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Assessment of nitrogen fertilization for the CO_2 balance during the production of poplar and rye

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ABSTRACT

This study was designed to consider all nitrogen fertilizer-related effects on crop production and emission of greenhouse gases on loamy sandy soils in Germany over a period of nine years (1999–2007). In order to set up a CO_2 balance for the production of energy crops, different nitrogen pathways were investigated, such as direct N_2O emissions from the soil and indirect emissions related to NO_3 leaching and fertilizer production. Fluxes of N_2O were measured in an experimental field using closed chambers. Poplar (*Populus maximowiczii* × *P. nigra*) and rye (*Secale cereale* L.) as one perennial and one annual crop were fertilized at rates of 0 kg N ha^{-1} yr^{-1}, 75 kg N ha^{-1} yr^{-1} and 150 kg N ha^{-1} yr^{-1}. The mean N_2O emissions from the soil ranged between 0.5 kg N ha^{-1} yr^{-1} and 2.5 kg N ha^{-1} yr^{-1} depending on fertilization rate, crop variety and year. The CO_2 fixed in the biomass of energy crops is reduced by up to 16% if direct N_2O emissions from soil and indirect N_2O emissions from NO_3 leaching and fertilizer production are included. Taking into account the main greenhouse gas emissions, which derive from the production and the use of N fertilizer, the growth of poplar and rye may replace the global warming potential of fossil fuels by up to 17.7 t CO_2 ha^{-1} yr^{-1} and 12.1 t CO_2 ha^{-1} yr^{-1}, respectively.

Contents

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1. Introduction

In order to fulfill the requirements of the Kyoto Protocol and face climate change, the production of biomass has been intensified worldwide and has a great potential, which is far away to be fully used yet [1,2]. Energy crop cultivation makes it possible to remove CO_2, and thermal conversion of these crops can act as a substitute for fossil fuels. A positive effect on CO_2 mitigation can be expected, however, this might be reduced by other greenhouse gases, which are released during the production and consumption of energy crops [3–6]. Emissions may occur either directly during agricultural operations such as fertilizing, ploughing and harvesting, or indirectly as a consequence of nitrate leaching, or during production and transport of fertilizers and pesticides. This study is not designed to employ a full life cycle assessment (LCA), which reflects a complete evaluation of all greenhouse gas sources and socio-economic aspects as emphasized by Hanegraaf et al. [7]. The focus of this study is on the use of mineral nitrogen fertilizer and its effect on the CO_2 balance of the production of one annual energy crop (rye) and one perennial energy crop (poplar) on a loamy sandy soil in Northeast Germany.

According to Wegener et al. [8], about 113 million tons of CO_2 equivalents are emitted from the German agricultural sector (Fig. 1). This amount does not include emissions linked with the production of mineral fertilizers. One-third (31.5%) of the agricultural sector derives from agricultural soils in the form of nitrous oxide (N_2O), a greenhouse gas, which is very important due to its global warming potential, 298 times higher than that of CO_2. Thus the CO_2 fixing capacity of renewable energy crops may be constrained. Agronomic practices such as tillage, harvesting and fertilizer applications can significantly affect the production and consumption of N_2O due to alteration of soil physical and chemical characteristics, and biochemical activities. Soil cultivation and precipitation affect the soil air exchange rate and thus influence microbial aerobic and anaerobic processes such as nitrification and denitrification [9–11]. Both processes may be stimulated after the application of nitrogen fertilizer, as reported by Freney [12].

Even the production of mineral nitrogen fertilizers results in considerable N_2O emissions besides the emission of CO_2 during this energy-consuming process [13,14]. In Western Europe 1.8% of total CO_2 and N_2O emissions and 0.9% of total energy consumption derive from the fertilizer industry [15]. Consequently, the emission of greenhouse gases through this pre-chain of biomass production comprises an important component of agricultural LCA [16]. It has been reported that the production of short rotation coppices such as poplar in particular needs only a low supply of nitrogen fertilizer [17,18]. Thus it may be hypothesized that poplar has a greater potential for reducing CO_2 emissions than the annual crop rye. The overall goal is to obtain more verified information about the ecological drawbacks of nitrogen fertilization and to find out at what fertilizer rate the highest net CO_2 sequestration can be expected from the production of rye and poplar.

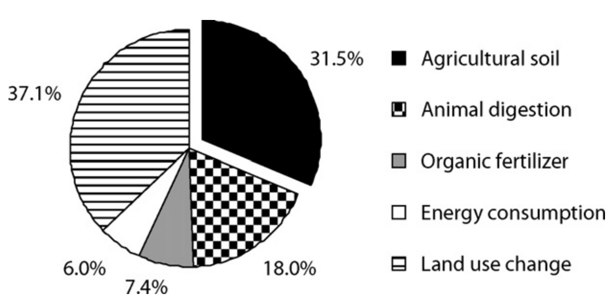

Fig. 1. Sources of greenhouse gases expressed as CO_2 equivalents from agriculture in Germany according to Wegener et al. [8]. Greenhouse gas emissions from agricultural soils were the main subject of this study.

2. Methods

2.1. System boundary

This study focused on the growing period of energy crops and the utilization of nitrogen fertilizer in the field. From this on-farm stage, the main components included in the CO_2 balance are both, the carbon fixation by above-ground crop biomass and direct and indirect greenhouse gas emissions from the soil. Carbon sequestration by below-ground biomass and by soil was not included in this study.

Among the pre-farm stages, only the production of mineral N fertilizer is taken into consideration, since it is known as a highly energy-consuming process [19,20]. In Germany, 1.8 million tons of mineral fertilizer nitrogen was sold in 2007/2008. This amount includes 0.81 million tons of calcium ammonium nitrate (CAN) nitrogen [21]. Since CAN played the main role among all nitrogen fertilizers applied in German agriculture and also in other European countries during the last ten years, this type of mineral nitrogen fertilizer has been evaluated in terms of CO_2 equivalents related to its manufacturing process [22].

Greenhouse gas emissions arising during the transport of raw materials and their products have been reported as playing a minor role of between 1% and 3% of total emissions during biomass production [23], and have therefore been neglected. Biomass yields were obtained after harvesting; however harvesting and post-harvest processes themselves have not been considered in this CO_2 balance.

2.2. Study area

The study was performed from February 1999 to December 2007 on an experimental field at the Leibniz-Institute for Agricultural Engineering (ATB) in Potsdam, Germany (52°26′N, 13°00′E). The topsoil (0–30 cm) can be characterized as loamy sand with a carbon content of up to 0.8% and pH 6.0 (Table 1). Deeper layers are relatively rich in organic matter, which must be due to former applications of lake sediments and other organic enrichments during a period of fruit-growing in the 1980s and before. The mean air temperature and precipitation during the study period were 10.1 °C and 580 mm yr^{-1}.

2.3. Field design

The experimental field with a total area of 4.1 ha was parcelled out for the cultivation trials in 1994 [24]. In our study, a CO_2 balance was drawn up for one perennial and one annual crop. The perennial crop was poplar (*Populus maximowiczii* × *P. nigra*), a short rotation crop with a four-year rotation period (study period 1999–2007), and the annual crop was rye (*Secale cereale* L.). Only the six years (1999, 2001, 2003, 2005, 2006 and 2007) when rye was planted at the same site were considered in case of rye. Both crops were arranged in

Table 1
Soil characteristics with grain sizes from Scholz [46] and C_{tot} and N_{tot} analyses from December 2005.

Soil horizon	Depth (cm)	Grain size (%)			C_{Tot} (g kg^{-1})	N_{Tot} (g kg^{-1})
		Sand	Silt	Clay		
Ap	0–30	77.9	15.9	6.2	7.6	1.04
Ah	30–60	75.7	18.3	6.0	5.8	0.75
Bt	60–82	62.0	20.6	17.4	5.8	0.49
Cv	>82	62.1	25.7	12.2		