CO_2 emissions from willow and poplar short rotation forestry on a derelict mining soil

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Abstract. Contaminated soils, e.g., from mining, inhibit food production due to potential risks for human and animal health. Such sites may be suitable, however, for short rotation forestry (SRF) to extract biomass for energy purposes. SRF can be applied to marginal lands and brown fields. Thus SRF can help in decreasing the conflict between food and energy crops by reducing competition on arable lands. Yet is SRF truly sustainable? Does SRF positively influence the GHG balance in comparison with other land-use alternatives? The aim of this study is to investigate the reduction of CO_2 emissions from SRF soil. To achieve this aim, a SRF site and two alternative energy crop production sites (rye, field mustard and rapeseed) were compared under the same weather and soil type conditions.

Key words

Soil CO_2 emissions, short rotation forestry, contaminated and derelict soil.

Introduction

Mining activity may potentially cause soil contamination, e.g., with toxic trace metals. Contaminated soils inhibit food production and may yield potential risks for human and animal health (Maxted et al. 2007). Such sites may be suitable however, for short rotation forestry (SRF) to extract biomass for energy purposes –and to provoke a longer-term self-cleaning of the sites. SRF can be established on a broad range of land-use areas (Broeckx et al. 2012), and may be applied to marginal lands and brown fields. Thus, SRF may support efforts to decrease conflicts between food and energy crops by reducing the competition on arable lands. Furthermore, SRF can restore slightly contaminated soils to be used again as arable lands to produce edible crops (Maxted et al. 2007). Poeplau and Don (2013) mentioned that the mean soil organic carbon (SOC) in the topsoil accumulated, when converting cropland to forest. Changes in SOC yield the ability to significantly alter the atmospheric CO_2 concentration.

Plants play an important role in the carbon cycle. They absorb atmospheric CO_2 and transfer C into the soil. This C-sequestration is considered a tool to rehabilitate the environment. Soil, the second largest store of C after the oceans, can increase or decrease atmospheric CO_2, depending on land management practices (European Commission 2011; Gupta et al. 2009; Sainju et al. 2008). The aim of this study is to investigate the reduction potential for CO_2 emissions from SRF soils. Here, a SRF site and two alternative energy crop production sites (rye, field mustard and rapeseed) were compared under the same weather and soil type conditions.

Material and methods

Study areas: The Saxon State Office for Environment, Agriculture and Geology (LfULG) established a SRF (2 ha) in 2005 on an arsenic (118 mg As kg^{-1}) and other trace metal-contaminated soil in Krummenhennersdorf (~ 8 km N of Freiberg, Saxony). SRF was cultivated with different cultivars of poplar (*Populus sp.*) and willow (*Salix sp.*) in a double row system with high planting density (11,850 trees ha^{-1}). The annual average rainfall at the SRF site is 820 mm; the mean annual temperature is 7.2°C. The other two sites are located in Lippersdorf and Hilbersdorf (23 km and 7 km from the SRF site, respectively) with the same weather conditions and soil quality.

Measuring CO_2 emissions: Different points were chosen randomly at all sites to measure the CO_2-emission at the SRF site. 108 readings were taken in June, August and November 2012, and 55 readings were taken from both alternative sites. The number of readings depended on the number of plant cultivars in the location. A manual soil respiration chamber system was used, which has been developed by Cornelius Oertel (TU Bergakademie Freiberg) in the GREGASO project (http://tu-freiberg.de/fakult3/min/geochemie/Mitarbeiter/Oertel/GREGASO/index.html). The system consists of a transparent cylindrical chamber (acrylic glass) to trap emitted CO_2 from the soil surface. An IR-CO_2 sensor (Vaisala GMP343) inside the chamber logs the concentrations. Air inside the chamber is homogenized with a small fan. Additional sensors measure different parameter, e.g., volumetric water content, soil and air temperature, and photosynthetic active radiation (PAR). The chamber is connected to a portable computer to collect and store the data. Laganière et al. (2012) mentioned that mosses have no significant effect on CO_2 emission, thus mosses were not removed from sites during the measurement process to avoid soil disturbance, which could affect the rate of CO_2 emissions. CO_2 was registered by placing the chamber on collars, inserted in the soil up to 8 cm depth. These collars are provided with a rubber ring to prevent gas leakage. Each measurement lasted for 7–8 minutes, followed by another 5 minutes to restore ambient conditions inside the chamber. The CO_2 flux was calculated with linear regression of the concentration in ppm_v versus time.

Analysis: A Mann-Whitney W-test was performed, using STATGRAPHICS Centurion XVI.I software, to compare the median CO_2 concentration of the SRF site with the other two alternative sites. A non-parametric method was chosen since the data are not normally distributed.

Results and disscussion

During the growing season, both of the alternative sites (Lippersdorf and Hilbersdorf) show significantly higher CO_2-emissions than the SRF site. Namely in June, the median emission values were 136 and 256 mg CO_2-C m^{-2} h^{-1} at SRF and Lippersdorf, respectively (Fig. 1). In August, the median emissions were 73 and 110 mg CO_2-C m^{-2} h^{-1}at SRF and Lippersdorf, respectively. The alternative site Lippersdorf shows 188% and 150% higher emission than the SRF site in June and August. In November, emission rate was 78% lower (61 and 48 mg CO_2-C m^{-2} h^{-1}at SRF and Lippersdorf).

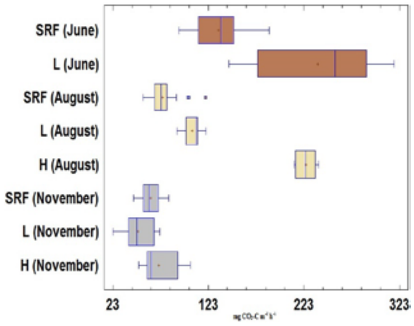

Figure 1. *Box-and-Whisker Plot for CO_2 emission from short rotation forestry (SRF), Lippersdorf (L) and Hilbersdorf (H) in June, August and November 2012.*

At the second alternative site (Hilbersdorf), emission rate was 306% higher in August than at SRF (225 and 73 mg CO_2-C m^{-2} h^{-1} at Hilbersdorf and SRF respectively). There was no significant difference between the two sites in November (61 and 63 mg CO_2-C m^{-2} h^{-1} at SRF and Hilbersdorf respectively; Fig. 1). Furthermore, there was no significant difference between emission rates at both alternative sites in November.

Vegetation type and land-use affect soil C input (Poeplau and Don 2013). Each of the three sites bears a different vegetation cover. It is thus expected that each site will have a different C input, which will affect CO_2 emission rates. In June, rye (*Secale cereale*) was cultivated in Lippersdorf; plants were well developed (height ~ 1 m). PAR was 130 and 1,248 µmol m^{-2} s^{-1} at SRF and Lippersdorf, respectively. The low PAR value at SRF is due the dense cultivation system, well developed canopy and tree height. These factors reduce light penetration and affect soil temperature. Therefore, soil temperature at the SRF site is lower than at the others. As a result, the activity of soil microorganisms will be affected by soil temperature and thus the production of CO_2 will be reduced. On the other hand, soil moisture content, which affects soil respiration, was almost the same at both sites. Broeckx et al. (2012) mentioned that between late August and early October the Leaf Area Index (LAI) reaches its maximum, depending on the start of growing season. King and Evans (1967) reported that photosynthesis increases with LAI. Vargas et al. (2011) mentioned that canopy photosynthesis affects soil CO_2 efflux. This explains the difference of CO_2 emission between SRF and the alternative sites.

The significant difference during the growing season (June and August) between SRF and the two alternative sites is caused by tillage, fertilization and crop cultivation. In contrast, the trees were completely barren at the SRF site in November. Accordingly, more solar energy can reach the upper soil, also shown by higher measured PAR values and soil temperature, compared to the alternative sites. This leads to comparable CO_2 emission values from SFR soils and the second alternative site. At Lippersdorf, which showed lower CO_2 emission in November, plants were well developed (~ 90 cm). Thus, photosynthesis was active, while plants were only 5 cm high at Hilbersdorf, and showed non-significant difference with the SRF site.

Conclusions

We recommended planting SRF on marginal land and brownfields, parallel with other sustainable land management options. Such land-use will reduce the demand for fertile and non-contaminated arable land for energy crops. Consequently, more fertile land remains available for food and animal feed production. At the same time, SRF contributes on a longer term to continuous soil quality and biodiversity improvement, groundwater protection, and soil erosion prevention. For validation of the results, more field experiments will continue during the vegetation period 2013.

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