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RESEARCH ARTICLE

Comparative effects of nitrogen application on growth and nitrogen use in a winter wheat/summer maize rotation system

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Abstract

The application of fertilizer in agricultural production has become universally common for achieving high crop yields and economic benefits, but it has potential impacts on food safety, energy crisis and environmental pollution. Optimal management of fertilization is thus necessary for maintaining sustainable agriculture. Two-year (2013–2015) field experiment was conducted, in Yangling (108°24´E, 34°20´N, and 521 m a.s.l.), Shaanxi Province, China, to explore the effects of different nitrogen (N) applications on biomass accumulation, crop N uptake, nitrate N (NO_3^--N) distribution, yield, and N use with a winter wheat/summer maize rotation system. The N applications consisted of conventional urea (U) (at 80 (U80), 160 (U160), and 240 (U240) kg N ha^{-1}; 40% applied as a basal fertilizer and 60% top-dressed at jointing stage) and controlled-release urea (CRU) (at 60 (C60), 120 (C120), 180 (C180), and 240 (C240) kg N ha^{-1}; all applied as a basal fertilizer) with no N application as a control (CK). The continuous release of N from CRU matched well with the N demands of crop throughout entire growing stages. Soil NO_3^--N content varied less and peaked shallower in CRU than that in urea treatments. The differences, however, were smaller in winter wheat than that in summer maize seasons. The average yield of summer maize was the highest in C120 in CRU treatments and in U160 in urea treatments, and apparent N use efficiency (NUE) and N agronomic efficiency (NAE) were higher in C120 than in U160 by averages of 22.67 and 41.91%, respectively. The average yield of winter wheat was the highest in C180 in CRU treatments and in U240 in urea treatments with C180 increasing NUE and NAE by averages of 14.89 and 35.62% over U240, respectively. The annual yields under the two N fertilizers were the highest in C120 and U160. The results suggested that CRU as a basal fertilizer once could be a promising alternative of urea as split application in semiarid areas.

Keywords: controlled-release urea, nitrogen availability, soil fertility, nitrogen use efficiency, soil productivity

1. Introduction

Nitrogen (N), the most fundamental nutrient element, with a vital role in improving the productivity of agricultural ecosystem, is most commonly supplied by chemical fertilizers. Increasing N application has been an important practice for obtaining high outputs in agricultural production, but crop yield and N application rate are not always positively correlated. Excessive amounts of N in soil cannot be absorbed

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by crops but instead can limit plant growth, reduce fertilizer use efficiency, waste resources, and even degrade the environment, through soil degradation, water eutrophication, groundwater pollution, and greenhouse gases emission (Officer *et al.* 2015; Sun *et al.* 2016). The average N use efficiency (NUE) in China is only 27.5% (Zhang *et al.* 2008), and the extra N application represents an unnecessary economic expenditure for farmers. Therefore, effective measures to coordinate crop yield and quality, save resource, and alleviate the potential influence of N fertilization in agricultural areas as non-point sources of pollution are imperative.

Many useful N application techniques have been developed. Banding fertilizer in plant rows can improve NUE by concentrating the fertilizer near the root zone (Zhang *et al.* 2016). Split application of urea, where a portion is applied before seeding and a portion is applied at later growth stages, contributes to shorten the residence time of soil nitrate N (NO_3^--N) prior to crop uptake (Grant *et al.* 2012). Appropriate synchronization between the rate and timing of N application greatly helps to improve both crop yield and quality and decrease NO_3^--N leaching (Yang *et al.* 2011). The combined use of organic and inorganic fertilizers does well in maintaining soil nutrient balance, optimizing soil physical and chemical properties, and improving the availability of soil nutrients (Cavoski *et al.* 2016).

Applying controlled-release urea (CRU) is a new approach for maximizing N use and minimizing environmental pollution (Zebarth and Rosen 2007). CRU is designed to release N in close association with the crop N requirement and it can reduce residual nitrates in soil solutions. CRU also requires only a single basal fertilization, thereby reducing labor and energy compared to split applications of urea (Ye *et al.* 2013). Soil NO_3^--N content was markedly lower at spike formation but was evidently higher after flowering in CRU treatments than that in conventional urea treatments (Hu *et al.* 2013). What is more, NUE was 10–30% higher under CRU than urea at the same N application rate, and the N application rate was 10–40% lower under CRU than urea at the same target yield (Jiang 2013).

The studies above mainly focused on the effects of the rate, timing, placement, and source of N application on crop growth, N uptake, and soil properties. CRU in agronomic production of grain crops has chiefly related to rice. Comparisons of the effects of different CRU and urea application rates on crop growth and N use, however, are limited. Winter wheat (*Triticum aestivum* L.)/summer maize (*Zea mays* L.) cropping is common in Guanzhong region, Shaanxi Province, where excessive amounts of N fertilizers are used to achieve high crop yields. We thus conducted a continuous two-year experiment with a winter wheat/summer maize rotation to evaluate the effects of CRU and urea application rates on crop growth, NO_3^--N distribution, and N use. The objectives of this study were to determine the effect of N fertilizer type and N application rate on crop growth, yield, and N use in a winter wheat/summer maize rotation system and to provide a theoretical reference for the application of CRU.

2. Materials and methods

2.1. Plant materials, experimental design and treatments

Experimental site and plant materials Two-year experiment with a winter wheat/summer maize rotation was conducted from June 2013 to June 2015 at the Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Areas of Ministry of Education, Northwest A&F University, in Yangling (108°24´E, 34°20´N, and 521 m a.s.l.), Shaanxi Province, China. The region has a sub-humid drought-prone climate, with a mean annual temperature of 13°C and mean annual precipitation of 632 mm, nearly 60% of the rain falling during July–September. The soil is a Lou soil with a dry bulk density of 1.40 g cm^{-3}, water content (gravimetric) at field capacity of 24%, and permanent wilting point of 8.5%. The basic properties of the surface soil (0–20 cm) at the study site before sowing in 2013 were: pH, 8.13; organic matter content, 10.18 g kg^{-1}; total N content, 0.94 g kg^{-1}; total phosphorus (P) content, 0.60 g kg^{-1}; total potassium (K) content, 14.10 g kg^{-1}; available N content, 76.01 g kg^{-1}; available P content, 25.22 g kg^{-1}; and available K content, 131.97 g kg^{-1}. Weekly rainfall and average temperature during the crop seasons were presented in Fig. 1. Luodan 9 and Xiaoyan 22, two predominant local varieties of summer maize and winter wheat, respectively, were used.

Experimental design and treatments The experiment adopted a split plot design with eight triplicate treatments (the same for maize and wheat). The main plots were two N fertilizer types: conventional urea (U, 46% N) and CRU (C, 42% N released over 120 days). The subplots were N application rates. Conventional urea was applied at 80 (U80), 160 (U160), and 240 (U240) kg N ha^{-1}, with 40% applied as a basic fertilizer and 60% top dressed at jointing stage; CRU was applied at 60 (C60), 120 (C120), 180 (C180), and 240 (C240) kg N ha^{-1}, all applied as a basal fertilizer. A treatment with no N application served as a control (CK). P_2O_5 (16% P, calcium superphosphate, 120 kg P ha^{-1}), K_2O (50% K, potassium sulfate, 60 kg K ha^{-1}), and the basal N were broadcast and incorporated into the top 15 cm depth before sowing. Maize was sowed at a row spacing of 60 cm and a plant spacing of 30 cm. Wheat was seeded at a rate of 180 kg ha^{-1} and a row spacing of 20 cm. The area of each plot was 20 m^2 (4 m×5 m) separated with a 0.5-m alley. Maize was sowed in mid-June and harvested in early