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The nitrate leached below maize root zone is available for deep-rooted wheat in winter wheat–summer maize rotation in the North China Plain

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Deep-rooted wheat can recycle nitrate leached from maize root zone in winter wheat–summer maize rotation system.

Abstract

In winter wheat (*Triticum aestivum* L.)–summer maize (*Zea mays* L.) rotation system in the North China Plain, maize roots do not extend beyond 1.2 m in the vertical soil profile, but wheat roots can reach up to 2.0 m. Increases in soil nitrate content at maize harvest and significant reductions after winter wheat harvest were observed in the 1.4–2.0 m depth under field conditions. The recovery of ^{15}N isotope (calcium nitrate) from various (1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 m) soil depths showed that deep-rooting winter wheat could use soil nitrate up to the 2.0 m depth. This accounted partially, for the reduced nitrate in the 1.4–2.0 m depth of the soil after harvest of wheat in the rotation system.

Keywords: Winter wheat–summer maize rotation; Root vertical distribution; Nitrate; Leaching and recycling

1. Introduction

Nitrate-nitrogen (NO_3^--N) is a primary source of N for crops. The chemical characteristics of nitrate make it susceptible to leaching, which not only reduces N use efficiency (NUE) but also contaminates groundwater. Nitrate pollution of groundwater is mainly caused by the application of N fertilizers to agricultural land (Singh and Sekhon, 1978/1979; Croll and Hayes, 1988; Zhang et al., 1995; Elmi et al., 2000; Peralta and Stockle, 2002). According to a long-term simulation study, reduction of fertilization rate is believed to be the only effective approach to restrict nitrate leaching (Peralta and Stockle, 2002). However, even with economic and optimum N fertilization in maize, there was still 41–138 kg N ha^{-1} leached to the 1.2 m soil depth in summer (Roth and Fox, 1990). Nitrate loss through leaching can be alleviated by optimizing soil and crop management practices, such as timing and rate of N fertilizer application (Schepers et al., 1995; Oenema et al., 2005), choice of fertilizer types (Diez et al., 1994; Delgado and Mosier, 1996; Shoji et al., 2001; Maeda et al., 2003; Daudén and Quílez, 2004; Basso and Ritchie, 2005), irrigation management (Asadi et al., 2002; Allaire-Leung et al., 2002), farming practices (Angle et al., 1989; Joshi et al., 1994; Hansen and Djurhuus, 1997; Catt et al., 2000), and mulching (Islam et al., 1994; Kitchen et al., 1998; Romic et al., 2003). If crops did not utilize nitrate, its downward leaching cannot be avoided because of its high solubility in water and low retention in soil.

Winter wheat–summer maize double cropping is an important rotation system in the North China Plain, and contributed 48 and 39% of total wheat and maize production in China, respectively (Liu and Mu, 1993). The climate in the North China Plain is warm-temperate, sub-humid continental monsoon, with cold winter and hot summer. The annual precipitation

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is 500–700 mm, with 60–70% of rainfall occurring in summer (June–August). Since the rainfall coincides with summer maize growth, the accumulated residual nitrate is readily leached to deeper soil layers. Liu et al. (2003) reported that accumulation and/or leaching of NO_3^--N below 1.0 m depth was the main pathway for N losses in the winter wheat–summer maize cropping system in the North China Plain. From our investigation of temporal and spatial variation in soil nitrate using six varieties of summer maize and five N fertilizer rates, there was no difference in nitrate content at the 1.0 m soil depth even after 2 days of heavy rainfall (516 mm) (Zhou et al., 2002). In China, excessive application of N fertilizer is a common practice for ensuring maximum yield in winter wheat–summer maize rotation system. Therefore, it is difficult to persuade farmers to decrease fertilization rates.

Cropping systems can be used to scavenge residual soil NO_3^--N leached from previous shallower rooted crops. Shipley et al. (1992) reported that cereal rye recovered more ^{15}N-labelled N fertilizer applied in corn than hairy vetch, crimson clove and native weed cover, and attributed the phenomena to root growth capacity of cereal rye in cool weather. Delgado et al. (1998) developed a new NLEAP model to simulate the effects of shallow- and deep-rooted crops on NO_3^--N dynamics and leaching. Delgado (1998) reported that winter cover rye and winter cover wheat planted after lettuce increased the NUE of the system by scavenging NO_3^--N leached from the root zone of the previous shallower rooted lettuce. Additionally wheat and rye also reduced the NO_3^--N leached from the following potato crop and increased NUE from 48 to 55%. Delgado et al. (2001a) also evaluated NO_3^--N transport in 0.9 m depth soil profile in potato–barley rotations. They reported that best management practices for irrigation kept leaching losses of NO_3^--N from the root zone of potato (0–0.4 m) to a minimum, and facilitated the scavenging of residual soil nitrate to the deeper rooted barley (0.61 m), increasing NUE of the cropping system and reducing the NO_3^--N losses. These identified basic principles and correlations reported by Delgado et al. (2001b) between root depth and NUE and root depth and mining of NO_3^--N from underground water have been used as inputs and factors for the new cutting edge N indexes tools (Shaffer and Delgado, 2002; Wu et al., 2005; Delgado et al., 2006). In agro-forestry systems, the safety-net hypothesis was proposed by Rowe et al. (1999) based on the safety-net role of tree roots, assuming that trees in alley cropping are capable of recycling soil nutrients leached from the crop rooting zone, thereby reducing groundwater contamination and increasing nutrient use efficiency in the system. The safety-net hypothesis was tested by applying ^{15}N-labelled ammonium sulfate at three soil depths (5, 35, 55 cm) between mixed hedgerows of deep-rooted *Peltophorum dasyrrhachis* and shallow-rooted *Gliricidia sepium* (Rowe et al., 1999), and in a pecan-cotton alley cropping system in northwestern Florida (Allen et al., 2004).

There is a significant difference between rooting depths of winter wheat and summer maize. The general objectives of this study were: (1) to confirm the difference in vertical root distribution between winter wheat and summer maize, (2) to examine whether the deep-rooted winter wheat can use nitrate in deeper soil layers, and (3) to evaluate the possibility that the nitrate leached below summer maize root zone is available for deep-rooted winter wheat in winter wheat–summer maize rotation system.

2. Materials and methods

2.1. Study site

This study was conducted in a research station in Wuqiao county, Hebei Province, China. Wuqiao county (37°29′–37°47′ N; 116°19′–116°42′ E) is in the middle of Heilonggang Catchment. The altitude is 14–22.6 m above sea level, and the average groundwater table is 6–9 m. The average annual rainfall for the last 20 years is 562 mm, with a sharp yearly fluctuation and erratic seasonal distribution. Generally, 60–70% of the yearly precipitation occurs from June to August. The average rainfall during wheat growth period is 124.8 mm, accounting for 22.2% of total annual rainfall. During this study, the rainfall was 381.3 and 109.5 mm during summer maize and winter wheat growing periods, respectively (Fig. 1).

The soil at the site is locally classified as a salted light loam soil with a pH of 8.12. The organic matter content in the topsoil was 11.2 g kg^{-1}, total N was 0.8 g kg^{-1}, Olsen-P (P_2O_5) was 18.2 mg kg^{-1} and exchangeable K was 76.8 mg kg^{-1}. Prior to the experiment, the site was under continuous winter wheat–summer maize rotation using traditional tillage for 5 years.

2.2. Experimental design and management

On 13 Jun 2003, the hybrid maize cultivar, 'Nongda 108' was sown with zero-tillage with inter-plant spacing of 25 cm within rows and 80 cm between rows for a density of 50,000 seedlings ha^{-1}. Four doses of N fertilizer (urea) were applied: N_0, 0 kg N ha^{-1}; N_{90}, 90 kg N ha^{-1}; N_{180}, 180 kg N ha^{-1}; and N_{270}, 270 kg N ha^{-1}. The plots, each with a 5 × 20 m size, were separated by 2 m wide alley ways and arranged into a randomized complete block design with three replications. N fertilizer was split-applied with 40% at planting and 60% at side-dressing on the nine-leaf stage. At the first split N fertilization, 103.5 kg P_2O_5 ha^{-1}, 162.7 kg K_2O ha^{-1}, and 30 kg $ZnSO_4$ ha^{-1} were also applied to all plots. After maize harvest, the field was irrigated, fertilized and plowed. Urea was applied to each plot to provide 157.5 kg N ha^{-1} together with 138.5 kg P_2O_5 ha^{-1}, 113 kg K_2O ha^{-1}, 30 kg $ZnSO_4$ ha^{-1} and

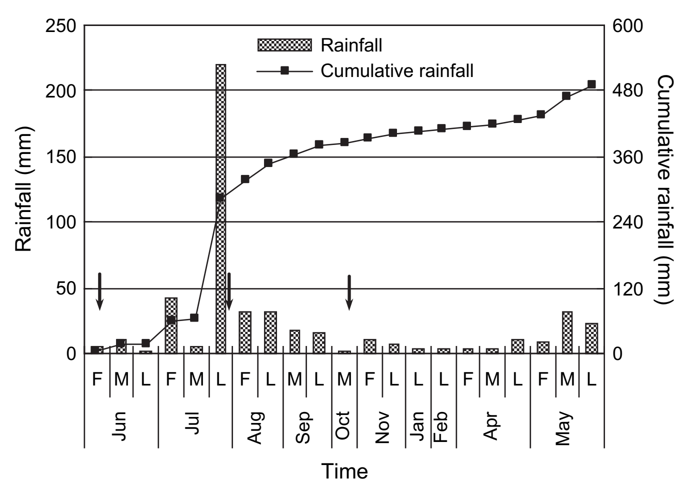

Fig. 1. Rainfall and cumulative rainfall from Jun 2003 to May 2004 at Wuqiao Experimental Station, Hebei Province, China. The growth period was from Jun to Sep 2003 for summer maize, and Oct 2003 to May 2004 for winter wheat. Solid arrows (↓) show N fertilization date. F is the first 10 days of a month; M, the middle 10 days of a month; and L, the last 10 days of a month.