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Effects of maize residue return rate on nitrogen transformations and gaseous losses in an arable soil

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ABSTRACT

Residue return in combination with synthetic nitrogen (N) fertilizer is increasingly being considered to be beneficial to soil fertility and crop yield. In most studies, however, attention has mainly been paid to the way that significant changes in the soil N mineralization process affect the soil N cycle, while the effect of different residue return amounts on ammonia (NH_3) volatilization and nitrous oxide (N_2O) emissions, potentially the most important components of N losses and environmental effects has, to a certain extent, been neglected, notably in north-eastern China. Therefore, a trial was set up in an Alfisol/arable soil during 2015–2016 to monitor annual NH_3 volatilization and N_2O emission dynamics from a fertilized maize field with residue return at different rates. Treatments included N fertilizer alone and N fertilizer in combination with either half or the full yield of the maize residue (5.8×10^3 or 11.6×10^3 kg ha^{-1}, respectively) returned to the soil surface after harvest.

Over a growing season of maize, the NH_3 volatilization loss rate from the full residue return treatment was 4.6%, which was significantly lower than that in the N fertilizer application only and half residue return plots (6.1%). Meanwhile, residue return rates showed a significant effect on annual N_2O emissions from the maize system. Half residue return increased N_2O emission (921.1 g N·ha^{-1}), while full residue return marginally decreased N_2O emissions (862.6 g N·ha^{-1}) during the maize growing season, compared to the fertilizer-only treatment (881.2 g N·ha^{-1}) ($P < 0.05$). In spite of the fact that N_2O emissions in the non-growing season increased with the quantity of maize residue applied, the return of the full yield of maize residue to the soil could reduce both annual NH_3 and annual N_2O losses and increase soil total N and C storage after long-term use. It is suggested that residue application rate is a key factor when assessing residue benefits but the influence is in a nonlinear pattern. The combined application of full maize residue and synthetic N fertilizer is a promising N management strategy for mitigating gaseous N emissions.

1. Introduction

Ammonia (NH_3) and nitrous oxide (N_2O) in the atmosphere significantly influence the environment at both regional and global scale. Ammonia, the most abundant alkaline constituent in the atmosphere, regulates atmospheric acidity (Brasseur et al., 1999) and soil acidification (Roclofs et al., 1987). N_2O is an important anthropogenic greenhouse gas, contributing to global warming and the depletion of stratospheric ozone (IPCC, 2007; Ravishankara et al., 2009). Agricultural fields have become one of the major anthropogenic sources for atmospheric NH_3 and N_2O, mainly from fertilization and related management. Therefore, there is a need to ensure that fertilizers are managed in ways that minimize environmental effects (Khalil et al., 2006; Li and Wang, 2008). Simultaneous measurement of the two gaseous N compounds can provide valuable information about their formation processes and contributions to air and environmental pollution (Vinten et al., 2002; Tahovská et al., 2013). Emissions of these two gases are significantly influenced by agricultural management such as crop residue return, which is increasingly being considered to be beneficial to soil fertility and crop yield.

As one of the practical ways of returning crop residue, large amounts may be left on the soil surface in the cropping system and this may affect soil temperature and moisture, soil N content, dissolved organic carbon (DOC) content, and microbial activity; and therefore

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affect the soil N_2O emissions in a complex manner (Yao et al., 2009; Liu et al., 2011). Some studies have reported that covering soil with crop residues may stimulate N_2O production, as crop residue decomposition provides substrates for nitrifiers/denitrifiers and promotes anaerobic conditions for denitrification (Huang et al., 2013). Nevertheless, in other studies the residue cover has been shown to reduce, or have no significant effect on, N_2O emissions, since microorganisms degrading residues with a high C:N ratio compete with nitrifiers/denitrifiers for available N (Malhi et al., 2006; Ma et al., 2007). The above complexity means that crop residues have no consistent effect on N_2O emissions under field conditions, which are affected not only by site-specific conditions (e.g. soil physical and chemical properties, climate and management practices) but also by quality (e.g. C:N ratios) and quantity of crop residue, even at the same site (Shan and Yan, 2013; Chen et al., 2013). The C:N ratio may affect N_2O emissions by altering the microbial nitrogen use efficiency (Mooshammer et al., 2014; Liang et al., 2015). The addition of residue will intensify the competition for NH_4^+ between nitrification and microbial immobilisation, which will determine the N_2O losses. The effect of the combined application of crop residues with inorganic fertilizer on N_2O emissions is, therefore, worth investigating further.

Previous studies have indicated that when soil pH, soil carbonate content, or fertilizer N application rates are high, the NH_4^+ concentration in the soil and its volatilization as NH_3 increase (Friedel and Gabel, 2001). Therefore, factors such as residue quantity and quality, incorporation timing, fertilizer application, soil properties, and climate conditions must be considered when evaluating the impacts of crop residue on NH_3 emissions (Liu et al., 2011; Huang et al., 2013). However, few studies regarding the effect of residue mulching on soil NH_3 volatilization have been reported (Velthof et al., 2002; Pul et al., 2008) and the effects of application of residue on the emissions of both NH_3 and N_2O are not clear.

An experiment was established at a typical maize field in northeastern China to assess the effects of residue return on N transformations and gaseous N losses. The objectives of this study were (1) to monitor the changes in soil physicochemical characteristics and N dynamics after residue and fertilizer amendment; (2) to assess the effects of different application rates of residue return on NH_3 volatilization and N_2O emission from the experimental plots over one year.

2. Materials and methods

2.1. Site and soil description

The field experiment was conducted in Shenyang Experimental Station of Ecology of the Chinese Academy of Sciences (41°32N' latitude, 123°23′E longitude) in Liaoning province, northeastern China. The weather at the site is typical of a temperate and humid continental monsoon climate. The mean annual temperature is 7.0–8.0 °C, with 147–164 frost-free days, and the mean annual precipitation is approximately 700 mm. The soil at the experimental site is classified as Alfisol (Soil Taxonomy) or Luvisol (World Reference Base), the main soil type for agricultural production in the region. Soil texture at 0–20 cm depth is silt loam (sand 289.1 g kg^{-1}, silt 501.1 g kg^{-1}, clay 203.8 g kg^{-1}). The top 20 cm of the soil had the following properties: pH of 5.5, soil organic carbon (SOC) of 12.3 g kg^{-1}, total nitrogen (TN) of 1.13 g kg^{-1}, total phosphorus (TP) of 0.44 g kg^{-1}, total potassium (TK) of 16.4 g kg^{-1}, soil available N (AN) of 97.3 mg kg^{-1}, available P (AP) of 10.6 mg kg^{-1} and available K (AK) of 88.0 mg kg^{-1}. At this site maize (*Zea mays* L.) is planted annually in April at a mean density of 57,700 plants ha^{-1} and harvested in late September.

2.2. Experimental design and field management

The experiment was arranged in a randomized design with three replicates. Micro-plots (1.6 m × 1.3 m) were randomly placed in the field at distances of approximately 3 m apart. The micro-plots were surrounded by poly-vinyl-chloride (PVC) boards that had an above ground height of 10 cm and were pressed into the soil to a depth of 50 cm. Maize was sown at a density of 12 plants $plot^{-1}$.

Three treatments were included in this study. Treatment 1 (T1): Ammonium sulphate ($(NH_4)_2SO_4$) applied at a rate of 200 kg N ha^{-1} yr^{-1}. Treatment 2 (T2): $(NH_4)_2SO_4$ (200 kg N ha^{-1}) combined with 50% of the maize residue after harvesting returned to the soil (5.8×10^3 kg ha^{-1}). Treatment 3 (T3): $(NH_4)_2SO_4$ (200 kg N ha^{-1}) combined with 100% of the maize residue after harvesting returned to the soil (11.6×10^3 kg ha^{-1}). The fertilizer application rate of 200 kg N ha^{-1} was chosen because this was the rate commonly used by local farmers. In order to increase the use efficiency of the applied N fertilizer the $(NH_4)_2SO_4$ was applied in three applications: 50 kg N ha^{-1} as the basal fertilizer before seeding, 100 kg N ha^{-1} as the first topdressing at the jointing stage of the maize growth and 50 kg N ha^{-1} as the second topdressing at the silking stage. In addition, P and K fertilizers, as KH_2PO_4 and K_2SO_4 in the form of pellets, were applied at 30 kg P ha^{-1} and 58 kg K ha^{-1} at the sowing stage for all treatments (Lü et al., 2013). Seedbeds for each plot were prepared manually with minimal disturbance to the soil, and the basal fertilizers were incorporated into the topsoil (0–10 cm) prior to maize sowing. After seed sowing, maize residue was applied onto the surface of the plots after being cut into 10 cm pieces. The maize residue annual average yield was 11.6 Mg ha^{-1} with C of 5014 kg C ha^{-1} and N of 96.6 kg N ha^{-1}. The plots were manually weeded, and the weeds were left on the surface of the plot (Hu et al., 2015).

2.3. Soil sampling and measurement

Soil samples were collected on four occasions (sowing, jointing and silking stages of maize growth and after maize harvest) from each plot at depths of 0–10, 10–20, 20–40, and 40–60 cm. Three individual samples at each soil layer were taken with a 3-cm-diameter soil auger and then thoroughly mixed by hand to obtain individual bulked plot soil samples. The mineral N content (NH_4^+-N and NO_3^--N) was measured by sieving some of the fresh soil (< 2 mm) and extracting with 2 M KCl. The extracts were analysed using the MgO-Devarda's alloy distillation method. The remainder of the sample was air-dried, all visible roots and un-decomposed residue were removed, and then the samples were milled in a rolling drum sieve to < 0.15 mm. A 20 g sample was oven-dried at 105 °C for 24 h to determine soil-water content and to calculate the water-filled pore space (WFPS). The total N and organic C of the soil samples were determined by combustion with an elemental analyzer (Model CN, Vario Macro Elemental Analyser System, GmbH, Germany).

2.4. Ammonia sampling and measurement

Ammonia volatilization was measured using a modified vented-chamber method, similar to that used by Wang et al. (2004). The vented chamber was made of gray round PVC tube (15 cm internal diameter and 12 cm high). Two pieces of round sponge (16 cm in diameter and 2 cm in thickness) were put into each chamber after being moistened with 15 ml of phosphate/glycerol solution (50 ml analytical phosphate and 40 ml glycerol diluted to 1000 ml with pure water). Since the volume of the solution only accounted for 3.7% of the volume of the sponge, the sponge was still ventilative after being moistened. One sponge was fitted inside the chamber 5 cm away from the soil surface and used to absorb NH_3 volatilized from the soil. The second sponge was fitted inside the top of the chamber for absorbing any NH_3 from ambient air that entered the chamber through the vent. Glycerol in the sponges was to absorb moisture from the air to prevent the sponges from drying out.

In the field, four sets of the vented-chamber devices were evenly placed at different locations in each plot in the way described above.