission control measures at midday would be more effective than at other times.

Monthly variation coefficients of ammonia emissions from nitrogen fertilizer ap-

plication are shown in [Figure 3: see original paper]. Coefficients increased gradually from January to August, then decreased from August to December, with the minimum in January and maximum in August. Coefficients from June to August were significantly higher than in other months, primarily because temperature increased from January to August (peaking in August) then decreased, and because fertilizer application begins in spring, increases in summer, and essentially stops in winter. Therefore, control measures should focus on the June–August period.

2.4 Spatial Distribution Characteristics of Ammonia Emissions from Nitrogen Fertilizer Application

Areas with high ammonia emissions were mainly distributed in northern Jixian, southeastern Baodi, northwestern Wuqing, and central Xiqing [Figure 4: see original paper], primarily to supply agricultural products to urban residents. Low-emission areas were mainly in the central urban districts and coastal Binhai, where farmland is scarce according to Tianjin’s urban planning. Therefore, ammonia emission control should target these high-emission areas.

3.1 Comparison with Other Studies

This study estimated total ammonia emissions from nitrogen fertilizer application in Tianjin in 2014 at 17,999.91 t, with an emission intensity of $3.27 \text{ t} \cdot \text{km}^{-2}$. Zhang et al. [19] reported agricultural ammonia emissions of 25,200 t from the North China Plain in 2004. Dong et al. [11] estimated Tianjin’s farmland nitrogen fertilizer ammonia emissions at 35,600 t in 2006. Zhou et al. [20] reported 30,700 t for the Beijing-Tianjin-Hebei region in 2010. Our results are consistent in magnitude with these studies but somewhat lower, primarily due to continued urbanization in Tianjin in recent years, which has reduced farmland area.

Comparison with studies from Chongqing’s main urban area, the Yangtze River Delta, Taiyuan, and Guangdong shows that Tianjin’s ammonia emissions are higher than Chongqing and Taiyuan but much lower than the Yangtze River Delta and Guangdong, with similar patterns in emission intensity. This indicates that Tianjin’s nitrogen fertilizer application level is moderate nationally—lower than economically developed regions but higher than average. Regarding crop contribution rates, Liu et al. [14] found for Nanjing: rice (53.30%), wheat (25.46%), and rapeseed (*Brassica campestris*) (21.24%). Our results show: vegetables (38.91%), maize (29.43%), wheat (19.66%), peanut (6.54%), rice (3.78%), soybean (1.35%), cotton (0.22%), and tubers (0.10%). These differences mainly reflect variations in crop planting structures between Tianjin and Nanjing.

3.2 Uncertainty Analysis

This study used emission factors from the national *Technical Guidelines for Compilation of Atmospheric Ammonia Source Emission Inventories*, which provide recommended values. However, actual emission factors in Tianjin likely dif-

fer from these recommendations, introducing some uncertainty. Activity level data were primarily obtained from the *2015 Tianjin Statistical Yearbook* and some published academic papers. While these data are reliable, some were derived through indirect calculations rather than direct measurement, also introducing uncertainty.

Conclusion

This study estimated that ammonia emissions from nitrogen fertilizer application in Tianjin farmland totaled 17,999.91 t in 2014, with an emission intensity of $3.27 \text{ t} \cdot \text{km}^{-2}$. Urea contributed 83.13% of emissions from nitrogen fertilizer application, making it the largest source. Among crop types, vegetables contributed 38.91%, representing the largest emission source. Temporal characteristics showed higher emissions at noon and lower emissions at night, peaking in August and reaching a minimum in January. Spatially, Wuqing District had the highest emissions, followed by Baodi District and Jixian County, while the six central urban districts and Binhai New Area had lower emissions. Controlling ammonia emissions from nitrogen fertilizer application in Tianjin should focus on scientific urea application during vegetable cultivation in Wuqing, Baodi, and Jixian districts during June-August.

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