INITIAL SOIL CARBON SEQUESTRATION UNDER MONO CULTURES AND SHORT ROTATION ALLEY COPPICES WITH POPLAR AND WILLOW

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Introduction

Short rotation coppice (SRC) is a land use system using fast growing trees species such as poplar and willow grown on agricultural land to provide the highest possible amounts of woody biomass in the shortest time possible. Woody biomass production in SRC is the most cost- and impact-effective land use system in terms of avoiding CO_2-emissions of the various means of renewable biomass feedstock production in agriculture (Don et al. 2012). SRC may either be applied as monocultures or in association with common agricultural crops to improve specific ecological services (e.g. increasing wind and soil erosion protection, enhancing structural biodiversity and soil organic carbon sequestration). Applied in rows, those SRC plantations can be identified as agroforestry systems (AFS) and may be called "alley coppices". In the present work, we focus on the initial impact of SRC applications on carbon (C) sequestration.

Material and methods

Research plots are located south of Göttingen, Germany near the village Reiffenhausen (51°39'83"N / 9°98'75"E) and were installed on former cropland in March 2011 (for further details see Hartmann et al. 2014). Two blocks of monocultures with either the willow variety "Tordis" ((Salix viminalis x Salix schwerinii) x Salix viminalis)), hereinafter referred to as the "Willow-SRC" or the poplar variety "Max 1" (Populus nigra x Populus maximowiczii), referred to as the "Poplar-SRC".were applied. A third plot was arranged as an AFS with rows of the willow variety "Tordis" and grassland alleys in-between (four willow strips, each 7,5 m width and 75 m length and grassland strips in-between, 9 m width, 75 m length, hereafter called "Willow-AF"). The neighboring cropland served as a reference plot (see **Fig. 1**). The soil texture of the site is varying from loamy sand in the NE part to silty clay in the SW corner.

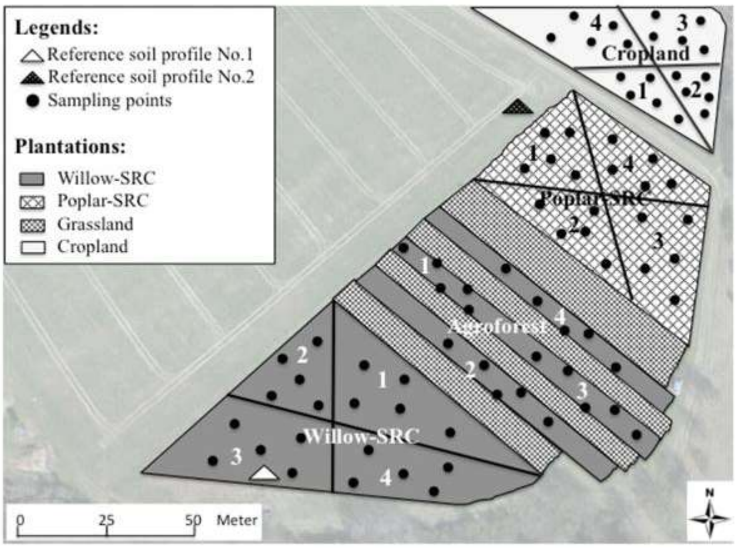

Figure 1: Soil sampling design site Reiffenhausen in 2014. The lines separate the quadrates in each plot; black dots represent the single sampling points. Triangles indicate the location of the initial reference soil profiles applied before plot installation in 2011.

Soil samples were collected in 2014, i.e., three years after the establishment of the SRC plots. Each plot was divided into four quadrates and five independent samples were collected following the random selection approach from each quadrate by steal cylinder (30 cm length and 6 cm diameter; Fig.1). Gained samples of the five sampling spots were mixed to one composite sample per quadrat and horizon for further analysis, resulting in n=4 analytical samples per plot and horizon. During a first sampling campaign in March 2014 the upper 30 cm soil layer was analysed for total C in 7 single layers (0-3, 3-6, 6-9, 9-12, 12-15, 15-20, 20-30 cm) to identify potential fine scale C accumulation patterns. Inorganic carbon was not further considered, as previous investigations by Hartmann et al. (2014) showed that carbonates were only rarely and scattered available in the upper soil horizons and if present, with a maximum content of 1.4 %. However, results of this first analysis indicated a significant C accumulation under willow SRC down to a depth of 20 cm, but under willow AF only in the uppermost layer of 0-3 cm (**Fig. 2**). Thus, a second sampling for advanced analytics (aggregate analysis, microbial biomass carbon (MBC), density fractionation) with the same sampling design was applied only for the soil depths of 0-3, 3-20 and 20-30 cm in May 2014.

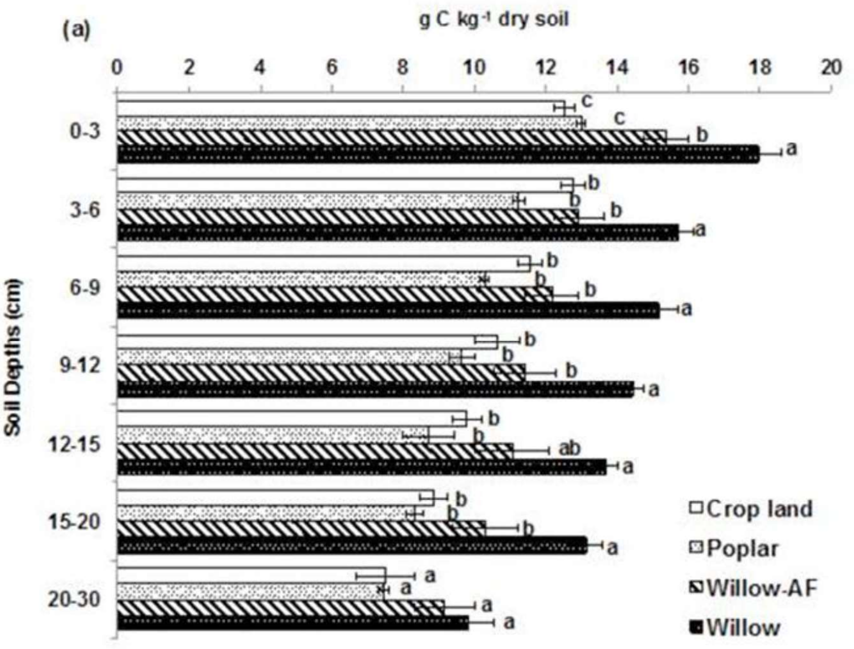

Figure 2: Total C [g kg^{-1} dry soil] in 3, respective 5 cm soil sections up to 30 cm soil depth under cropland (reference plot), Poplar-SRC, Willow-SRC and Willow-AF. Values represent mean of four replications ± standard error. Different letters indicate significant difference ($p<0.05$) between plantation types at each soil depth.

Aggregate size distribution (large macro-aggregates >2000 µm, small macro-aggregates 250-2000 µm, micro-aggregates <250 µm) was determined by the dry sieving method. Microbial biomass carbon (MBC) was measured after the fumigation-extraction procedure. The density fractionation with sodium polytungstate solution was applied only for samples of the 0-3 cm soil layer free light fraction (fLF<1.6), occluded light fraction, (oLF<1.6), occluded dense fraction (oDF1.6-2.0), and mineral fraction (MF>2.0); [g cm^{-3}, respectively] were separated. Total C was measured by dry combustion (C/N analyser, Elementar, Vario-EL II Germany).

Results

Results indicated that large macro-aggregates (LMA) dominated at each soil depth and for all plots, with the highest portion under Willow-SRC (up to 90 %) and the lowest in the cropland (30-50 %). The LMA under Willow-SRC also accumulated the highest portion of C, whereas this aggregate size class contained significantly less carbon under cropland (data not shown). The MBC significantly ($p<0.05$) increased in the order: crop land < Poplar-SRC, Willow-AF < Willow-SRC and varied in the 0-3 cm soil layer from 266 (cropland) to 789 µg C g^{-1} soil (Willow-SRC; **Fig. 3**). The MBC decreased significantly from top to bottom soil layers in all plots except the cropland, where it was uniformly distributed in the first 0-20 cm. In all plots, the major part (ca. 80%) of total C of the top soil (0-3 cm) was associated with the MF>2.0 (**Fig. 4**, right axis), with the highest C content under Willow-SRC. The C content in the fLF<1.6 was similar in all plots (Fig. 4, left axis) and the lowest C content was found in the oLF<1.6 under cropland.

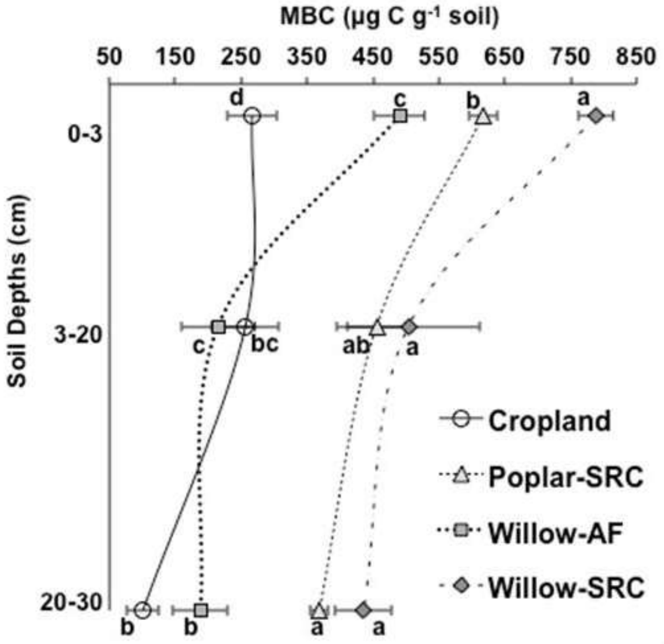

Figure 3: Microbial biomass carbon (MBC) [µg C g^{-1} dry soil] in 0-30 soil horizons of crop land, Poplar-SRC, Willow-SRC and Willow-AF plots. Values represent mean of four replications ± standard error. Different letters indicate significant differences ($p<0.05$) between plantation types at each soil depth.

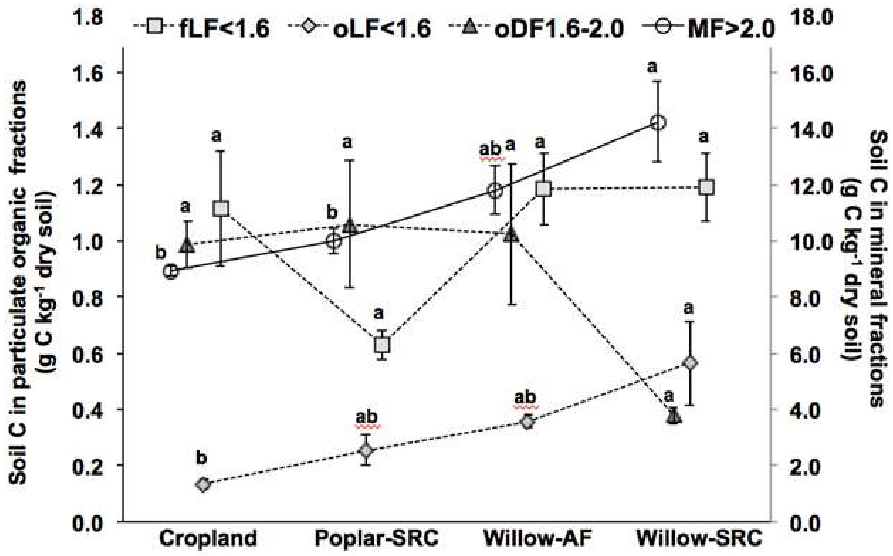

Figure 4: C content [g C kg^{-1}] in soil fractions, separated from the top soils (0-3 cm) under cropland, Poplar-SRC, Willow-SRC and Willow-AF. For the fLF<1.6, oLF<1.6 and oDF 1.6-2.0, see left y-axis; for the MF>2.0, see right y-axis [g cm^{-3}, respectively]. Values represent mean of four replications ± standard error. Different letters indicate significant difference ($p<0.05$) between plantation types at each density fraction.

Discussion

Soil texture analysis of these plots (n=3 per plot, 0-30 cm soil depth; Hartmann et al. 2014) revealed a substantial gradient in the clay content of the upper soil horizons between plots. Significantly higher clay content was observed for the Willow-SRC plot, medium to lower values for the Willow-AF, respectively the Poplar-SRC plot. Based on this texture analysis, a linear increase of C content with the clay content in the most upper 0-3 cm soil depth was found (see **Fig. 5**). Consequently, plant community effect determines less than 50% of the variation in C accumulation under Willow-SRC and Willow-AF.

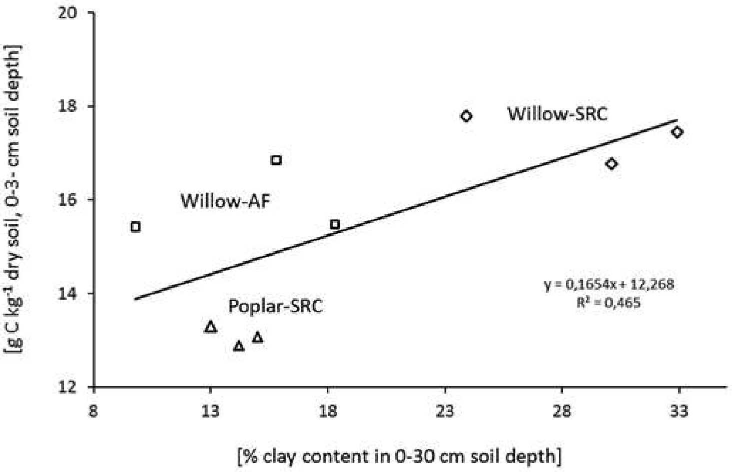

Figure 5: Correlation between [%] clay content, measured by Hartmann et al. (2014) in 0-30 cm soil depth (n=3 per plot) and spatially related C contents [g C kg^{-1}], measured in this study in 0-3 cm soil depth under Poplar-SRC, Willow-SRC and Willow-AF (no separate clay content data were available for the cropland reference plot).

In this context, Walter et al. (2014) has already shown a significant positive effect of clay content on C stocks under SRC, which, adapted to the given variability of the clay content in our site, would amount to a C stock variability of about ± 50 Mg ha^{-1}, calculated to a soil depth of 80 cm. Furthermore, a comparison of mean C contents in 0-10 cm soil depth prior (2011) and three years after the afforestation for only the reference soil profiles did not indicate any C accumulation (reference soil profile No 2) or unrealistic high C accumulation (reference soil profile No 1 = +2 Mg ha^{-1}) within the first three years of the SRC growth. As determined by Hartmann et al. (2015), leaf litter production under willow, as the main input for soil C sequestration, was far less than 0.5 Mg $ha^{-1}year^{-1}$ (2011/12, Willow-SRC 0.36, Willow-AF 0.14, Poplar-SRC 0.94 [Mg ha^{-1}]) and thus could not serve as an explanation for enhanced C accumulation and also not for differences between plots. Furthermore, litter dry loss was highest under poplar (67 %), compared to the willow plots, after 1 year of exposure (Willow-SRC 50 %, Willow-AF 48 %; Hartmann et al. 2015). Root turnover as an additional C input was not investigated until now.

Finally we conclude that already three years after the implementation of SRC plantations a positive effect on SOC sequestration in the top soil layer, especially under willow, might be visible, but has to be taken with high caution, due to confounding factors (here, variations in clay content at the plot scale). Also it seems to be quite obvious that it is exceedingly difficult to determine C sequestration under various types of SRC applications within a short period of time after forest implementation and that far more analytical effort has to be applied (e.g., repeated analysis with high spatial resolution of years or even decades, including also full texture analysis) to give evidence for significant changes in C sequestration. Nonetheless, reduced soil disturbance is obvious under all SRC applications, which can be clearly seen from enhanced macro-aggregate formation and increased microbial biomass.

References:
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