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Review paper

# A review of soil NO transformation: Associated processes and possible physiological significance on organisms

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ABSTRACT

NO emissions from soils and ecosystems are of outstanding importance for atmospheric chemistry. Here we review the current knowledge on processes involved in the formation and consumption of NO in soils, the importance of NO for the physiological functioning of different organisms, and for inter- and intra-species signaling and competition, e.g. in the rooting zone between microbes and plants. We also show that prokaryotes and eukaryotes are able to produce NO by multiple pathways and that unspecific enzymo-oxidative mechanisms of NO production are likely to occur in soils. Nitric oxide production in soils is not only linked to NO production by nitrifying and denitrifying microorganisms, but also linked to extracellular enzymes from a wide range of microorganisms.

Further investigations are needed to clarify molecular mechanisms of NO production and consumption, its controlling factors, and the significance of NO as a regulator for microbial, animal and plant processes. Such process understanding is required to elucidate the importance of soils as sources (and sinks) for atmospheric NO.



## 1. Introduction

Nitric oxide (nitrogen monoxide, NO) is a highly reactive constituent of the troposphere (Fowler et al., 2009) and is considered to be the main precursor of ground-level tropospheric ozone in rural areas (Chameides et al., 1994; Laville et al., 2011), impacting human health and plant productivity (Staffelbach et al., 1997; Ludwig et al., 2001). The main sources of NO in the troposphere are fossil fuel combustion, biomass burning, soil emissions and lightning (Delmas et al., 1997). Nevertheless agricultural soils can be the predominant NO source in rural regions, where the contribution of fossil fuel combustion is low (Bouwman et al., 2002; Butterbach-Bahl et al., 2009).

The global soil NO production is estimated at ~8.9 Tg N $a^{-1}$, of which ~15% is produced in Europe (IPCC, 2007). However, an earlier estimate by Davidson and Kingerlee's (1997) provided much higher values ranging from 13 to 21 Tg N $a^{-1}$. Such large divergence between estimates results from insufficient knowledge of the full range of soil microbial processes involved in NO production and consumption and the interactions of these processes with environmental variables.

Biological N transformation processes in soils, namely nitrification and denitrification, are usually considered the dominant sources of soil NO production. However, also abiotic chemical N transformations can be an important source (Ludwig et al., 2001; Butterbach-Bahl et al., 2011, 2013). Linking NO production, consumption and emission to the source and sink processes of nitrification and denitrification *in situ* still remains challenging, as they can occur simultaneously and in the same soil aggregates (Arah,

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