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Effect of application of dairy manure, effluent and inorganic fertilizer on nitrogen leaching in clayey fluvo-aquic soil: A lysimeter study

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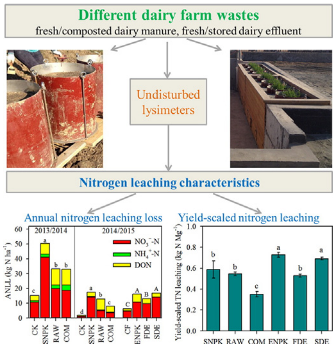
HIGHLIGHTS

- Application of dairy farm manure and effluent or inorganic fertilizer raises concerns on groundwater quality.
- NO_3^- contributed 34–92% of total N leaching loss, followed by DON (14–57%).
- Annual N leaching from inorganic N fertilizer treatment was the highest among treatments.
- Yield-scaled N leaching of composted manure was the lowest among the treatments.
- Use of composted manure could reduce N leaching loss while ensuring high crop yield.

GRAPHICAL ABSTRACT



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ABSTRACT

Dairy farm manure and effluent are applied to cropland in China to provide a source of plant nutrients, but there are concerns over its effect on nitrogen (N) leaching loss and groundwater quality. To investigate the effects of land application of dairy manure and effluent on potential N leaching loss, two lysimeter trials were set up in clayey fluvo-aquic soil in a winter wheat-summer maize rotation cropping system on the North China Plain. The solid dairy manure trial included control without N fertilization (CK), inorganic N fertilizer (SNPK), and fresh (RAW) and composted (COM) dairy manure. The liquid dairy effluent trial consisted of control without N fertilization (CF), inorganic N fertilizer (ENPK), and fresh (FDE) and stored (SDE) dairy effluent. The N application rate was 225 kg N ha^{-1} for inorganic N fertilizer, dairy manure, and effluent treatments in both seasons. Annual N leaching loss (ANLL) was highest in SNPK (53.02 and 16.21 kg N ha^{-1} in 2013/2014 and 2014/2015, respectively), which were 1.65- and 2.04-fold that of COM, and 1.59- and 1.26-fold that of RAW. In the effluent trial (2014/2015), ANLL for ENPK and SDE (16.22 and 16.86 kg N ha^{-1}, respectively) were significantly higher than CF and FDE (6.3 and 13.21 kg N ha^{-1}, respectively). NO_3^- contributed the most (34–92%) to total N leaching loss among all treatments, followed by dissolved organic N (14–57%). COM showed the lowest N leaching loss due to a reduction in NO_3^- loss. Yield-scaled N leaching in COM (0.35 kg N Mg^{-1} silage) was significantly ($P < 0.05$) lower than

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that in the other fertilization treatments. Therefore, the use of composted dairy manure should be increased and that of inorganic fertilizer decreased to reduce N leaching loss while ensuring high crop yield in the North China Plain.

1. Introduction

The winter wheat-summer maize rotation is an important cropping system used on the North China Plain (NCP), which contributes approximately 48% of the total wheat production and 39% of the total maize production in China (China Statistical Year Book, 2015). This intensive cropping production system is frequently treated with large amounts of inorganic nitrogen (N) fertilizer to produce high crop yields and increase profits (Zhu and Chen, 2002; Yang et al., 2015). However, <30% of the applied inorganic N is used by the crops (Cai et al., 2002; Ju et al., 2009), resulting in a significant amount of N loss to the environment.

Alongside the rapid growth and intensification of dairy farming in China due to the increasing demand for high quality milk (Li, 2009), there has been an increase in the production of dairy farm manure and effluent, and their application to agricultural land. The amount of organic N, including manure N, applied to wheat-maize rotation fields reached 74 kg N ha^{-1} yr^{-1} on the NCP in the past two decades (Pei et al., 2015). Dairy farm manure and effluent contain valuable plant nutrients, such as N, phosphorus (P), potassium (K), and sulfur (S). When applied to land, they generally improve soil fertility and increase the resource use efficiency of farming systems (Goss et al., 2013; Maillard and Angers, 2014). However, there are environmental concerns associated with the land application of manure and effluent, including N leaching, ammonia (NH_3) volatilization, and nitrous oxide (N_2O) emission (Korsaeth and Eltun, 2000; Bolan et al., 2004; Luo et al., 2008; Zhou et al., 2014). A survey of groundwater NO_3^--N concentrations showed that up to 55% of 394 groundwater samples on the NCP exceeded the WHO drinking water standard of 11.3 mg N L^{-1} for NO_3^--N (Chen et al., 2010). The presence of NO_3^--N in groundwater has severely lowered the quality of the water resources on the NCP (Hu et al., 2005; Jia et al., 2014). N leaching loss from cropland can also cause surface water eutrophication (Dinnes et al., 2002; Ju et al., 2009; Valkama et al., 2015; Gu et al., 2016).

The impact of different N sources on N leaching is not yet clear, because the N dynamics in soil and its leaching to groundwater are affected by a complex set of interrelationships between rainfall patterns (Fang et al., 2013), irrigation (Jamali et al., 2015), fertilizer type and rates (Zhang et al., 2015; Demurtas et al., 2016), and soil type and cropping systems (Barros et al., 2012; Jabloun et al., 2015). The amount of N leaching significantly increases with the inorganic N application rate (Mack et al., 2005; Yang et al., 2015; Zhang et al., 2015; Gu et al., 2016). However, the reported results on the effects of organic amendment on N leaching are inconsistent. The application of solid animal manure has been widely reported to increase N use efficiency and decrease NO_3^--N leaching loss compared with the application of inorganic N fertilizer alone (Daudén and Quilez, 2004; Zavattaro et al., 2012; Zhou et al., 2014). However, Shepherd and Newell-Price (2013) reported that annual application of farmyard manure increased NO_3^- leaching on average by 39% more than the application of inorganic fertilizer during a 7-year study period in loamy sand soil in England. Other studies have also reported a higher potential risk of NO_3^- leaching when solid manure was applied at an inappropriate time or in soil with high soil organic matter (Beckwith et al., 1998; Chambers et al., 2000; Chalmers, 2001; Yan et al., 2002). Liquid dairy effluent has been recommended for land use in many countries for its rapid nutrient availability, high resource use efficiency, and potential benefit on soil organic carbon (SOC) (Wang et al., 2004; Li et al., 2014; Maillard et al., 2016). Experiments in an Italian high yield maize cropping system showed that the NO_3^- leaching loss from the application of slurries could be reduced by 30–50% compared with urea application (Zavattaro et al., 2012). However, it was also recognized that NO_3^- leaching could be a serious problem when liquid effluents are used (Chambers et al., 2000; Giola et al., 2012). For example, an increase in NO_3^- leaching by 15–34% was observed under liquid slurry application compared with inorganic fertilization from a 5-year field experiment on sandy soil in Sweden (Torstensson and Aronsson, 2000). These inconsistent results suggest that further studies are needed to develop site-specific sustainable fertilization management options for mitigating N leaching loss (Zavattaro et al., 2012; Demurtas et al., 2016).

The objective of this study was to evaluate the effects of dairy manure and effluent on N leaching under field conditions in a wheat-maize rotation system on the NCP using undisturbed drainage lysimeters from 2013 to 2015.

2. Materials and methods

2.1. Site description

The field experiment was conducted on a typical cropland with an annual rotation of winter wheat (*Triticum aestivum* L.)-summer maize (*Zea mays* L.) in Yutian County, Hebei Province, China (39°45′29″N, 117°37′48″E). The mean annual temperature, calculated for the past 30 years, is 11.3 °C, and the lowest and highest mean monthly values are −6.4 °C in January and 25.2 °C in July, respectively. The mean annual precipitation is 693 mm, with most of the rainfall occurring from July to September. The soil, developed on alluvial sediments of the Yellow River and classified as aquic inceptisol under the U.S. soil taxonomy, has a clayey texture. Soil properties are shown in Table S1.

2.2. Experimental design

Two field experiments were conducted using lysimeters (intact soil columns). The dairy manure experiment, conducted from October 2013 to September 2015, included four treatments: a control without N fertilization (CK), inorganic fertilizer NPK (SNPK), fresh manure plus fertilizer N (RAW), and composted manure plus fertilizer N (COM). To determine the effect of dairy effluent on N leaching, a dairy effluent trial was carried out from October 2014 to October 2015 using four treatments: a control without N fertilization (CF), inorganic fertilizer NPK (ENPK), fresh dairy effluent plus fertilizer N (FDE), and stored dairy effluent plus fertilizer N (SDE). Four replicates of each treatment were laid out in a randomized block design. The winter wheat (cultivar Lunxuan 987) and summer maize (cultivar Pioneer Xianyu 688) were directly seeded to a 5-cm depth. Seeds were sown at rates of 45 g m^{-2} for wheat and 7.5 plants per m^{-2} for maize, as per local recommendation. The winter wheat was seeded in late October and harvested in early June, while the summer maize was planted in late June and harvested in late September. Weeds were removed by hand. The N application rate for each crop was 225 kg N ha^{-1}, which is a typical N level in the study region, with a basal and supplemental fertilizer ratio of 1:1. The application rate of phosphorus (P) and potassium (K) for each crop was 75 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1}, respectively. The amount of P and K in the manure and effluent were generally less than the prescribed doses, and superphosphate and potassium sulfate were therefore supplemented in these treatments. All P, K, and manure, or effluent, were applied as basal fertilizers, whereas urea was added in two applications as both the basal and supplementary fertilizer in the