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Mineral nitrogen in a rhizosphere soil and in standing water during rice (*Oryza sativa* L.) growth: effect of hydroquinone and dicyandiamide

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Abstract

Inhibitors are applied to improve the efficiency of N fertilizer use and to reduce N losses from the soil. However, little information is available on the effects of a urease inhibitor, hydroquinone (HQ), and a nitrification inhibitor, dicyandiamide (DCD), on urea-derived mineral N in the rhizosphere of rice plants and in the standing water. Furthermore, this is important to understand the contribution of rice plants to gaseous N losses in the presence of inhibitor(s). A rhizobox was used to simultaneously study urea-derived mineral N in the soil at increasing distances from rice roots, and the effect of growing plants on the behavior of fertilizer-N in soil. The combined application of urea (U) with DCD showed a significantly positive effect on rice growth. The redox potentials in the rhizosphere soil were higher in the presence than in the absence of DCD, especially when rice plants entered their vigorous growth stage. During the entire experimental period, NH_4^+–N concentrations in the rhizosphere of rice plants were smaller in the U + DCD and U + HQ + DCD treatments than in the U and U + HQ treatments. On days 20 and 60 after fertilization, the U + DCD and U + HQ + DCD treatments showed a smaller concentration of (NO_3^- + NO_2^-)–N in soil less than 0.5 cm from the rhizobox, compared to the U treatment. During the early period of rice growth, the NH_4^+–N concentration of the standing water was higher in the presence than in the absence of DCD. However, there were no significant differences in NH_4^+–N among all treatments after 20 days. In the absence of rice plants, also, the application of DCD and especially DCD and HQ, always increased the level of NH_4^+–N and pH in the standing water. Thus, rice plants might reduce potential gaseous N losses from a urea-fertilized, flooded soil, due to the stimulating effect on rice growth in the presence of DCD or DCD + HQ. The N_2O emissions from the urea-fertilized, rice-planted soil significantly decreased when DCD or DCD + HQ was used. From the results obtained, we conclude that DCD and DCD + HQ together with U can be an effective tool to improving crop growth and reducing N loss

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as N_2O in rice cultivation, and that the use of a rhizobox is useful to study the interaction between plant uptake and the behavior of fertilizer-N in soil.

Keywords: Nitrification; Urease; Inhibitor; Urea; Rice; Rhizosphere; Nitrous oxide

1. Introduction

Urea fertilizers are widely used in rice cultivation. Upon application to flooded rice soils urea is rapidly hydrolysed to NH_4^+, which can subsequently be removed by plant roots or lost as NH_3, NO, N_2O and N_2. To reduce the accumulation and volatilization of NH_3, urease inhibitors (e.g. hydroquinone) are commonly used (Wang et al., 1991; Chaiwanakupt et al., 1996; Keerthisinghe and Freney, 1996). In flooded rice soils, oxygen diffusing from rice roots (Armstrong, 1969, 1979) into their surrounding anaerobic environment can form a thin zone (oxidized rhizosphere) (Flessa and Fischer, 1992; Kludze et al., 1993), where NH_4^+ can be oxidized to NO_3^- (Adhya et al., 1996; Schneiders and Scherer, 1998; Arth and Frenzel, 2000). The O_2 secretion from rice roots may make a great contribution to the dynamic of non-exchangeable NH_4^+ in the rhizosphere (Zhang and Scherer, 2002). The conversion of NH_4^+ to NO_3^- in the rhizosphere of rice plants and at the floodwater–soil interface should be avoided by application of a nitrification inhibitor. Otherwise, the NO_3^-–N formed can enter the anaerobic zone surrounding the roots and the deep-depth soil layer in the field and then be denitrified (Reddy and Patrick, 1986; Reddy et al., 1990; Zhu et al., 1997). However, in an irrigated rice soil, NO_3^- may be limiting overall N losses due to coupled nitrification–denitrification in the rhizosphere (Smith and DeLaune, 1984) and at the floodwater–soil interface (Buresh et al., 1991). Although nitrification inhibitors may enhance NH_4^+ concentration in the standing water when added together with ammonium-based fertilizers, their combination with urease inhibitors can effectively regulate the concentration of NH_4^+ and NO_3^- in a rice-planted rhizosphere soil and in the standing water, reducing nitrification–denitrification N losses and NH_3 loss.

Under anaerobic or aerobic soil conditions, nitrification inhibitors (e.g. dicyandiamide) are generally applied to retard the accumulation of NO_3^- (e.g. Chen et al., 1995; Xu et al., 2000, 2001). There is some evidence that nitrification inhibitors can improve fertilizer N utilization in irrigated rice (Prasad and Powder, 1995), and reduce N_2O emissions from soil–rice systems (Bronson and Mosier, 1991; Kumar et al., 2000; Majumdar et al., 2000; Xu et al., 2002a, 2002b). Our previous studies showed that the effect of a nitrification inhibitor, dicyandiamide, and a urease inhibitor, hydroquinone, on urea-^{15}N transformations and the recovery of fertilizer ^{15}N in a cambisol soil was greatest under well-drained conditions (Xu et al., 2001). The combined application of both inhibitors can also improve crop quality, while reducing N loss to the environment during wheat growth (Xu et al., 2000). To date, our knowledge is still limited with regard to the effect of both inhibitors on urea-derived mineral N in the rhizosphere soil and in the floodwater during rice growth.

Regulating N transformations in the rhizosphere of rice plants is an important method to improve the efficiency of fertilizer N use in rice cultivation. Unfortunately, the effect of rice roots on soil mineral N is more or less neglected in most studies (Adhya et al., 1996; Arth and Frenzel, 2000). There are still limitations on determining the distribution of mineral N status in the rhizosphere using both rice-planted and plant-free treatments (Reddy and Patrick, 1986; Mosier et al., 1990; Adhya et al., 1996). Different types of chambers have been used to collect soil samples at increasing distances from the roots (Harley and Russell, 1979; Helal and Sauerbeck, 1983; Schneiders and Scherer, 1998). However, the separation of individual soil zones for analysis is quite time-consuming.

Our previous papers showed in detail the effect of urea-N together with inhibitors on methane and nitrous oxide emissions from rice–soil systems; there was an obvious difference in both emissions during rice growth (Xu et al., 2002a, 2002b). The behavior of mineral N in a rhizosphere soil and in standing water as well as soil E_h can be associated with CH_4 and N_2O