Wise use of drained peatlands – carbon balance of bioenergy crops on cutover peatlands

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Summary

Four years of continuous eddy covariance measurements of CO_2 exchange from a bioenergy crop cultivation on a cutover peatland in eastern Finland are presented in this paper. The cultivation of reed canary grass as a bioenergy crop is gaining importance in Finland. Striking differences existed in the amount and distribution of precipitation and site hydrological conditions among the different measurement years. Years 2004 and 2007 were wet and 2005 and 2006 were dry compared to climatic normals for the region. The ecosystem accumulated atmospheric C in all measurement years, being a strong sink during wet years and a weaker one during dry years. The ecosystem tended to remain a sink for C during wet years even after accounting for the C losses in the form of harvested biomass. These results suggest that the cultivation reed canary grass is a promising land use option on cutover peat soils in Finland.

Key index words: reed canary grass, eddy covariance, drained peatlands, land use change, boreal environments, greenhouses gases, carbon balance, peat extraction for energy

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Introduction

In Finland, the area under the cultivation of reed canary grass (*Phalaris arundinacea* L.) as a bioenergy and/or fibre crop is fast increasing. Cultivation of reed canary grass (RCG) was initiated in the mid 1990s in Finland and thus, is a recent development. Although RCG can be grown on most soil types, humus-rich, wet soils have been recommended for its cultivation. The crop thrives well with the highest biomass yields on such soil types (Venendaal *et al.,* 1997). As a result, RCG is generally cultivated in Finland on cutover peatlands abandoned after peat extraction. Agricultural organic soils are the soil types with a high environmental risk. Owing to drainage, these soils have been known to be persistent sources of CO_2 (Ahlholm and Silvola, 1990; Lohila *et al.*, 2004; Maljanen *et al.*, 2004). They are known to release large amounts of CO_2 even when they are cultivated with forage grasses, barley or other cereals (Lohila *et al.,* 2004; Maljanen *et al.*, 2004). While several studies have documented the carbon balance of forage grasses and cereal crops on organic soils, there is hardly any information on the carbon balance of a bioenergy crop such as RCG on these risky soil types.

Moreover, to understand whether a certain bioenergy system is sustainable, it is crucial to assess in detail the greenhouse gas implications of bioenergy use by means of a life cycle analysis (Schlamadinger *et al.,* 1997). With this background in view, we are measuring greenhouse gas balance of RCG cultivation on an organic soil (a cutover peatland) in eastern Finland since April 2004 employing micrometeorological eddy covariance and chamber techniques. The main objectives of this paper are to quantify the net ecosystem CO_2 exchange during four years with varying climatic conditions.

Materials and methods

The study site is a 15-ha cutover peatland with reed canary grass cultivation in the Linnansuo peat extraction area in the Tuupovaara village in eastern Finland The site is located at 62° 30’ N latitude and 30° 30’ E longitude. An adjacent, active peat extraction area serves as a control site. Based on the 1961-1990 climatic normals, the region experiences a mean temperature of -11.9°C in January and 15.8°C in July. Annual mean temperature of the region is 2.0°C and annual precipitation amounts to 600 mm. The mean annual duration of snow cover in the region is 183 days with a mean annual snow depth 63 cm.

The eddy covariance system consists of a 3-D sonic anemometer (CSAT-3, Campbell Sci.) and an open path infrared CO_2/H_2O analyser (Li-7500, LI-COR). The instruments are mounted at a height of 3.7 m above the ground and aligned at an angle of 225°, as the predominant winds in the region are from southwest. Supporting measurements include air temperature, air relative humidity and pressure, net radiation and its components, photosynthetically active radiation wind speed and direction, soil temperature profile, precipitation, soil water potential, soil moisture, water table level and snow depth.

The measurements began on March 23, 2004 and have been continuing since then. The eddy covariance data are measured at a frequency of 10 Hz and the raw data are stored in a binary format on storage devices. Real time flux calculations are performed to obtain 30 min averaged flux estimates. Post processing of the raw data was performed using the Edire software developed at the University of Edinburgh. We filled missing data gaps employing the online eddy correlation data gap filling facility developed at the University of Tuscia, Italy. A detailed description of the data gap filling and flux partitioning procedures is available at http://gaia.agraria.unitus.it/database/eddyproc/.

Results and discussion

Climatic conditions during the measurement period

The volumetric soil water content measured at 2.5 (q2.5) and 10 cm (q10) soil depths during May through September of each year are given in Fig. 1. Daily precipitation amount and snow depth are also presented in this figure. Striking differences existed in the amount of rainfall received during the various growing seasons. The May through September period in 2004 was the wettest (554 mm), relatively drier in 2007 (423 mm) and the driest during 2005 and 2006 (246 and 249 mm, respectively). Compared to a regional 30-year (1971-2000) average value (338 mm), the May September rain amount was higher by 164% in 2004, by 125% in 2007 and 73 and 74% lower in 2005 and 2006, respectively. Thus, 2004 and 2007 growing seasons were wetter and 2005 and 2006 seasons were drier than normal.

The soil moisture at 30 cm depth was consistently high with little variation among the years. q2.5 varied the most, followed by q10. After the snowmelt in late April 2004, q2.5 was high. While the increasing evaporative demand caused a subsequent decline in q2.5, intermittent rain events kept recharging the water table and increasing the moisture content. The range of variation in q2.5 during May through September 2004 was from 0.8 to 0.4 m^3 m^{-3} with a narrower variation range in q10. The snow cover during January through mid April in 2005 was high. After the snowmelt in mid April, a long dry spell until mid May kept the soil moisture at both 2.5 and 10 cm low. Rain

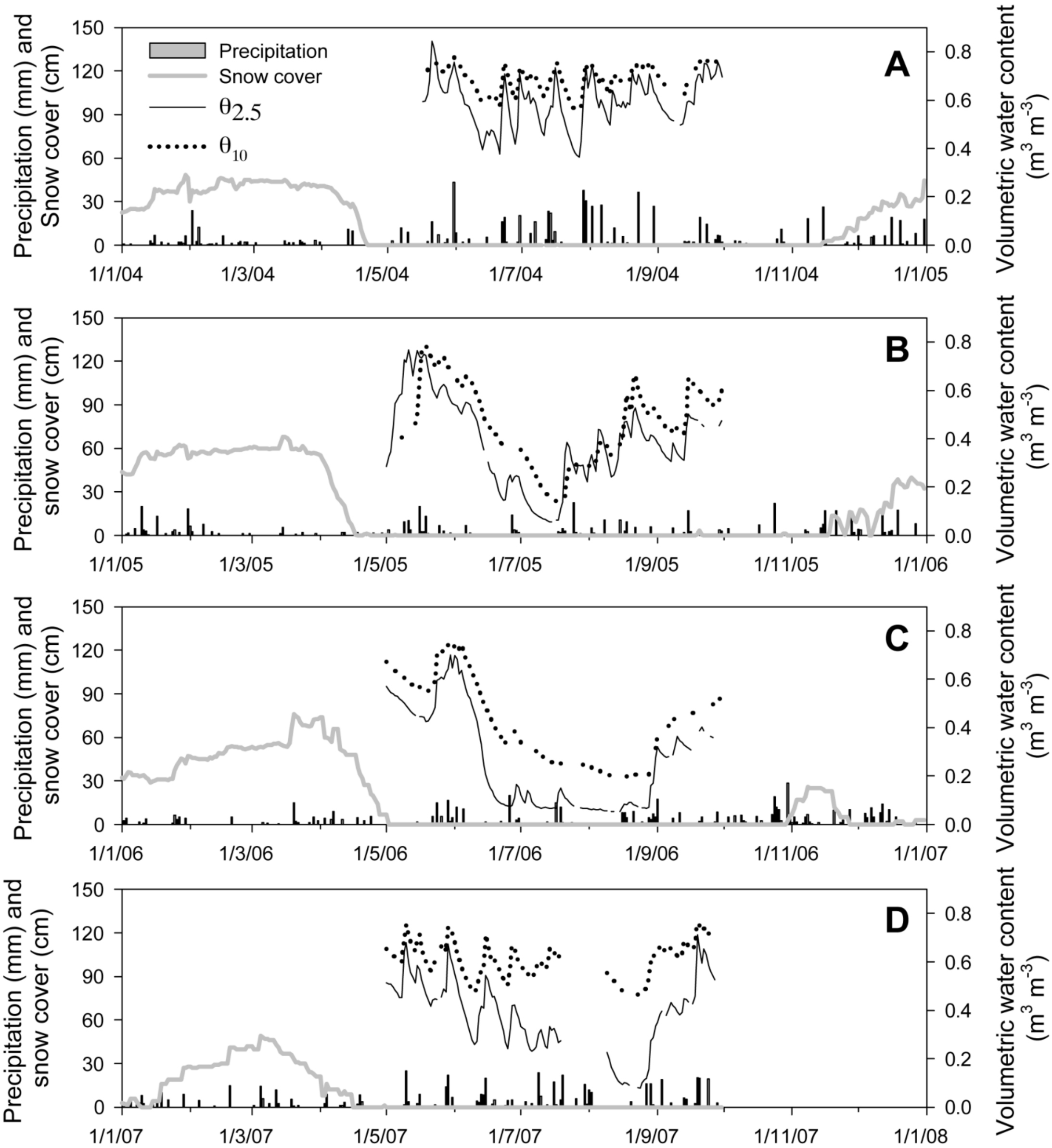

Figure 1. Seasonal trends of daily total precipitation, snow depth and volumetric water content measured at 2.5 and 10 cm depths below the soil surface (measured between May and September in each year) during (A) 2004, (B) 2005, (C) 2006 and (D) 2007.

events during mid May temporarily increased the moisture content. Following this, the moisture content at both depths declined continuously reaching a low of 0.1 $m^3 m^{-3}$ during mid July. Subsequent rain events increased q2.5 and q10. However, the surface layer remained dry throughout the growing season. The snow melted in the first week of May in 2006. The soil moisture at 2.5 and 10 cm depths were high in the first week of June. However, continuous dry spells throughout the major part of the growing season resulted in low soil moisture at both depths during the season. Comparatively, the snow cover in early part of the year in 2007 was the least. Intermittent rain events during the growing season kept the soil moisture, particularly at 10 cm depth at moderately high levels. The 2.5 cm soil moisture reached the lowest values during late August.

Daily, seasonal and annual CO_2 exchange

Daily integrated values of gross photosynthesis (GPP) and ecosystem respiration (TER) during the period from April 2004 to September 2007 are shown in Figure 2A and net ecosystem CO_2 exchange (NEE) in Figure 2B. Peak daily rates of GPP were high during wet years and low during dry years. The maximum daily GPP value in 2004 was -15.8 g C $m^{-2} d^{-1}$, whereas in 2005, 2006 and 2007, the peak values were -8.5, -9.8 and -11.9g C $m^{-2} d^{-1}$, respectively. The peak GPP occurred during mid July in 2004, early July in 2005 and 2007 and late June in 2006. Maximum daily ecosystem respiration (TER) rates in 2004, 2005, 2006 and 2007 were 7.6, 7.1, 5.3 and 6.3 g C $m^{-2} d^{-1}$, respectively. Peak NEE rates in 2004, 2005, 2006 and 2007 were -9.6, -4.5, -5.5 and -7.5 g C $m^{-2} d^{-1}$, respectively. The daily variation in

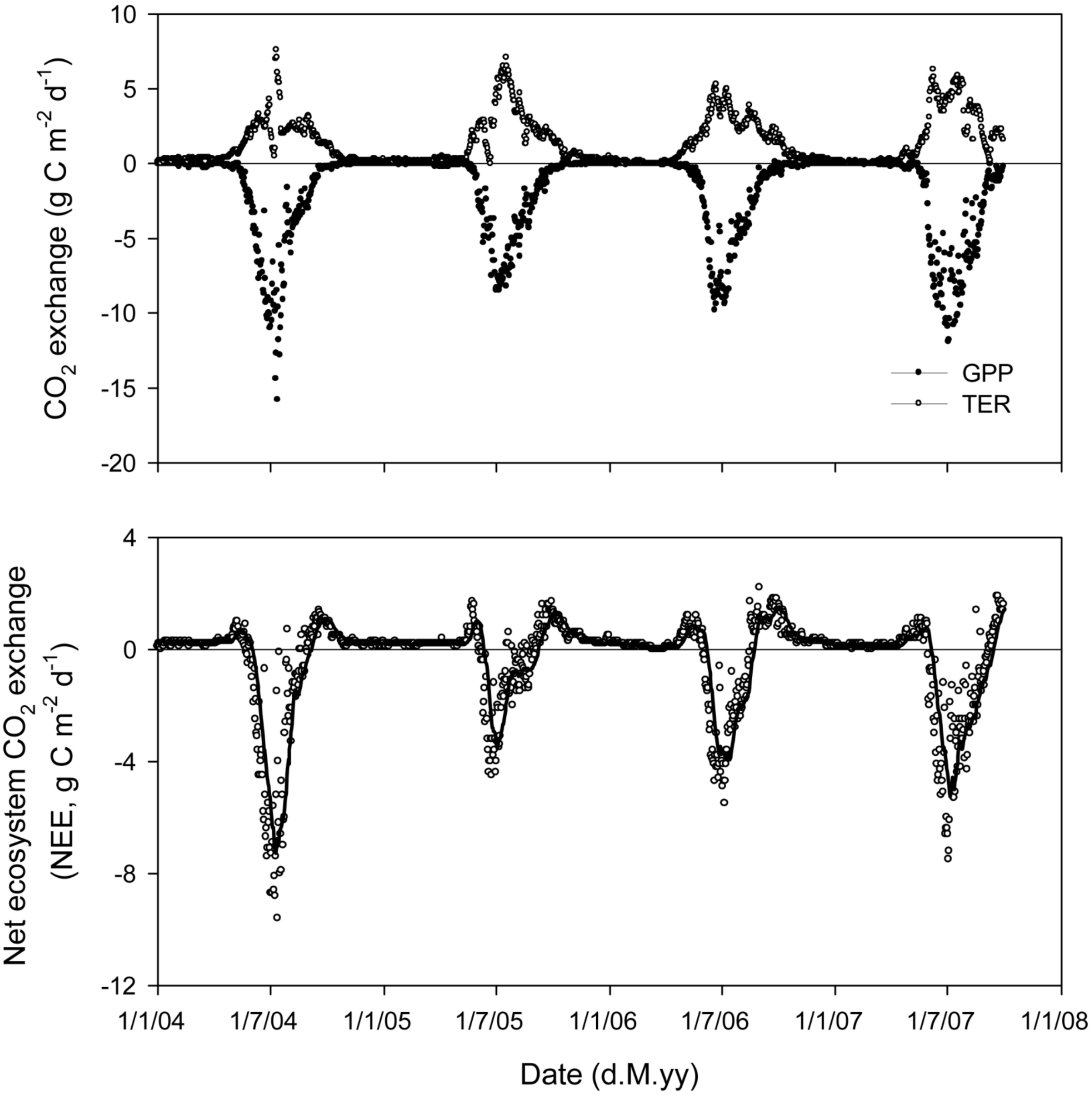

Figure 2. Seasonal trends in daily (A) gross photosynthesis (GPP) and ecosystem respiration (TER) (B) net ecosystem CO_2 exchange (NEE) from reed canary grass cultivated on a cutover peatland in eastern Finland during the period from Jan 2004 to September 2007

CO_2 exchange during the growing season was regulated by variations in soil moisture in the uppermost layers of the soil, incident light levels, air and soil temperature and vapor pressure deficit. Rainfall amount and its distribution during a growing season were the key factors affecting the C exchange in this ecosystem. The cumulative net ecosystem CO_2 exchange from 1 Jan 2004 to 30 September 2007 is shown in Figure 3. The number of days during which the ecosystem was a net sink for atmospheric CO_2 also varied from year to year. It was 71 days in 2004, 88 days in 2005, 66 days in 2006 and 96 days in 2007. Despite the less number of days of sink strength in 2004, the net uptake during this season was the highest. This is indicative of the high potential of RCG as a bioenergy crop in fixing the atmospheric C, given the high soil moisture regime and proper atmospheric conditions (such as low to moderate temperatures, low VPD and high PAR levels).

We divided each calendar year into three parts - Jan to April, May to September and October to December. The ecosystem accumulated 468 g C m^{-2} during the period from 1 Jan 2004 to 30 September 2007 (Figure 3). The ecosystem was a net sink for atmospheric CO_2 in all years. During wet years, the ecosystem was a strong sink and a weaker one during dry years. The annual NEE values in 2004, 2005, 2006 and 2007 (from Jan 1 to Sep 30) were -211, -9, -52 and -196 g C m^{-2} , respectively.

During the wettest year of 2004, there was a net gain of 211 g C m^{-2}. The ecosystem acted as a strong sink for atmospheric CO_2 during this year (Fig. 3). The conditions during this period were favourable for high GPP and low TER resulting in a net C sink. The 2005 and 2006 seasons were drier than normal and therefore, they were weaker sinks for carbon. The year 2005 accumulated about 9 g C m^{-2}, while the year 2006 had a net uptake of 52 g C m^{-2}. The total rainfall during the May – September period in these two years was nearly the same. Nevertheless, the net uptake during the 2006 season was relatively higher compared to 2005. Considering the poor crop performance during the 2005 season, lime was added to the soil in the beginning of the 2006 season to improve the soil pH. This may have resulted in relatively better growth conditions for the RCG plants and also, there could be small extraneous CO_2 contribution to the ecosystem due to lime during 2006. The soil moisture conditions were better during the May – September of 2007 with above normal rainfall. The GPP was the highest during the period among all years. However, TER was also the highest during this period. Higher rates of CO_2 uptake were offset by high rates of CO_2 loss and therefore, this period in 2007 accumulated less C than the 2004 season. While TER is more or less similar during January – April and October – December period over the years, TER during the May September period showed an increasing trend from 2004 to 2007. RCG is cultivated in the region as a perennial crop and therefore has the tendency to develop increasing rootstocks over the successive cultivation years. Autotrophic respiration and root respiration, in particular, seems to be a dominant component in TER at our study. In view of this, increasing TER trend from 2004 to 2007 is not unexpected.

Net biome productivity (NBP)

Net biome productivity in the context of this study refers to the net ecosystem CO_2 exchange after the CO_2 losses due to removal of the biomass from the ecosystem in harvest have been accounted for. The general RCG cultivation practice in the Fenno-Scandinavian region is to harvest the crop in the spring of the following year. The RCG crop yield for the 2004 season (harvested in spring of 2005) was 3.7 ton ha^{-1}. The yield values for the 2005 and 2006 seasons harvested in 2006 and 2007 spring were 2.0 and 3.6 ton ha^{-1}, respectively. As the 2007 season crop will be harvested in the spring of 2008, yield data is not available yet. Therefore, the NBP analysis is being presented only for the first three years (2004 - 2006). Accounting for an average

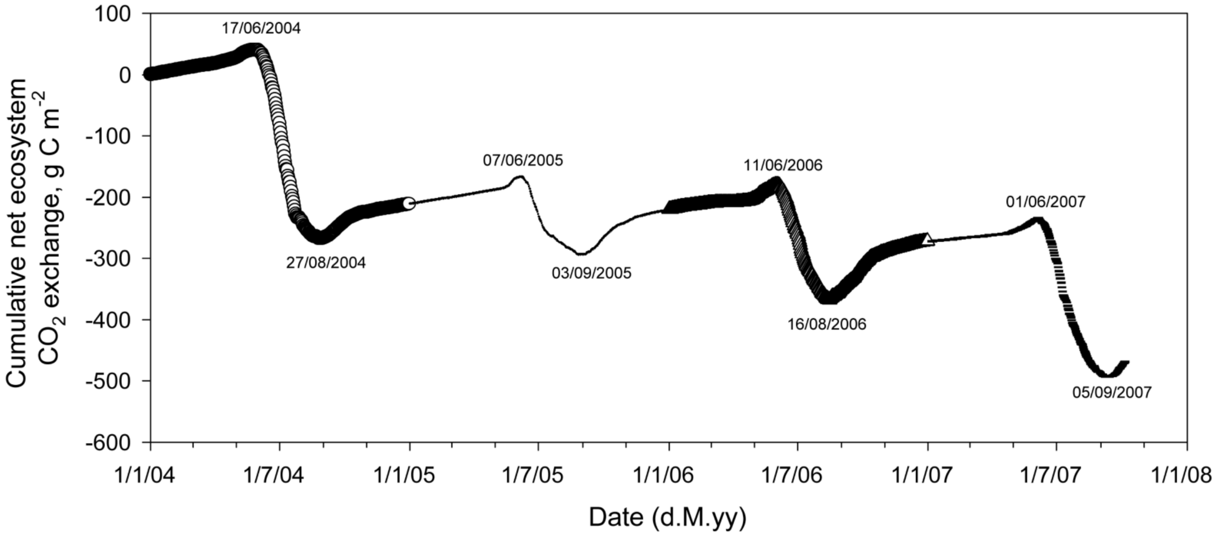

Figure 3. Cumulative CO_2 exchange from reed canary grass cultivated on a cutover peatland in eastern Finland during the period from Jan 2004 to September 2007

moisture content of 17.5% and carbon content of 45.8%, the 2004, 2005 and 2006 seasonal biomass yields amount to 140, 76 and 136 g C m^{-2}, respectively. An annual NEE of -211 g C m^{-2} in 2004 reduces to an NBP of -71 g C m^{-2} after subtracting the biomass yield value of 140 g C m^{-2} from the NEE value. Similarly, NBP values for the 2005 and 2006 seasons were estimated to be 67 and 84 g C m^{-2}, respectively. It is interesting to note that NBP in 2004 is negative. This implies that even after accounting for the carbon in the harvested biomass, there is still some amount of fixed C left in the ecosystem and is sequestered in the soil during a wet year such as 2004. NBP values are positive during 2005 and 2006 seasons. During such dry years, the ecosystem becomes a source of carbon to the atmosphere after accounting for the C losses due to biomass harvest. Based on the NBP analysis, 2005 was a smaller source compared to 2006. NEE was less negative during 2005 and the harvested biomass was also low during this season. Despite a high net uptake during 2006, it was a bigger C source because of the high biomass yield.

Concluding remarks

These results have positive implications from the view point of the use of RCG as a bioenergy crop on the one hand and Finnish land use options, on the other. Cultivated organic soils and cutover peatlands left abandoned after peat extraction are environmentally unfriendly land use options in the sense that they emit large amounts of CO_2 to the atmosphere (Maljanen *et al.,* 2004; Nykänen *et al.,* 1996; Silvola *et al.,* 1996). Such organic soils have been known to be persistent sources of C to the atmosphere even after being cultivated with barley, potato or forage grasses (Lohila *et al.,* 2004, Maljanen *et al.,* 2003). For a complete greenhouse gas balance of the RCG cultivation system, a quantification of CH_4 and N_2O emissions from the system is crucial. The results presented in this paper provide a strong evidence to suggest that the cultivation of RCG on such problematic soils is a promising land use option. RCG has a high potential for use as a bioenergy crop in Finland and in the boreal region, in general.

References

Ahlholm, U. and Silvola, J. (1990). CO_2 release from peat-harvested peatlands and stockpiles. In *Peat 90. Int. Conf. on Peat Production and Use*, 1-12. The Association of Finnish Peat Industries, Jyväskylä, Finland.

Lohila, A., Aurela, M., Tuovinen, J-P. and Laurila, T. (2004). Annual CO_2 exchange of a peat field growing spring barleys or perennial forage grass. *J. of Geophys. Res.* **109**, D18116. doi:10.1029/2004JD004715.

Maljanen, M., Komulainen, V-M., Hytönen, J., Martikainen, P.J.and Laine, J. (2004). Carbon dioxide, nitrous oxide and methane dynamics in boreal organic agricultural soils with different soil management. *Soil Biol. Biochem.* **36**, 1801-1808.

Nykänen, H., Silvola, J., Alm, J. and Martikainen, P.J. (1996). Fluxes of greenhouse gases CH_4, CO_2 and N_2O on some peat mining areas in Finland. In R. Laiho, J. Laine, and H. Vasander, (eds.), *Northern Peatlands in Global Climate Change,* 141-147. Proceeding of the International Workshop held in Hyytiälä, Finland. Academy of Finland, Helsinki 1/96.

Schlamadinger B., Apps M, Bohlin F., Gustavsson L., Jungmeier G., Marland G., Pingoud K. and Savolainen I. (1997). Towards a Standard Methodology for Greenhouse Gas Balances of Bioenergy Systems in Comparison with Fossil Energy Systems. Biomass and Bioenergy **13**(**6**).

Silvola, J., Alm, J., Ahlholm, U., Nykänen, H. and Martikainen, P.J. (1996). CO_2 fluxes from peat in boreal mires under varying temperature and moisture conditions. *J . Ecol.* **84**, 219-228.

Venendaal, R., Jørgensen, U., and Foster, C. A. 1997. European energy crops: a synthesis. *Biomass Bioenergy* **13**, 147-185.