Control of Greenhouse gas emissions in a short rotation coppice (SRC) by reduced nitrogen fertilisation

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Abstract

A short rotation coppice was established on a loamy sand soil in the Northeast of Germany in 2008. During the initial stage of the trees poplar (*Populus maximovizcii x P. nigra*) and willow (*Salix viminalis*) different pathways of nitrogen flux were measured.

The experiment was arranged in a random block design with three levels of N-fertiliser (0, 50, and 75 kg N ha^{-1} yr^{-1}). After 2 years the trees were harvested for the first time. In the meantime environmental side effects were measured. Nitrous oxide emissions were measured by the closed chamber technique and nitrate leaching by Self-Integrating Accumulators (SIA).

After the first harvest it could be shown that fertilisation with mineral nitrogen did not affect the yields of both tree species. Although relatively high emissions of N_2O could be observed within the first year of planting, the maximum of nitrogen loss as N_2O was only 0.2 kg N ha^{-1} yr^{-1}. However, nitrogen fertilisation led to leaching of nitrogen. The application of 75 kg N ha^{-1} yr^{-1} caused an average increase of N leaching in the willow and poplar plots of 25 kg N ha^{-1} yr^{-1} and 40 kg N ha^{-1} yr^{-1}, respectively.

First results of the new established SRC indicate a more effective and environmentally sound wood production without the use of mineral nitrogen fertiliser.

Key words: Bioenergy, poplar, willow, N_2O, nitrogen balance.

1. Introduction

The production of biomass has been intensified worldwide during the last years. However, its potential to face climate change is far away to be fully used yet (Sims et al. 2006). Energy crop cultivation removes CO_2 from atmosphere and thermal conversion of these crops can replace fossil fuels. This form of CO_2-neutral energy consumption, however might be constrained by other greenhouse gases, which are released during the production and consumption of energy crops (Jorgensen et al. 1997, Crutzen et al. 2007).

The flux of greenhouse gases in agricultural soils is controlled by natural factors (soil type, temperature, precipitation) and by the soil management such as tillage and fertilisation. According to Djomo et al. (2011) fertilisation in SRC is a source of 12 to 77 % of the greenhouse gas (GHG) emissions of the whole wood production, depending on the application and the type of fertiliser used.

Particularly nitrogen applied as fertiliser to increase the biomass yield, induces the emission of N_2O. This GHG may play a key role in a life cycle assessment due to its high global warming potential. Average values for N fertiliser induced N_2O emission factors are reported for agricultural fields and grassland with a range of 0.5 to 5% (IPCC 2006). Relatively low values have been found for SRC (Hellebrand et al. 2008, Kern et al., 2010).

The objective of this study is to prove whether reduced nitrogen fertilisation may influence the yield of woody biomass on a site with low supply of nutrients and water. Among the environmental drawbacks during the production of willow and poplar, nitrous oxide emissions have been analysed besides the leaching of nitrate in order to optimise the fertilisation with nitrogen and to reduce environmental impacts during the production of energy crops.

2. Material and Methods

2.1. Study site

The experimental site in Potsdam-Bornim (52.44° N / 13.013 E) is characterised by a ground moraine. The soil is classified as Gleyic Cambisol with sand and small amounts of humus and silt within the upper 60 cm. The mean annual precipitation is 632 mm, and the mean annual temperature (average for the period 2000 - 2009) is 9.9 °C.

2.2. Field design

Poplar (*Populus maximovizcii x P. nigra*, clone max 4) and willow (*Salix viminalis*, clone Inger) treatments are examined in terms of yield, N_2O emissions as well as nitrate leaching. The experiment consists of three N-fertilisation treatments (0, 50, and 75 kg N ha^{-1} yr^{-1}). For the trial, a randomised block-design setup was chosen with four replicates. The experiment consists of two square large-plots (1800 m² each). The subplots have a size of 9 m x 10 m. In April 2008 the test cuttings were planted with 0.5 m distance in the row and with 1 m distance between the rows. To minimise boundary effects, only 48 internal plants of each plot were examined. At the beginning of each vegetation period (June 16, 2008; April 16, 2009; April 20, 2010), nitrogen was applied in form of calcium ammonium nitrate (CAN). In the winter of 2009 the aboveground biomass was harvested with a brush cutter. The main study period for the nitrogen balance run from May 2008 to April 2010.

2.3. N_2O emissions

The investigations of the seasonal variability of the nitrous oxide emissions started in June 2008 and were conducted four times a week. The soil was incubated *in situ* in closed chambers for 90 min in the morning (Figure 1). After this time accumulated gases were sampled by evacuated glass vials and analysed by gas chromatography and ECD at the same day.

FIGURE 1: Greenhouse gas measurements within the rows of the short rotation coppice.

2.4. Nitrogen leaching

For the measurement of area-related nitrate leaching, Self-Integrating Accumulators (SIA) filled with a resin-quartz sand mixture were installed at a depth of 90 cm, below the main root zone of willow and poplar trees according to *Bischoff* (2009). The SIA were set laterally below the undisturbed soil. They remained in the soil for half year periods, collecting and adsorbing nitrate from the leachate. After that time the SIA were excavated and nitrate was extracted from the resin material using 1 M NaCl. Results are expressed in leached nitrogen per hectare.

3. Results and Discussion

3.1. Biomass yield

Wood yields of poplar and willow did not correlate with the rate of nitrogen fertilisation during the first two years of plant production. Both energy crops produced yields between 1.3 and 1.5 t ha^{-1} yr^{-1}, which were considerably lower compared to other studies. This may be explained by the weed competition in the initial stage, the low precipitation and unfavorable soil texture. The fertiliser did not affect the yield because a high amount of fertiliser was leached and the nitrogen demand of the trees could have been met by atmospheric nitrogen deposition and by mineralisation of soil organic matter.

3.2. N_2O emissions

With increased nitrogen fertilisation the rates of N_2O emission increased. One exception was the beginning of 2009, when the emission rates of fertilised and non-fertilised plots did not differ. This can be explained by the soil management during the initial stage of the new plantation, which probably resulted in accelerated soil mineralisation and thus in a high nitrogen supply (Figure 2). In the plots with 75 kg N ha^{-1} yr^{-1} the mean fertiliser induced emission factors (N_2O flux of fertilised plot minus N_2O flux of non-fertilised plots / nitrogen fertilisation rate) for poplar and willow were 0.19% and 0.11%, respectively. These emission factors for N_2O are much lower compared to annual crops. Consequently poplar and willow seem to be a promising option for an environmentally sound use of arable land.

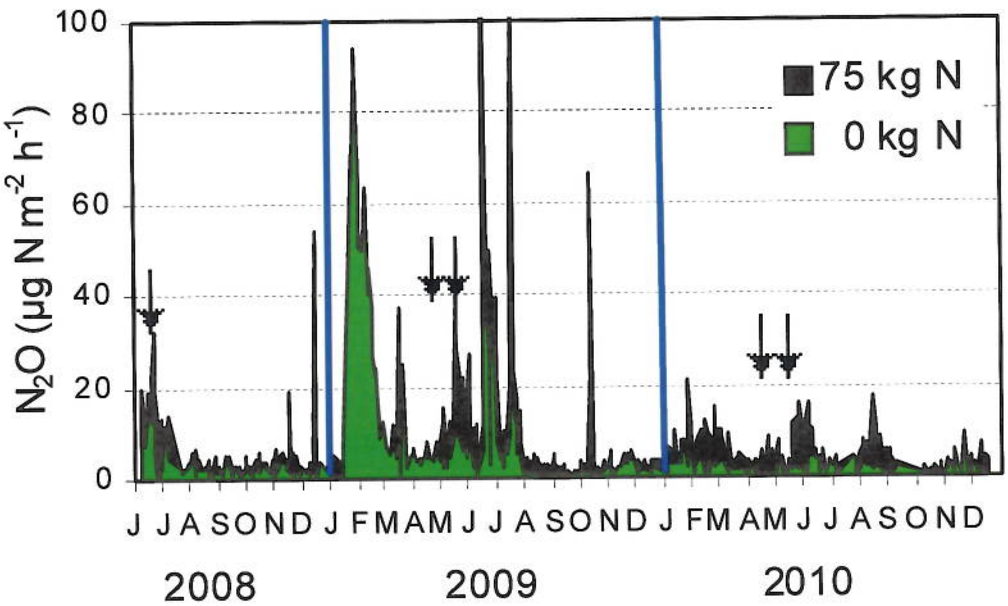

FIGURE 2: Nitrous oxide emission rates from the soils with poplar. Each daily value is the mean of 4 replications. Arrows indicate the time of fertiliser application.

3.3. Nitrogen leaching

Despite a high hydraulic conductivity and a low sorption capacity of the sandy soils, in the vegetation periods from May to October only small amounts of nitrate were leached from the top soil below the main root zone of 0.9 m. Most of the nitrate was leached during the winter, when evapotranspiration could be neglected. From the non-fertilised treatments the vertical nitrogen loss via seepage ranged between 3 and 16 kg N ha^{-1} yr^{-1} and increased with the level of fertilisation.

Leaching rates of nitrate were higher in the poplar plots than in the willow plots. Highest leaching rates were measured from the treatments with 75 kg N ha^{-1} yr^{-1} resulting in a maximum of 37 kg N ha^{-1} yr^{-1} and 60 kg N ha^{-1} yr^{-1} for willow and poplar, respectively. That means that more than 50% of the nitrogen applied as fertiliser was leached from the main root zone.

3.4. Nitrogen balance

Figure 3 shows the balance of the nitrogen input by atmospheric deposition and nitrogen fertilisation as well as the output of nitrogen due to the removal by harvested crops, leaching and emissions of N_2O. A further loss of N_2 due to denitrification has to be taken into account, which is not reflected by this picture. The amount of nitrogen incorporated into shoot biomass was only 14 - 34% of the applied fertiliser corresponding with results given by *Jug* et al. (1999). The nitrogen demand of willow and poplar was met by 46 - 70% by deposition, which implies that the soil under study is sufficiently supplied with a low rate of nitrogen fertilisation.

It could be shown in this study that the major path of nitrogen applied as fertiliser was lost by leaching. In contrast to the leaching loss, the nitrous oxide emissions, induced by fertilisation, were rather small. Another significant fate of nitrogen fertiliser was the increase of weed biomass primarily in the willow plots. The weed in the high fertilised treatments contained additional 25 kg N ha^{-1} yr^{-1}.

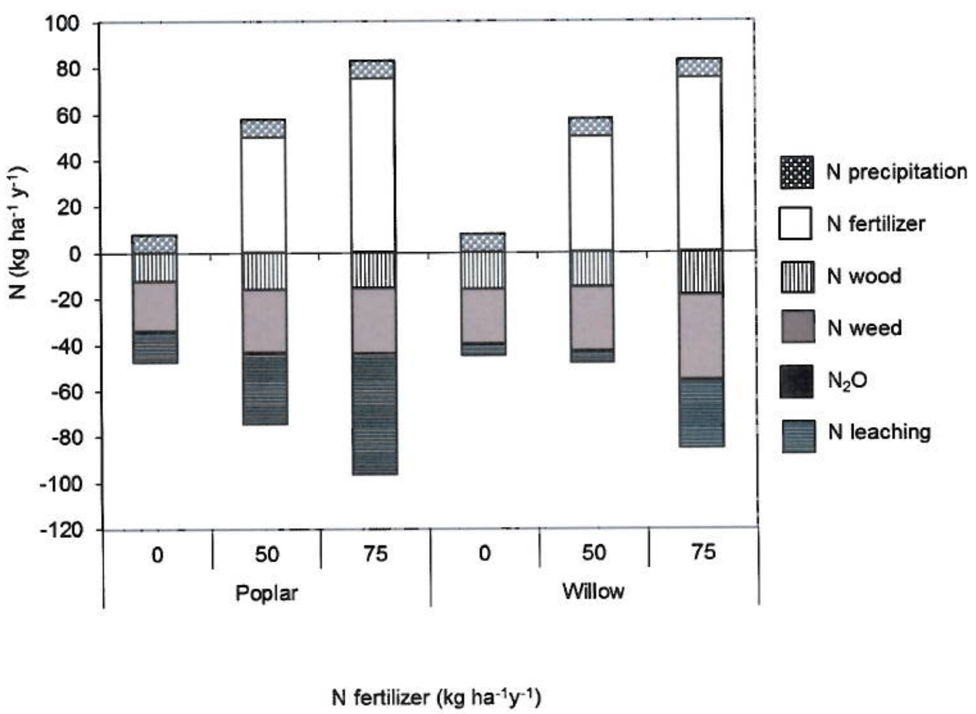

FIGURE 3: Nitrogen balance in a short rotation coppice during the initial stage 2008-2010.

4. Conclusions

Reducing the input of nitrogen fertilisers to arable land must not result in a decrease in biomass yield, but it has positive effects on the environment. It is one way of mitigating direct and indirect greenhouse gas emissions including those CO_2 equivalents required for the production of mineral nitrogen fertilisers. Further research is needed to give answers how far nitrogen supply for energy crop production is guaranteed on a long-term scale when nitrogen fertilisation is reduced or even omitted. The benefit of fertiliser savings may contribute to the excellence of perennial energy crops, which can enhance the distribution of poplar and willow in agriculture.

Acknowledgements

The authors greatly appreciate the grant given by the Federal Ministry of Food, Agriculture and Consumer Protection and the Fachagentur für Nachwachsende Rohstoffe (FNR). Further we acknowledge the assistance of Astrid Zimmermann, Jutta Venske, Angelika Krüger, Ulrike Knuth and Markus Schleusener.

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