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# Ammonia volatilization from a Chinese cabbage field under different nitrogen treatments in the Taihu Lake Basin, China

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ABSTRACT

Ammonia ($NH_3$) volatilization is a major pathway of nitrogen (N) loss from soil-crop systems. As vegetable cultivation is one of the most important agricultural land uses worldwide, a deeper understanding of $NH_3$ volatilization is necessary in vegetable production systems. We therefore conducted a 3-year (2010–2012) field experiment to characterize $NH_3$ volatilization and evaluate the effect of different N fertilizer treatments on this process during the growth period of Chinese cabbage. Ammonia volatilization rate, rainfall, soil water content, pH, and soil $NH_4^+$ were measured during the growth period. The results showed that $NH_3$ volatilization was significantly and positively correlated to topsoil pH and $NH_4^+$ concentration. Climate factors and fertilization method also significantly affected $NH_3$ volatilization. Specifically, organic fertilizer (OF) increased $NH_3$ volatilization by 11.77%–18.46%, compared to conventional fertilizer (CF, urea), while organic–inorganic compound fertilizer (OIF) reduced $NH_3$ volatilization by 8.82%–12.67% compared to CF. Furthermore, slow-release fertilizers had significantly positive effects on controlling $NH_3$ volatilization, with a 60.73%–68.80% reduction for sulfur-coated urea (SCU), a 71.85%–78.97% reduction for biological Carbon Power® urea (BCU), and a 77.66%–83.12% reduction for bulk-blend controlled-release fertilizer (BBCRF) relative to CF. This study provides much needed baseline information, which will help in fertilizer choice and management practices to reduce $NH_3$ volatilization and encourage the development of new strategies for vegetable planting.


## Introduction

Nitrogen (N) fertilizer is the most widely used fertilizer worldwide and the primary N input source in soil-crop systems. It plays an important role in increasing crop yields to meet the food demands of a growing global population. However, the excessive use of N fertilizer for crop production can cause substantial N losses through surface runoff, leaching, and gaseous emissions of ammonia ($NH_3$) and nitrous oxide ($N_2O$) (Alva et al., 2006; Duretz et al., 2011).

Ammonia volatilization is one of the major N loss pathways from N fertilizer application (Harrison and Webb, 2001). Agricultural activities reportedly contribute up to 90% of the total $NH_3$ emissions to the atmosphere (Boyer et al., 2002; Misselbrook et al., 2000), with the majority coming from livestock production and 12% resulting from N fertilizer application (Ferm, 1998). Approximately 15%–40% of farmland N application is lost through ammonia volatilization, equivalent to 20%–70% of total farmland N loss (Chien et al., 2009; Harrison and Webb, 2001). Ammonia volatilization negatively

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affects environmental quality, whereby $NH_3$ that is dissipated into the atmosphere reacts with atmospheric acids to form fine aerosols (Huckaby et al., 2012), or deposits return to the ground to cause soil acidification (Van der Eerden et al., 1998). Emitted $NH_3$ also becomes a secondary production source of $N_2O$, a major greenhouse gas (Sutton et al., 2008).

Ammonia volatilization is influenced by environmental factors such as soil pH, moisture, and texture, as well as air temperature, light, wind speed, and precipitation (Bouwmeester et al., 1985; He et al., 1999; Sommer and Ersboll, 1996). Furthermore, planting and management factors also affect $NH_3$ emissions; for example, the use of different types of N fertilizer and application methods, irrigation, and crop rotation systems (Holcomb et al., 2011; Xu et al., 2012; Zaman et al., 2009).

Different types of fertilizer have different effects on $NH_3$ volatilization from crop-soil systems. Urea is one of the most widely used N fertilizers worldwide because of its high N concentration. Indeed, $NH_3$ volatilization from urea accounts for approximately 10–35% of N applied in field crop planting (Christianson, 1989; Fan et al., 2005; Soares et al., 2012). A previous study found that four different N fertilizers each resulted in differing levels of $NH_3$ volatilization loss (% of N applied) $(NH_4)HCO_3 > (NH_4)_2SO_4 > CO(NH_2)_2 > NH_4NO_3$ (He et al., 1999). The application of composted manure may promote $NH_3$ volatilization in crop-soil systems, mainly due to the high pH of compost manure (Matsushima et al., 2009; Paramasivam et al., 2009). In addition to the benefits of slow-release N fertilizers for increasing crop yield or N absorption and utilization, studies have begun to focus on the consequential environmental effects of such fertilization. Rao (1987) found that sulfur-coated urea was effective in reducing $NH_3$ volatilization losses from 16.9% to 3.4% of N applied in paddy fields. Knight et al. (2007) reported that $NH_3$ volatilization from slow-release sources (dehydrated sewage sludge, sulfur-coated urea, polymer-coated urea, and methylene urea) was significantly reduced compared with that observed from surface-applied urea on creeping bent grass. Blaise and Prasad (1995) indicated that $NH_3$ volatilization loss from polymer-coated urea accounted for 7.6% of N applied, which was 11.6% lower than that observed using commercial prilled urea in paddy fields.

The Taihu Lake region is one of the most densely populated and intensively farmed areas in China. Vegetable fields are among the most important agricultural land uses in the Taihu Lake region, and are distinguished by their short growth cycle, high multiple cropping index, large N fertilizer demand, and substantial nonpoint source pollution (De Neve and Hofman, 1998). The average N fertilizer application for vegetables in the Taihu Lake region ranges from 300 to 700 kg N/ha per growing season but can even reach 3000 kg N/ha, more than 10 times the actual crop demand (Wu et al., 2011; Yan et al., 2010). Besides causing $NH_3$ volatilization, excess N fertilizer also results in nutrient imbalance for crops, excess nitrate content, and other environmental problems (Zhang et al., 2004).

Previous studies on the environmental effects of excessive N fertilizer application have focused on field crops (*e.g.*, rice, wheat, and corn), rather than vegetables, particularly when studying $NH_3$ volatilization. However, vegetable crops comprise a large percentage of agricultural production, and in China, the Chinese cabbage (*Brassica rapa* L. subsp. *pekinensis* (Lour.)) is one of the most important cultivated vegetables, reaching a planting area of $2.67 \times 10^6$ ha in 2010 (Zhang and Li, 2011). Thus, understanding the interaction of N fertilizer treatments and $NH_3$ volatilization in a vegetable-soil system is crucial for agronomic output.

We therefore conducted this study to evaluate and characterize $NH_3$ volatilization in a Chinese cabbage field subjected to different N fertilizer treatments over a 3-year period. Our results should prove useful in reducing $NH_3$ volatilization and improving fertilizer application strategies for vegetable planting.

## 1. Materials and methods

### 1.1. Site description

The experimental site was situated in the Taihu basin of China, at a vegetable production base of Hangzhou Yuhang Mengyuan Agricultural Science and Technology Co., Ltd. (30°21.57′′, 119°54.19′′E), which has been used for vegetable production since 2006. Experiments were conducted from September to December (Chinese cabbage growth period) of 2010–2012. The region has a subtropical monsoon climate, with an average annual air temperature of 15.8°C, and an annual precipitation of approximately 1200–1500 mm, mostly occurring between June and September. The cultivated soil for this study is classified as yellow-brown soil. The main properties of the soil in the top 20 cm layer at the start of the experiment were as follows: pH, 5.45 (1:5, soil/water); total N, 1.67 g/kg; total P, 2.39 g/kg; organic matter (OM), 25.73 g/kg; and bulk density, 1.29 g/cm$^3$.

### 1.2. Experimental design

Seven different fertilizer treatments were applied for comparison: (1) no fertilizer (CK); (2) organic fertilizer (OF; Chn-agri Jiangsu Fertilizer Co., Ltd., Nanjing, China), a commercial organic fertilizer, granulated, containing 1.53% N (pH, 8.53), with poultry litter as the main component; (3) conventional fertilizer (CF; Chn-agri Jiangsu Fertilizer Co., Ltd., Nanjing, China), using urea as an N fertilizer, containing 46% N; (4) organic–inorganic compound fertilizer (OIF; Zhejiang University and Zhejiang Academic of Agricultural Sciences, Hangzhou, China), a specific fertilizer for leaf vegetables, granulated, containing 13% N, composed of urea (46% N), diammonium phosphate (DAP, 16% N), potassium chloride, and organic fertilizer (1.5% N), with 90% inorganic N and 10% organic N; (5) sulfur-coated urea (SCU; Hanfeng Slow-release Fertilizer Co., Ltd., Taizhou, China), with sulfur-coated and microcrystalline wax acting as surface sealant, containing 37% N; (6) biological Carbon Power® urea (BCU; Hanfeng Slow-release Fertilizer Co., Ltd., Taizhou, China), a new type of slow-release urea covered with Carbon Power synergistic agents (CP), which is extracted from natural plants, contains more than 2000 types of Carbon Power active agents, and has 46% N; (7) bulk-blend controlled-release fertilizer (BBCRF; Hanfeng Slow-release Fertilizer Co., Ltd., Taizhou, China), a specific slow-release fertilizer for leaf vegetables, N supplied by SCU and BCU, containing 17% N. A randomized complete block design, including all seven treatments and three replications, was established in 21 plots of 21 m$^2$ (3.5 × 6 m) each.