Greenhouse gas emissions from cultivation of energy crops – is it important?

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Replacing fossil fuel-derived energy with biomass-derived energy is commonly emphasized as a means to reduce CO_2 emissions. However, our study highlights the risk of large greenhouse gas emissions when wastes from bioenergy production are recycled as fertilizer for energy crops. Crop management affects the magnitude of these emissions, which in some cases negate a considerable fraction of the global warming savings associated with biofuels.

Biofuels for self-sufficiency

A future goal within organic farming is to reduce the reliance of fossil fuels and reduce greenhouse gas emissions via local production of renewable energy. This could include bioethanol and biogas produced from energy crops and animal manure. Currently CO_2 from fossil fuel combustion accounts for 57% of the global greenhouse gas emissions, whereas the strong greenhouse gases nitrous oxide (N_2O) contributes with 8% (IPCC, 2007). Agricultural activity is the dominant source of N_2O, which is mainly associated with the use of nitrogen based fertilizers in agricultural production.

Field emissions are uncertain

Agro-biofuels are expected to reduce the emissions of greenhouse gases because CO_2 emitted during the combustion of the biofuels has recently been taken from the atmosphere by the fodder or energy crop, thus CO_2 is recycled between atmosphere, crop and biofuel. By changing from fossil fuels to biofuels the organic farmer avoids emitting fossil fuel-derived CO_2 into the atmosphere. However, a recent analysis of global emission data proposes that accelerated emissions of N_2O associated with the production of biomass for biofuel purposes will outweigh the avoided emissions of fossil fuel-derived CO_2 (Crutzen et al., 2008).

Objective: Greenhouse gas balances

In the present study we examined the effects on N_2O emissions when waste-stream material from a biogas plant is recycled as fertilizer for a maize energy crop within an organic cropping system. Furthermore, we assessed sustainability in terms of greenhouse gas balances for co-production of bioethanol and biogas from maize. This is compared to the greenhouse gas balance for winter rye as an alternative energy crop.

N_2O measurements in field experiment

The maize crop was sown on the 14th of May 2008, and on the same day anaerobic digested cattle slurry + maize residue was applied as organic fertilizer via simulated injection (Fig. 1). For comparison untreated cattle slurry was included in the experiment and both fertilizers were applied at a rate of 150 kg plant available N ha^{-1}. Emissions of N_2O were monitored regularly using two-part static chambers (Fig. 2). We found elevated emissions that persisted for almost two months, quite often at very high rates. The cumulative N_2O emissions during the two months amounted to 895, 583 and 46 mg N_2O-N m^{-2} in the digested slurry + maize, untreated slurry and control treatments, respectively. Thus, more N_2O was emitted from anaerobic digested slurry as compared to untreated slurry. The experiment was replicated in 2009, but here we found the opposite effect of anaerobic digestion on the N_2O flux. We believe that the fermentation process needs to be completely finalized in the biogas plant in order to obtain a reducing effect of anaerobic digestion on field emissions of N_2O related to the application of slurry-based fertilizers. The N_2O emission factor varied between 2.3 and 5.7% of the applied nitrogen (Table 1), which is substantial higher than the 1%-loss proposed by the Intergovernmental Panel on Climate Change (IPCC) for direct losses of N_2O from organic residues.

Comment [mthy1]: Later detailed analyses of the applied materials revealed differences in the N application rates. The correct N2O emission factors varied between 3.0 and 3.4%.

No advantage of fertilizing maize

The maize biomass was used for co-production of bioethanol and biogas. A greenhouse gas balance was made in order to highlight how much the field emissions of N_2O accounted for in comparison to the fossil fuel-derived CO_2, which was avoided by producing the biofuels. In general, there was no greenhouse gas advantage of fertilizing the maize crop, because the extra crop yield - and thereby biofuel production - was offset by increased field emissions of N_2O (Fig. 3A). This balance does not include fuels used by farm machinery and fuels used during the production of the biofuels, thus the actual net CO_2 reduction was lower than illustrated in Figure 3A, which means that the blue part of the column should be reduced even further.

Winter rye is a potential energy crop

The reason for the high N_2O emission after simulated injection of slurry-based fertilizers is partly that the fertilizers were applied before the maize crop was present to take up the nitrogen. Furthermore, injection of the liquid materials produced anaerobic zones in the soil with high availability of nitrogen and labile carbon compounds, which is favorable conditions for denitrification and thereby N_2O production. Finally, the maize was sown late in spring to ensure high soil temperatures, which also stimulates the microbial turnover of nitrogen. In comparison, a similar experiment was carried out in a winter rye energy crop in March 2009, but under different conditions regarding three important aspects: 1) The crop was present when the materials were applied, 2) materials were applied on the soil surface simulating application by trail hoses and 3) soil temperatures were predominantly in the range 0 to 5 °C. The greenhouse gas balance for bioethanol and biogas produced from the winter rye crop shows that application of the slurry-based fertilizers increased the crop yield without increasing the N_2O emissions to the same extent (Fig. 3B). The rye yield was similar to the maize yield, but the conversion of rye biomass into bioethanol and biogas was less efficient. Despite the slightly lower net CO_2 reduction we find that winter rye is a potential alternative to maize as an energy crop. It is important that the organic farmers have several options for energy crops as a high biodiversity in the agricultural landscape reduces the spread of pests and diseases between fields.

Crop and management specific emission factors

The N_2O emission factors were significantly lower when the slurry-based fertilizers were applied to winter rye as compared to maize (Table 1). In the literature, greenhouse gas balances for agro-biofuels are very often based on the IPCC emission factor of 1% to estimate field emissions of N_2O. For some crops and fertilizer managements this factor may underestimate N_2O as a greenhouse gas source. Maize is the most common energy crop grown in Europe and USA, and we found emission factors of 2.3-5.7% when waste-stream material from a biogas plant was used to fertilize maize energy crops. We therefore advocate for the use of crop and management specific N_2O emission factors in greenhouse gas balances in order to focus on growing the energy crops with the highest greenhouse gas reduction potential.

References

Crutzen, P.J. et al. (2008) N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmos. Chem. Phys. 8, 389-395.

IPCC (2007) Climate Change 2007: Synthesis Report.

Text for figures

Figure 1. Simulated injection of waste-stream material from a biogas plant after sowing of maize

Figure 2. Emission of N_2O was measured by manual gas sampling in gas-flux chambers

Figure 3. Greenhouse gas balance, expressed as CO_2-equivalent (CO_2-eq.), for biofuels produced from maize (A) or winter rye (B) fertilized with either anaerobic digested slurry + maize residue or raw slurry compared to unfertilized control. The blue part of the bars indicate the net CO_2 reduction when emissions of N_2O (red part) is taken into consideration.

Photo of winter rye: Our study showed that winter rye is a potential alternative to maize as an energy crop