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RESEARCH ARTICLE

Determination of optimum nitrogen application rates in Zhejiang Province, China, based on rice yields and ecological security

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Abstract

Excessive nitrogen (N) fertilization in intensive agricultural areas such as the plain region of South China has resulted in low nitrogen use efficiency and serious environmental problems. To determine the optimum N application rate, grain yield, apparent nitrogen recovery efficiency (ANRE), apparent N loss, and ammonium (NH_3) volatilization under different N application rates in the three years from 2012 to 2014 were studied. The results showed that the relationship between grain yields and N application rate in the three years were well fitted by quadratic equations. When N application rate reached 197 kg ha^{-1} in 2012, 199 kg ha^{-1} in 2013 and 196 kg ha^{-1} in 2014, the plateau of the grain yields appeared. With the increase of N application rate, the ANRE for rice decreased which could be expressed with sigmoidal equation; when N application rate was 305 kg ha^{-1} in 2012, 275 kg ha^{-1} in 2013 and 312 kg ha^{-1} in 2014, the curves of ANRE appeared turing points. Besides, the relationship between soil $N_{residual}$ and N application rate was fitted by the quadratic equation and the maximums of soil $N_{residual}$ were reached in the three years with the N application rate of 206, 244 and 170 kg ha^{-1}, respectively. Statistical analysis indicated that NH_3 volatilization and apparent N loss in three years all increased with the increasing N application rate. When the amount of NH_3 volatilization increased to 11.6 kg N ha^{-1} in 2012, 40.5 kg N ha^{-1} in 2013 and 57.0 kg N ha^{-1} in 2014, the apparent N loss in the three years had obvious increase. To determine the optimum N application rate, the average N application on the plateau of the grain yield was considered as the lower limit while the average N application rate at the turning points of ANRE, the residual N in soil and apparent N loss was taken as the upper limit. According to the results in three years, the optimum N application rate for rice in Zhejiang was 197–255 kg ha^{-1}.

Keywords: optimum nitrogen application rate, Zhejiang, rice yields, ecological security

1. Introduction

Nitrogen (N) is one of the major nutrients for the plant growth and also is an important limiting factor for soil productivity. In recent years, farmers increased the N fertilizer application rate in the planting process in order to maintain high crop production and achieve more economic profit. Excessive use of chemical N fertilizer could increase the crop yield to some extent, but it also brought a threat to the ecological environment (Camargo and Alonso 2006; Song *et al*. 2009; Guo *et al*. 2010). More and more attention is being drawn to environment pollution caused by the large scale of high amount of nitrogen fertilizer application, which has become an important research topic for non-point source pollution (Lang *et al*. 2013; Smith and Schallenberg 2013). The

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increase of the nitrogen use efficiency and the decrease of both the N dose and the fertilizer application rate lead to the economic and environmental benefits (Yu *et al*. 2015). Therefore, the determination of optimum N application rate is an important way to improve crop yield and nitrogen use efficiency and to reduce nitrogen loss.

In China, rice is one of major food crops with the biggest planting area, the highest grain yield and the largest N fertilizer application rate. The area of rice accounts for 27% of total areas of food crops and rice yield accounts for more than 40% of total cereal yields. The average N fertilizer application rate of single-season in paddy field of China is about 180 kg ha^{-1}, 75% higher than the average N fertilizer application rate of the world (Liu 2005; Chen *et al*. 2013). The plain region of South China is one of main rice producing areas, where topography is mainly plateau and hills. Due to the high intensity of rainfall and special terrain, soil erosion of cultivated lands in this region is more serious, and then N loss by soil erosion can be accelerated. In addition, 30–70% of N in the cultivated soils are lost by ways of ammonium volatilization, nitrification and denitrification, leaching and runoff loss (Polychronaki *et al*. 2012; Singh *et al*. 2013; Valkama *et al*. 2013). The loss of nitrogen will not only increase agricultural production costs, but also causes environmental pollution, leading to the ecological deterioration (Soares *et al*. 2012; Welten *et al*. 2013). Previous studies mainly focus on the effect of N fertilizer application on crop yield, quality, nitrogen use efficiency, and ecological environment (Camargo and Alonso 2006; Su *et al*. 2007; Yu *et al*. 2015). However, few informations regarding the studies on the determination of optimum nitrogen application rate based on rice yield and ecological security are available.

Zhejiang Province is a typical respresentive of plain region in the South China regarded as a land flowing with milk and honey, where we selected a fertilizer experiment as the research object. Our objectives were (i) to study the effect of N application rate on rice yield, apparent N use efficiency, apparent N loss, (ii) to examine the correlations among N application rate on rice yield, apparent N use efficiency and apparent N loss, (iii) to determine the optimum N application rate for rice in the region. Such studies can provide insight into the knowledge on how to apply N fertilizer to maximize grain yield, improve N uptake and minimize N loss in paddy soil of the plainregion of South China.

2. Results and discussion

2.1. The application of N effects on grain yield

From Fig. 1, the relationship between grain yields and N application rate in three years (2012–2014) can be described by parabolic equations, corresponding with the reports of Cui *et al*. (2010) and Xia and Yan (2012). When N application rate amounted to 384 kg ha^{-1} in 2012, 319 kg ha^{-1} in 2013 and 292 kg ha^{-1} in 2014, the grain yields reached maximums of 8581, 6041 and 7857 kg ha^{-1}, respectively. In Fig. 1, the grain yields in 2012 and 2014 were significantly higher than those in 2013 (P<0.01). The reason is that the temperature of July to September in 2013 reached the highest level in recent 50 years. High temperature negatively affect the growth of rice in the growing season, resulting in the early and large decline in grain yields of rice.

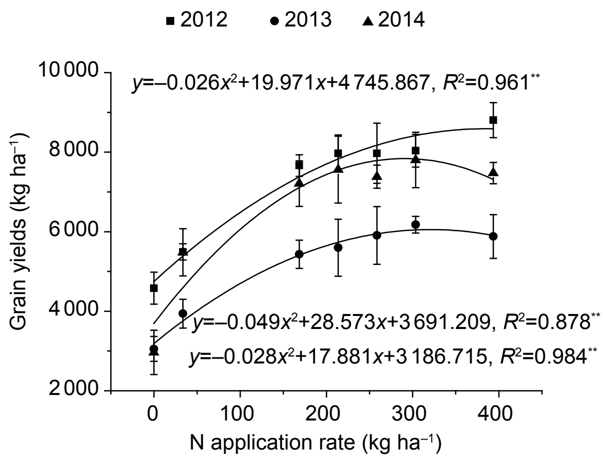

Fig. 1 Grain yields under different N application rates in three years (2012–2014). * represents a significant correlation at a significant level of P<0.05; ** represents a highly significant correlation at a significant level of P<0.01. The same as below.

Linear plus plateau model is often used to fit crop yields and fertilizer application rate, and it used to be achieved by programming with SAS or other specialized software (Alivelu *et al*. 2003). Analysing with this model, the plateau of grain yields from 2012 to 2014 were reached with N application rate of 197 kg ha^{-1} in 2012, 199 kg ha^{-1} in 2013 and 196 kg ha^{-1} in 2014, respectively. Thus, the average N application rate on the plateau of grain yields in the three years was 197 kg ha^{-1}.

2.2. The application of N effects on apparent nitrogen recovery efficiency (ANRE)

According to Fig. 2, ANRE of rice in the three years continuously decreased with the increase of N application rate, and exhibited a sigmoid behaviour. The general pattern of ANRE involved the following phases from the lowest to the highest N level: slow, rapid and slow decline. The relationship between ANRE and N application rate was demonstrated with sigmoidal equations (y_{2012}=35.275+10.252/(1+exp ((x–306.324)/12.228)), R^2=0.822*; y_{2013}=29.504+11.757/(1+ex-