Field Crops Research 184 (2015) 80–90

Contents lists available at ScienceDirect

Field Crops Research

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

Deep placement of nitrogen fertilizers reduces ammonia volatilization and increases nitrogen utilization efficiency in no-tillage paddy fields in central China

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ARTICLE INFO

Article history:
Received 8 July 2015
Received in revised form
14 September 2015
Accepted 14 September 2015

Keywords:
Broadcasting
Deep placement
NH_3 flux
Utilization efficiency
Yield

ABSTRACT

Deep placement of nitrogen fertilizer affects the fate of fertilizer nitrogen through influencing nitrogen transformation. Few studies have examined ammonia (NH_3) volatilization and nitrogen-utilization efficiency under deep placement of nitrogen fertilizers in no-tillage (NT) paddy fields. Therefore, a field experiment was conducted to investigate the different application methods of nitrogen fertilizers [no fertilizer, traditional nitrogen broadcasting (S), and point deep placed at 5 cm, 10 cm and 20 cm depths as basal fertilizer + nitrogen broadcasting as topdressing (e.g., 5D, 10D and 20D)] on NH_3 volatilization, nitrogen recovery efficiency (NRE), nitrogen partial factor productivity (NPFP), nitrogen agronomic efficiency (NAE), and grain yield in NT paddy fields during the 2012–2013 rice growing seasons in central China. Nitrogen deep placement significantly decreased mean floodwater pH by 2–4% and mean floodwater NH_4^+–N concentration by 29–98% compared with nitrogen broadcasting. Nitrogen deep placement treatments significantly decreased cumulative NH_3 volatilization by 20–45% in 2012 and by 15–40% in 2013 compared with S treatment. On average, nitrogen deep placement treatments significantly increased NRE by 26–93%, NPFP by 10–16%, NAE by 31–51%, and grain yield by 5–11% in both seasons compared with S treatment. In addition, 10D treatment showed the highest nitrogen utilization efficiency and grain yield, implying that this measure can be effective in increasing agricultural economic viability and decreasing NH_3 volatilization. However, given high labor requirement for manual deep placement, developing mechanical fertilization technology is necessary to overcome this difficulty in future.

1. Introduction

Rice is the most important food crop in China, where nitrogen fertilizer consumption was 49.5 million metric tons in 2012, and 4.1% of this nitrogen was used for rice production (Zhang and Zhang, 2013). However, nitrogen use efficiency of applied fertilizers in the rice system is low in China, which commonly ranges from 30% to 40% (Zhang and Zhang, 2013), leading to financial losses for farmers and a threat to the environment. The low nitrogen utilization efficiency may be attributed to rapid N losses from ammonia (NH_3) volatilization, nitrification, denitrification, surface runoff, and leaching in the soil–floodwater system (Peng et al., 2006). In general, NH_3 volatilization is the major pathway for N loss from flooded rice in China (Zhu, 1997; Chen et al., 2015a), and the NH_3 loss accounts for 9–40% of the total applied nitrogen fertilizer (Fan et al., 2006). Large amounts of volatilized NH_3 result in various environment problems, such as atmospheric haze, rain acidification, and surface water eutrophication (Liu et al., 2005; Emmett 2007). Therefore, understanding the relative importance of NH_3 volatilization is essential to develop effective nitrogen management strategies in paddy fields.

The labor shortage in agriculture has become a major factor that constrains rice production in China. Thus, no-tillage (NT), as a conservation technology, has been widely adopted in approximately 1.33 million hectares of land in China in 2008 (Derpsch et al., 2010). NT can conserve soils, reduce production costs, decrease greenhouse gas emissions and increase SOC sequestration compared with conventional intensive tillage (CT) (Huang et al., 2013; IPCC, 2014). However, nitrogen fertilizers are broadcast and do not mix with the soil in NT paddy fields in China, leading to high fer-

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http://dx.doi.org/10.1016/j.fcr.2015.09.011
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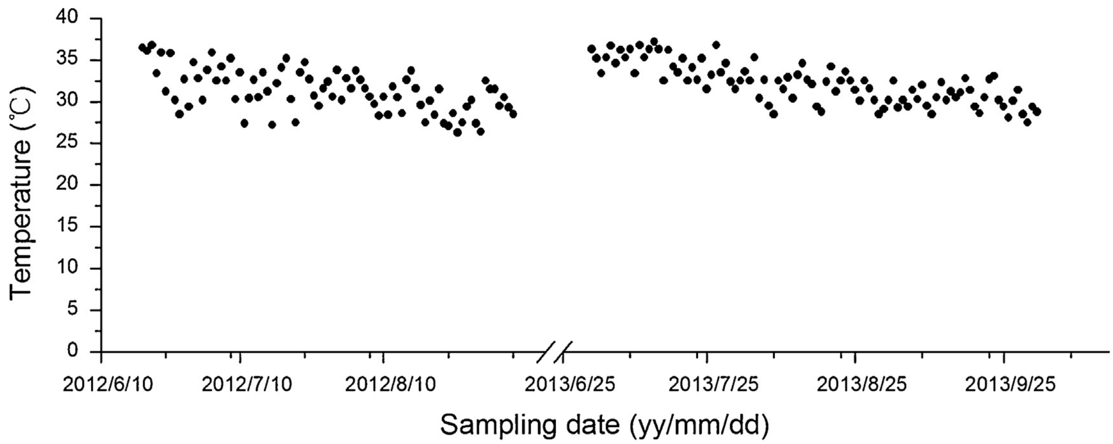

Fig. 1. Mean daily air temperature during the 2012–2013 rice growing seasons.

tilizer nitrogen losses through NH_3 volatilization, nitrification and surface runoff (Zhang et al., 2011). NT was reported to increase NH_3 volatilization under nitrogen broadcasting compared with CT (Mkhabela et al., 2008; Zhang et al., 2011); this increase in volatilization is due to the improvement of urease activity and the presence of crop residues under NT surface soil, as well as the penetration of a fraction of fertilizer nitrogen into shallow cracks under CT (Mkhabela et al., 2008; Rochette et al., 2009a,b). In addition, high fertilizer nitrogen losses under NT with nitrogen broadcasting subsequently result in a low nitrogen uptake by rice and nitrogen utilization efficiency (Chen et al., 2008). Therefore, optimizing agricultural management strategies is necessary for decreasing NH_3 volatilization and increasing nitrogen utilization efficiency in NT paddy fields.

Conventional nitrogen broadcasting is probably the most inefficient method for rice production because of extensive fertilizer nitrogen losses. Therefore, many strategies have been developed to reduce nitrogen losses and increase nitrogen utilization efficiency from applied nitrogen through proper timing, rate, modified forms of fertilizers, and use of nitrification and urease inhibitors (Mohanty et al., 1999; Tewari et al., 2007; Ma et al., 2013; Sun et al., 2015). However, the response of fertilizer nitrogen to these measures varies markedly because of the differences in weather, genotype, soil, agronomic practices, water regime, and pest management (Mohanty et al., 1999). Point deep placement of nitrogen fertilizers was reported to be effective application method in reducing nitrogen loss (Bautista et al., 2001; Sommer et al., 2004). Studies have shown that nitrogen deep placement can largely reduce NH_3 volatilization through reducing ammonium nitrogen (NH_4^+–N) levels in the floodwater (Vlek and Craswell 1979; Cao et al., 1984; Mohanty et al., 1999; Xu et al., 2013), thus increasing nitrogen utilization efficiency (Savant and Stangel 1990; Bautista et al., 2001). However, these studies were conducted under CT paddy fields. For NT paddy fields, the soil physicochemical properties are definitely different compared with CT paddy fields, possibly leading to changes in NH_3 volatilization pattern and nitrogen utilization efficiency. However, available information on NH_3 volatilization and nitrogen utilization efficiency under deep placement of nitrogen fertilizers under NT paddy fields remains limited. Therefore, this study aimed to investigate the effects of different application methods of nitrogen fertilizers (broadcasting or deep placement) on NH_3 volatilization, nitrogen utilization efficiency and grain yield under NT paddy fields during the rice growing seasons from 2012 to 2013 in central China.

2. Materials and methods

2.1. Experiment site

The experimental site is located in Huaqiao Town, Wuxue City, Hubei Province (29°57′N latitude, 115°33′E longitude), China. This site lies at 30 m above sea level in a subtropical climatic zone. The mean annual precipitation is 1361 mm, and the mean annual temperature is 17.8 °C. The mean daily temperature in the experimental

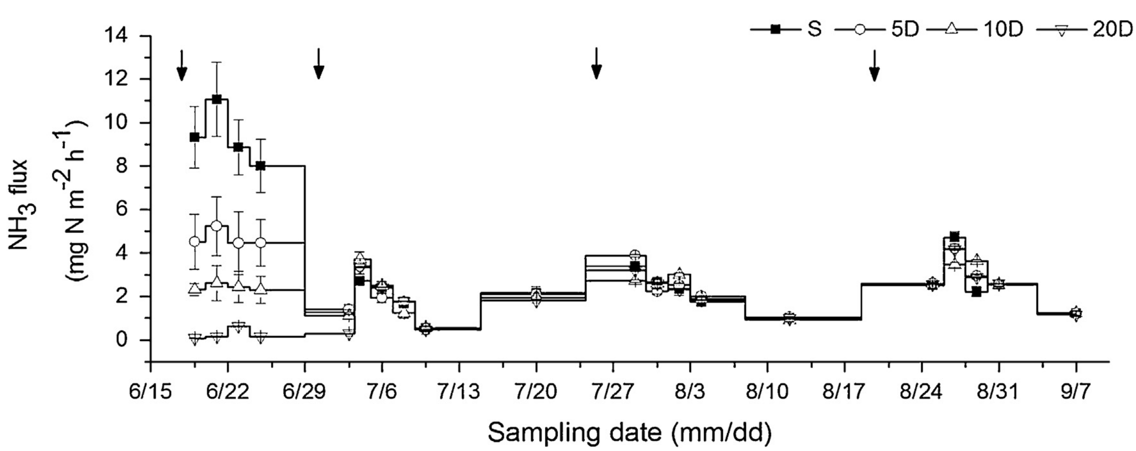

Fig. 2. Seasonal changes in NH_3 fluxes from NT paddy fields during the 2012 rice growing season. The arrows denote nitrogen fertilizer application. S, nitrogen broadcasting; 5D, nitrogen deep placement at 5 cm depth; 10D, nitrogen deep placement at 10 cm depth; 20D, nitrogen deep placement at 20 cm depth.