Title
Determining total N deposition in a winter wheat and maize cropping system

Authors
Chune, He
Liu, Xuejun
Fangmeier, Andreas
et al.

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Introduction

With the development of intensive agriculture and a rapid growth in energy consumption, more and more reactive N in both reduced and oxidized forms is being emitted into the atmosphere and re-desposited onto the surfaces of terrestrial and marine ecosystem (Matson et al., 2002; Duce et al. 2008). It has been estimated that annually more than 55 Tg yr^{-1} NH_3-N was emitted from global terrestrial ecosystems into the atmosphere, of which 50-75% came from organic manure and N fertilizer (Mosier, 2001). The North China Plain (NCP) has particular N pollution resulting in with large reactive N emissions due to the high-input intensive agricultural systems (Ju et al., 2009). Annual wet N deposition is up to 30 kg N ha^{-1} yr^{-1} in the Beijing area and ammonium N is the main form of N in precipitation (Liu et al., 2006), being closely linked to NH_3 volatilization from ammonium-based fertilizers and livestock. Total airborne N inputs will be much higher than wet deposition, especially if dry deposition and the direct uptake of atmospheric N species by aerial parts of plants are included. Therefore determinations of total N deposition into agroecosystems are urgently needed so that China can more accurately gauge the scale of its environmental nutrient and farmers can make better predictions of N fertilizer requirements. The objective of this study was to determine total airborne N input into a typical wheat-maize rotation in the NCP.

Materials and Methods

An ITNI (Integrated Total Nitrogen Input) system, based on the ^{15}N isotope dilution method and uses pot experiments, was used for determining the total atmospheric N input in the NCP. The ITNI system was introduced in detail by Russow et al. (2001).

Three sand-pot experiments with wheat and maize rotation were conducted simultaneously at Dongbeiwang (DBW), Wuqiao (WQ) and Quzhou (QZ) during 2005 and 2006. Maize was sown in May 2005 and harvested in mid September 2005; wheat was then planted and harvested in late May 2006. As a reference, Italian ryegrass (*Lolium multiflorum*) was also used as a monitoring plant at the same three sites. Fertilizer N was added to maize, wheat, and ryegrass at rates of 3.0, 1.5, and 0.8 g pot^{-1}, respectively.

Another experiment was carried out at DBW, Beijing in order to get reliable N deposition at key growth stages of maize. Maize was sown on 12 June 2006; the first harvest was taken on 4 July 2006 after the third leaf was fully expanded; the second harvest was taken on 2 August 2006 after the tenth leaf was fully expanded; the third harvest was taken on 30 August 2006 during grain filling; and the final harvest was on 30 September 2006 at maturity.

After harvest, ^{15}N abundance in the various parts of the plants and in the sand and nutrient solution was analyzed by mass spectrometry (DELTA^{PLUS}XP, Thermo Finnigan) and calculated as described by He et al. (2007).

Results and Discussions

Total N deposition and plant available N in a whole year

Figure 1 shows the total airborne N input in these three sites during the whole year of May 2005 to May 2006, covering a full summer maize-winter wheat rotation. We find a total N input of 88.2 kg N ha^{-1} yr^{-1} on average for the whole rotation, corresponding well with the result of 83 kg N ha^{-1} yr^{-1} measured at the Changping long-term experiment (He et al., 2007). The mean N deposition was 98.8 kg N ha^{-1} yr^{-1} over the same period when estimated by perennial ryegrass (Fig. 2). Thus the results of both the ITNI pot experiments and the long-term experiment suggest an N deposition of 80-90 kg N ha^{-1} yr^{-1} to a typical maize-wheat rotation at DBW, WQ and QZ in the NCP.

In the maize-wheat rotation, only 50 kg N ha^{-1} yr^{-1} was used directly by maize and wheat (Fig. 3), equal to 57% of the total N deposition (Table 1). The remaining 43% was found in the sand and solution. By comparison, 76 kg N ha^{-1} yr^{-1} was available for ryegrass (Fig. 4) and the ratio of plant available deposition to the total N deposition was 77% over the whole year (Table 1). Furthermore, the contribution of atmospheric N to the total N content of the sand-plant system per pot was 33.7%, 20.5%, and 50.5% for maize, wheat, and ryegrass (May 2005 to May 2006), respectively, suggesting a higher use efficiency of atmospheric N for ryegrass (Table 1).

Total N deposition and plant available N deposition at key growth stages of maize

Table 2 shows the total N deposition and plant available N from deposition for maize at key growth stages. Estimated total N deposition and plant available N from deposition during the whole maize growing season were 47.4 kg N ha^{-1} and 27.8 kg N ha^{-1}, respectively. The estimated total N deposition and plant available N from deposition were only 1.2 and 0.3 kg N ha^{-1} during the period from sowing to third-expanded leaf stage. During the period from three-leaf stage to ten-leaf stage, total airborne N deposition was 21.4 kg N ha^{-1} with 9.4 kg N ha^{-1} for maize available N from deposition. The value of total N deposition during the period from ten-expanded leaf stage to grain filling and the period from grain filling to maturity dropped to 12.1 and 12.7 kg N ha^{-1}, while plant available deposition was 10.1 and 8.1 kg N ha^{-1} during the two periods.

In summary, total airborne N input into the maize-wheat rotation system in the NCP is 80-90 kg N ha^{-1} yr^{-1}, and the plant available N from deposition for maize and wheat is c. 50 kg N ha^{-1} yr^{-1}, accounting for 55-60% of the total N deposition. Thus N deposition should be taken into account when calculating the N fertilizer requirements for winter wheat and maize.

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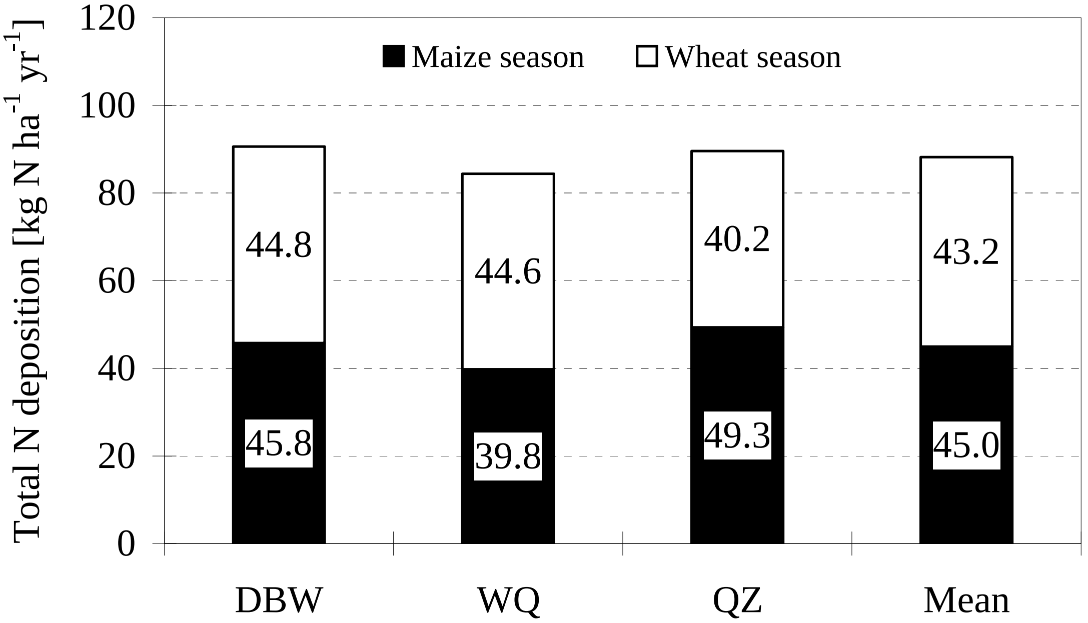

Figure 1. Atmospheric N deposition to a complete maize-wheat rotation from May 2005 to May 2006

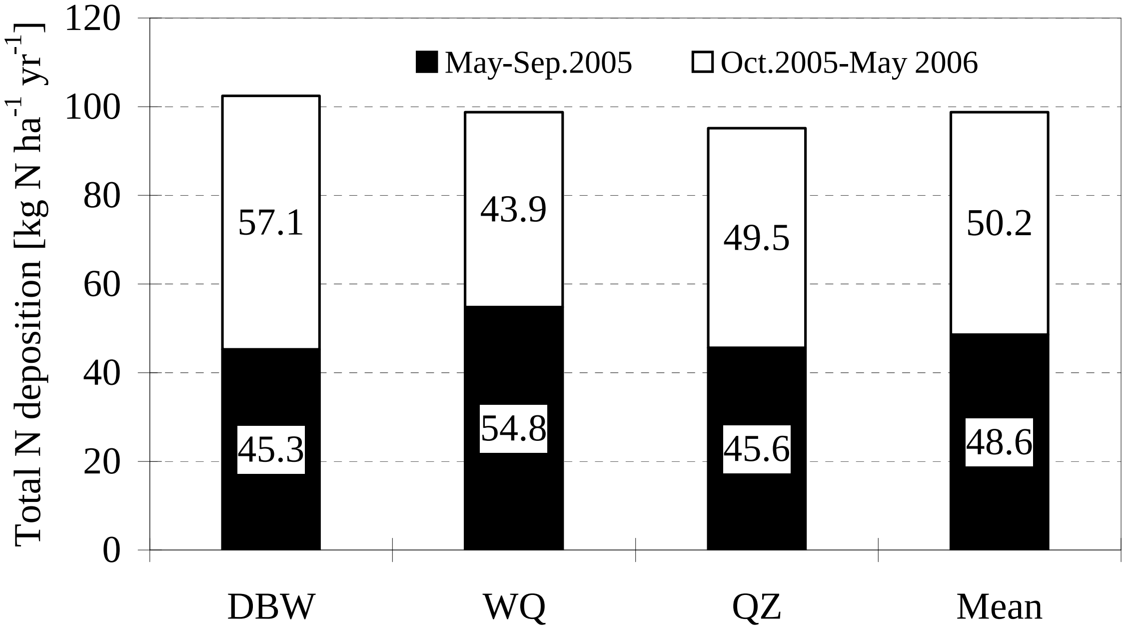

Figure 2 Atmospheric N deposition to ryegrass from May 2005 to May 2006.

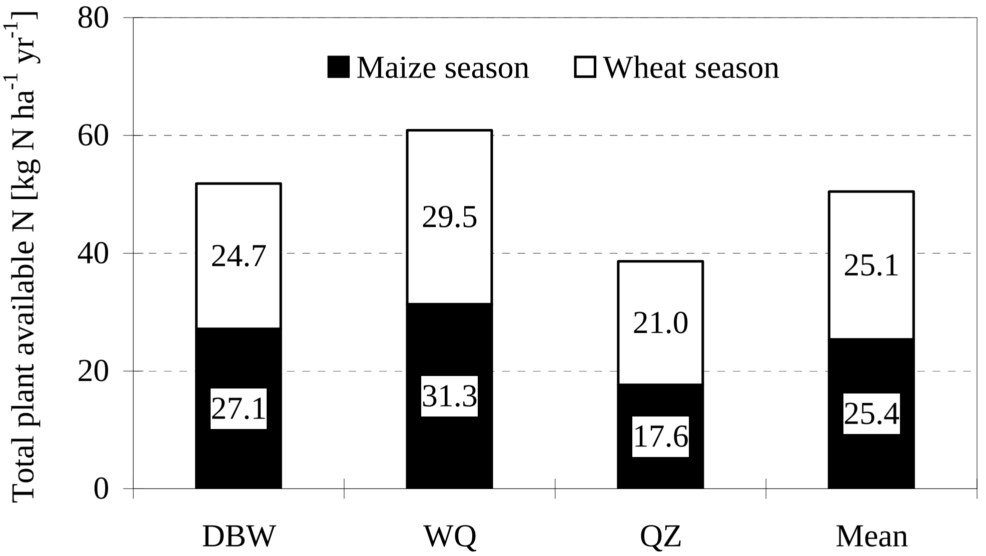

Figure 3 Total plant available N from atmospheric N deposition for a complete maize-wheat rotation from May 2005 to May 2006.

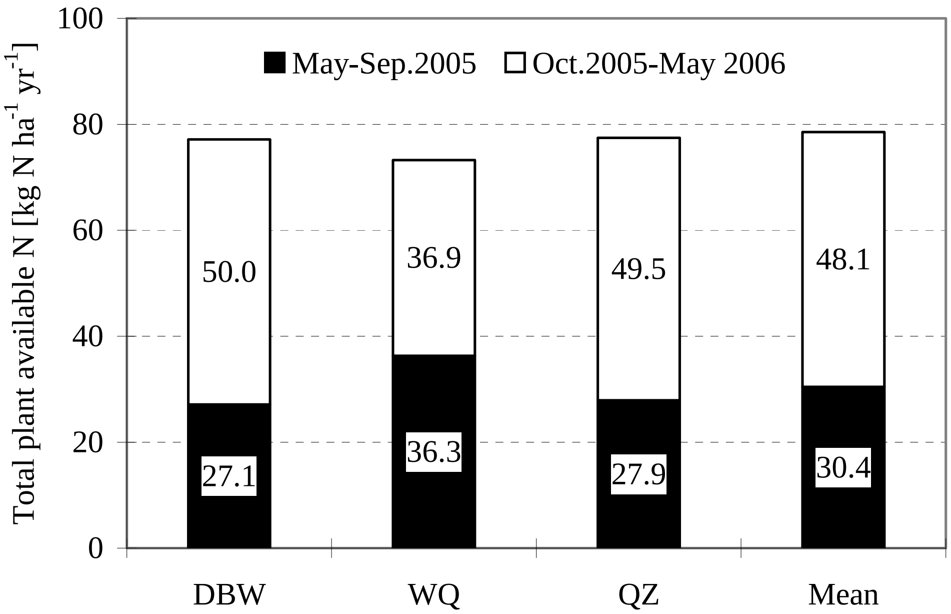

Figure 4. Total plant available N from atmospheric N deposition for ryegrass from May 2005 to May 2006.

Table 1. Ratio of plant available airborne N to the total N deposition and the ratio of N from deposition to total N content per pot (%)

Period	Monitoring crops	DBW	WQ	QZ	Mean
Ratio of plant available N from deposition to the total N deposition					
May-Sep. 2005	Maize	59.3	78.7	35.8	56.4
	Ryegrass	59.9	66.2	61.2	62.7
Oct. 2005-May 2006	Wheat	55.0	66.3	52.2	58.0
	Ryegrass	87.6	84.1	100.0	95.8
May 2005-May 2006	Σ(Maize + wheat)	57.2	72.1	43.1	57.2
	Σ(ryegrass)	75.3	74.2	81.4	76.9
Ratio of N from deposition to total N content per pot (%)					
May-Sep. 2005	Maize	36.8	28.9	35.6	33.7
Oct. 2005-May 2006	Wheat	19.4	22.4	19.7	20.5
May 2005-May 2006	Ryegrass	53.4	48.8	49.1	50.5

Table 2. Total N deposition and the N from this available to plants for maize at key growth stages from May to September, 2006.

Harvest stage	Days	Dry matter	Total N deposition	Plant available N	Ratio of plant available N from deposition to the total N deposition (%)
		g pot^{-1}	kg N ha^{-1}	kg N ha^{-1}	
Planting to Three-expanded leaf	15	0.3	1.2	0.3	23
Three-expanded leaf to Ten-expanded leaf	51	23.4	22.6	9.6	43
Ten-expanded leaf to Grain filling	79	90.2	34.7	19.7	57
Grain filling to Maturity	110	126.9	47.4	27.8	59