Soil & Tillage Research 180 (2018) 259–267

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Long-term fertilization on nitrogen use efficiency and greenhouse gas emissions in a double maize cropping system in subtropical China

Daniel Afreh[a,1], Jun Zhang[a,1], Dahai Guan[b], Kailou Liu[c], Zhenwei Song[a], Chengyan Zheng[a], Aixing Deng[a], Xiaomin Feng[a], Xin Zhang[a], Yan Wu[c], Qianru Huang[c,*], Weijian Zhang[a,*]

[a] *Institute of Crop Science, Chinese Academy of Agricultural Sciences/ Key Laboratory of Crop Physiology and Ecology, Ministry of Agriculture, Beijing, 100081, China*
[b] *Rural Energy and Environment Agency, Ministry of Agriculture, Beijing, 100125, China*
[c] *National Engineering and Technology Research Center for Red Soil Improvement, Jiangxi Institute of Red Soil, Nanchang, 331717, China*

ARTICLE INFO

Keywords:
Soil fertility management
Nitrogen use efficiency
N_2O emission
Global warming potential
Maize

ABSTRACT

Fertilizer application often significantly affects soil quality and crop productivity, thus, can affect soil greenhouse gas (GHG) emissions and nitrogen use efficiency (NUE) as well. However, the impacts have not been well documented under double maize cropping system in subtropical China. Based on a thirty-year field experiment with five fertilization treatments (i.e. no fertilizer (CK), organic manure (OM), N, NPK and NPK plus OM (NPKM)), maize cultivar (Yedan 13) was planted both at the early maize season and late maize season, we assessed the impacts of different fertilizer application on nitrous oxide (N_2O) and methane (CH_4) emissions, grain yield and NUE. Compared to the NPK, manure application (i.e. OM and NPKM) significantly increased N_2O emissions, and maize yield. Nevertheless, there was no significant difference in yield–scaled global warming potential (GWP) among NPK, OM, and NPKM. Manure application increased soil pH, soil organic carbon, and soil total N, suggesting it can improve soil quality. The NPKM treatment had the highest N uptake, but in terms of NUE, it was lower than OM, due to double N application. Our results suggest that manure application can compensate its negative impacts on N_2O emission through improving soil quality, maize yield and N use efficiency.

1. Introduction

Maize (*Zea mays* L.) is currently the most important crop with more than 200 million metric tons per annum in China (Niu et al., 2013; He and Zhou, 2016), as well as in the tropics and subtropics (Sorkhi and Fateh, 2014). Although, sustainability of high crop yield under intensive cultivation is possible only through the use of chemical fertilizer (Ma et al., 2014), it has been estimated that over 50% of the nitrogen applied to the soil is usually lost through leaching, denitrification, volatilization and soil erosion (Abbasi et al., 2013). These losses have adverses effects on the environment, ecosystem functions, biodiversity and human health (Godinot et al., 2016). Therefore, improving nitrogen use efficiency (NUE) and limiting nitrogen fertilizer use are necessary for improving environment health and promoting sustainable maize production.

The evaluation of NUE is a commonly used in determining the fate of nitrogen fertilizers and their role in improving crop yields. Increasing NUE requires innovative crop and soil management practices that would maximize crop nitrogen uptake, minimize nitrogen losses, and optimize indigenous soil nitrogen supply (Cassman et al., 2002; Ladha et al., 2005). The form or the source of nitrogen fertilizers plays a vital role in regulating nitrogen transformations, changing nitrogen loss patterns and influencing NUE which eventually affects grain yield (Abbasi et al., 2013). For instance, Hernandez-Ramirez et al. (2011) showed that source of nitrogen contributes significantly to nitrogen uptake and utilization with urea-ammonium nitrate more efficiently utilized by maize as compared to liquid swine manure (C/N ratio: 2:1, 80% of N as NH_4^+). Also, application of manure significantly increased NUE in maize-wheat rotation system as compared to chemical fertilizer (Duan et al., 2014). Maize yield and soil fertility were also optimized with the addition of manure (Wang et al., 2017). These findings suggest that manure application plays a critical role in enhancing NUE in maize cropping systems.

Manure application could significantly increase nitrous oxide (N_2O) emission via nitrification and denitrification (Ding et al., 2007; Jarecki et al., 2008; Smith et al., 2012). Zhai et al. (2011) reported that manure

---

[*] Corresponding authors.
E-mail addresses: danafreh@yahoo.co.uk (D. Afreh), qianruhuang@163.com (Q. Huang), zhangweijian@caas.cn (W. Zhang).
[1] These authors contributed equally to this study.

https://doi.org/10.1016/j.still.2018.03.016
Received 1 September 2017; Received in revised form 18 March 2018; Accepted 21 March 2018

significantly stimulated N_2O emission in a maize-wheat rotation system in red soil. Nitrous oxide emission in crop production is directly linked to manure and inorganic fertilizer applications. According to Sun and Huang (2012) nitrogen fertilizers alone accounts for about 60% of the global anthropogenic N_2O emission. Due to crops inability to use all applied nitrogen, the portion that is not used is lost as N_2O or leached. More than 50% of the crops in the world is routinely fertilized (Vergé et al., 2007), meaning crop production systems would continue to emit N_2O. The decomposition of manure and crop residues are also sources of N_2O production (Vergé et al., 2007; Zhai et al., 2011). To obtain high nitrogen use efficiency as well as low N_2O emission, improved approaches including proper fertilization, irrigation, soil and crop cultivation managements need to be employed in an integrated manner (Cai et al., 2013). Manure and inorganic amendments could also contribute to methane (CH_4) emissions especially under wet and submerged conditions, by methanogenic bacteria during anaerobic digestion of organic matter (Le Mer and Roger et al., 2001). However, upland soils act as a sink for atmospheric CH_4 depending on the soil temperature and moisture (Gao et al., 2014).

Good fertilization practices are important not only for sustaining maize cropping with high yield but also for ensuring good environmental health. However, to our knowledge, fewer field observations have been reported about the comprehensive impacts of fertilizer application on maize NUE and GHG emissions based on long-term field experiments. Most of the previous studies focused on short-term effects of soil fertility management (SFM) through fertilization on maize NUE and GHG emissions (Cui et al., 2012; Hu et al., 2013). Although, the major crop produced in Southern China is rice for the flat farmland (Zhang et al., 2017), maize is an important crop for the dry land in this region (Zhang et al., 2014). Therefore, a better understanding of how SFM practices affect maize NUE and N_2O emission will promote better maize production practices in this region. Based on a thirty-year field experiment under a double maize cropping system in subtropical China, which typically consists of early maize (grown from April to July) and late maize (grown from July to November), followed by a 5-month long fallow season, we assessed the impacts of different fertilizer application on N_2O and CH_4 emissions, grain yield and NUE. To determine the effects of balanced fertilization vs. inorganic nitrogen application (N), we selected the treatments of N, combined inorganic nitrogen, phosphorus and potassium fertilization (NPK) and no fertilizer application (CK). Also, to compare the effects of inorganic vs. organic fertilizers, we selected the treatments of organic manure fertilization (OM) and the combination of NPK fertilizer and organic manure (NPKM).

2. Materials and methods

2.1. Site description

The long-term fertilization field experiment for the double maize cropping is located in Jinxian, Jiangxi Province, China (28°37′N, 116°26′E, 26 m above sea level). The site was established in 1986 at the Institute of Red Soil. This area has a typical subtropical climate with two distinct growing patterns: April-July and August- November with the former being wetter than the later. The mean annual rainfall is 1549.0 mm. However, the uneven distribution of rainfall causes strong seasonal drought in summer and/or early autumn (Fishman, 2016). The mean annual temperature is 17.7 °C, and the total rainfall and average daily temperature in 2015 and 2016 were 2407.9 mm and 1690.8 mm, 18.9 °C and 18.5 °C, respectively (Fig.1).

The soil was mainly formed by quaternary clay and had the following initial chemical properties in 1986: pH 6.0, organic C 9.39 $g\,kg^{-1}$, total N 0.98 $g\,kg^{-1}$, total P 0.42 $g\,kg^{-1}$, total K 1.07 $g\,kg^{-1}$, hydrolyzable N 60.3 $mg\,kg^{-1}$, available P 12.9 $mg\,kg^{-1}$, and available K 102 $mg\,kg^{-1}$.

2.2. Experimental design

The experiment is arranged in a randomized complete block design with fifteen plots (including five treatments and three replications). The five treatments are: CK, OM, N, NPK and NPKM. Each replicated plot was 4.00 m × 5.55 m in size. Successive plots were demarcated by 20 cm cement bund (Appendix I).

The application rates of the chemical fertilizers have been described in Table 1, which were recommended based on soil tests done by the Jiangxi Institute of Red Soil at the beginning of the experiment. All the P fertilizer and manure were applied as basal fertilizers before plowing in each corn season, while half of the N and K fertilizers were incorporated as basal fertilizers with the other half applied at 4 weeks after planting. The forms of inorganic N, P and K fertilizers used are urea, calcium superphosphate, and potassium chloride, respectively. The total N rate for N, NPK and OM treatments was 60 $kg\,N\,ha^{-1}$ while that of NPKM was 120 $kg\,N\,ha^{-1}$. The manure fertilizer used in the field experiment was pig manure because mostly farmers feed pigs to sustain stable livelihoods. The total N rate for manure was applied at a rate of 15,000 $kg\,ha^{-1}$ on a fresh weight basis with the water content of 70% for each growing season. Based on dry weight, the manure contained 28.3 $g\,N\,kg^{-1}$, 10.3 $g\,P\,kg^{-1}$, 9.8 $g\,K\,kg^{-1}$.

The first and second maize crops were sown in 15th April and 30th July, and harvested in 20th July and 15th November, respectively in 2015 and 2016. Maize cultivar (Yedan 13) was seeded by hand in hills at intervals of 50 cm in line and 33 cm in row with two seeds per stand. Herbicides (i.e. atrazine, propisochlor) and pesticides (i.e. avermectins, isocarbophos, emamectin benzoate, pymetrozine) were applied during the cropping season. All aboveground crop biomass was removed from the plot following corn harvest, simulating that corn residues were used mainly as fuels by local farmers.

2.3. Sampling methods and measurements

2.3.1. Soil sampling and measurements

Soil samples were collected from the topsoil (0 − 20 cm) at flowering and after harvest in each season. In the central area of each plot, we randomly collect three soil samples by stainless steel corer including an open bottom hollow cylinder (5 cm in diameter). The three samples were mixed to make a composite sample. The collected soil samples were sieved through a 2 mm sieve to remove large particles, plant debris and stones. Part of the sieved soil was air dried and the other part was kept in the fridge at a temperature of 4 °C for analysis that required the use of fresh soil. Part of the sieved dried soil was used to determine the pH (at soil: distilled water ratio of 1:2.5 w/v) by using pH meter (PB-10). Sub-samples of the sieved soils were ground to 0.15 mm and 0.25 mm for the measurements of soil organic carbon (SOC) and nitrogen concentration respectively. The modified procedures of potassium dichromate oxidation-redox titration method (Nelson and Sommers, 1996) was used for the determination of SOC. Briefly, 0.25 g air-dried soil was transferred to 100 mL digestion tube. This was followed by the addition of 5 mL of 0.8 mol/L $K_2Cr_2O_7$ and then 5 mL of 98% (w/w) H_2SO_4. After digestion was conducted for 30 min in block digester preheated to 175 °C, the tube was removed and allowed to cool. The mixture was quantitatively transferred to 250 mL Erlenmeyer flasks, and distilled water was added to make it up to 60 ml. After adding N-phenylanthranilic acid indicator solution, the mixture was titrated against 0.2 mol/L ferrous ammonium sulfate. The Semi micro Kjeldahl method (Kjeldahl Azotometer, SPD50, China) was used for total N. NH_4^+ and NO_3^- were measured using 5 g of the fresh moist soil (< 2 mm) extracted with 50 ml of 2 mol/L KCl. The supernatant was filtered through Whatman No.42 filter paper. The solution was then analyzed using Ultraviolet spectrophotometry method (UV-1800, Norman and Stucki, 1981). Incubation using Acetylene Inhibition Technique described by Abalos et al. (2013) and Tellez-Rio et al. (2015) was used to determine denitrification capacity.