CARBON SEQUESTRATION IN INTENSIVE HARDWOOD PLANTATIONS: INFLUENCE OF MANAGEMENT

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Introduction

The importance of C sequestration relies in its use as a strategy for mitigating climate change, which is believed to be caused by the increasing greenhouse gases concentrations, mostly CO_2 (IPCC 2014). Recent studies in temperate regions have shown that agroforestry systems have greater C sequestration potential than monocropping systems. Some examples are provided by Cardinael et al. (2015) for an alley cropping under Mediterranean climate, and for Patagonian silvopastures under humid Boreal climate (Dube et al. 2012). In Europe, there is a growing interest in the establishment of hardwood plantations with intensive management, including irrigation, fertilization and chemical weed control, for reducing rotation length. However, these operations may produce important environmental impacts similar to intensive agriculture, such as nitrate contamination, impoverishment of C and biodiversity loss (Babcock et al. 2003). Therefore, new techniques should be tested to avoid negative environmental impacts. The implantation of forage legumes could increase the available nutrients in soil, mainly N, improve pasture production and quality, and optimize the environmental functions of these plantations (O'Dea et al. 2015). Grazing allows controlling the understory vegetation. Moreover, grazing intensity has an effect on C stocks, by modifying the amount, plant type and composition and decomposition rates of residual plant material (Soussana and Lemaire 2014). The aim of this study is to identify the optimal management practices in these quality wood production intensive systems with the aim of optimizing both soil C sequestration and the productivity of the forest.

Material and methods

The experiment was carried out in Extremadura, in the mid-western region of Spain between 2011 and 2014, in a 13- year old hybrid walnut (*Juglans major* x *nigra* mj 209xra) plantation, with a density of 333 trees ha^{-1}. Two essays were established: one experiment for testing legume implantation (hereafter Fertilized Walnut) (a mixture of 25 kg ha^{-1} of *Trifolium michelanium* and 10 kg ha^{-1} of *Ornithopus compressus* complemented by the same quantities of PK as mineral treatment) as alternative to the traditional inorganic fertilization (40 kg N ha^{-1}, 40 kg P2O5 ha^{-1} and 50 kg K2O ha^{-1}); and one with different techniques for controlling the competition of herbaceous strata beneath trees (hereafter Grazed Walnut): mowing, ploughing and grazing with sheep (1 sheep ha-1). Treatments were applied during three years (2011-13). Nine replicates were used for each treatment. The estimation of the variations in carbon sequestration was based in SOM (soil organic matter) and biomass in tree trunk (stem and branches) and herbaceous (fine roots) and tree roots (thick and fine roots), from data collected in 2014. 70 soil cylinders were taken each 10 cm until 1 m depth. Roots were separated in tree and pasture and then weighted. For determining the relation between DBH (diameter at breast height) and tree biomass, 12 trees were cut in December 2014. Allometric equations according to the formulas of Montero et al. (2005) were fitted to the data in order to obtain the tree trunk (stem, thick and fine branches) and tree root (thick roots) biomass from the DBH. Sequestered C in vegetation was obtained multiplying the aerial and root biomass by 0.5. The effects of fertilization and control of competing vegetation methods on tree growth, root weight and SOM were determined using Analysis of Variance. In cases where ANOVA test yielded statistically significant differences ($p<0.10$), an LSD test was used for subsequent pair-wise comparisons.

Results

In the essay of control of herbaceous vegetation (**Figure 1**, Grazed Walnut), mowing produced the greatest contribution of C to the system (132 Mg ha-1) by increasing the SOC (106 Mg ha-1) ($p= 0.09$). Mowing was followed by grazing (116 Mg ha-1) and ploughing (108 Mg ha-1), since grazing enhanced SOC (91.2 Mg ha-1) with respect to ploughing (81.5 Mg ha-1). In the essay of fertilization treatments (Figure 1, Fertilized Walnut), legume sowing recorded the highest C sequestration values (101 Mg ha-1), similar to inorganic fertilization (100 Mg ha-1), as well as SOC evolution (82.6 Mg ha-1 and 81.4 Mg ha-1, respectively). However, in this essay it was only a trend since no significant differences were detected. No change of C sequestration in vegetation biomass (tree trunk and thick and fine roots) was noted between treatments.

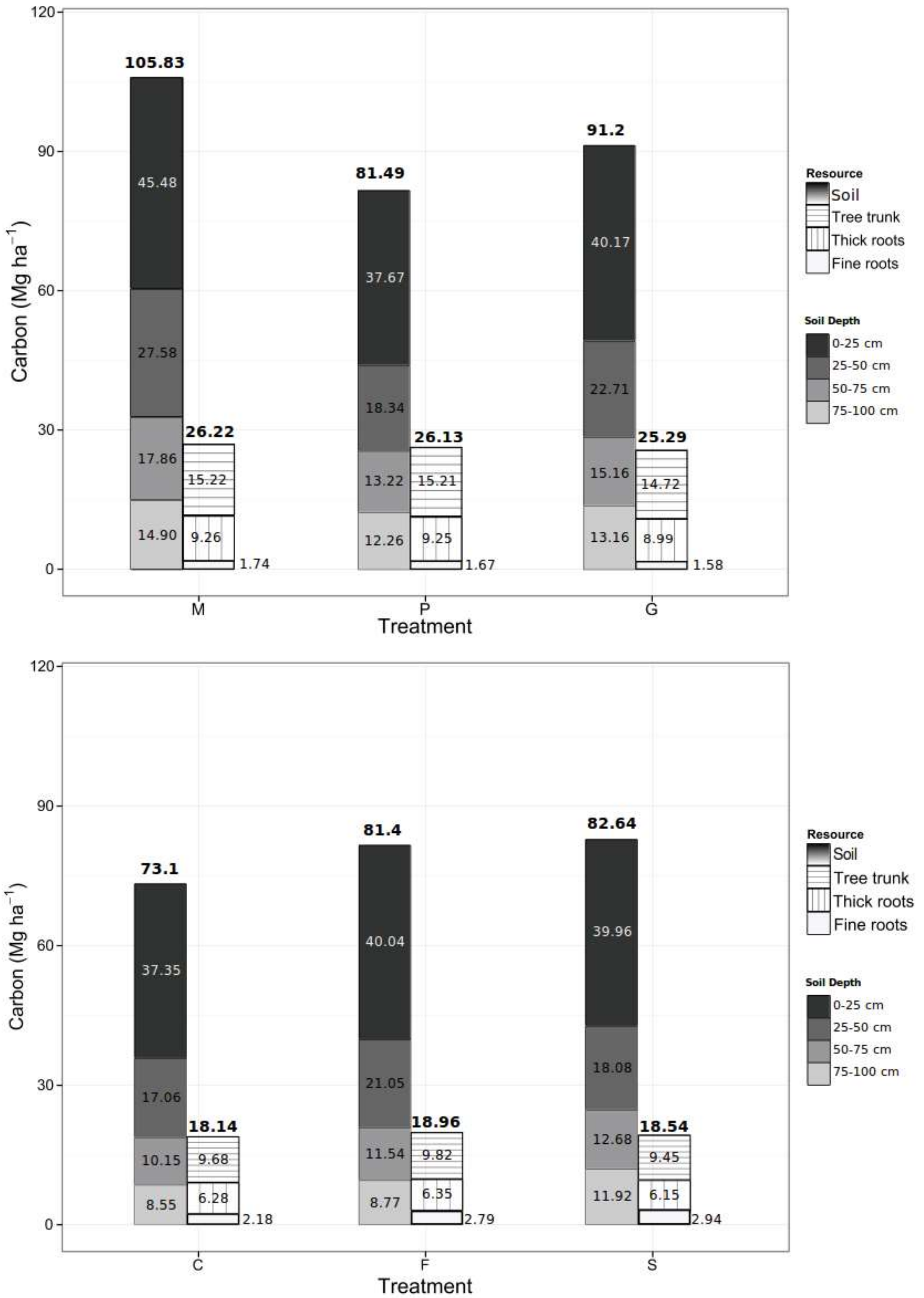

Figure 1: Carbon sequestration (Mg C ha-1) in soil, aerial biomass (Tree trunk), and tree thick roots (Tree root) and fine roots (tree and pasture) (Fine roots) under different treatments of control of herbaceous vegetation (above) and fertilization treatments (below). M: mowing; P: ploughing; G: grazing; C: control; F: inorganic fertilization; S: legume sowing. Bold values over the columns indicate total C sequestration in soil (0-100 cm depth) and in vegetation.

Discussion

The results suggested that the largest reservoir of C in all cases was SOC (75.9-82.5%), mainly in surface soil (0-25 cm of depth: between 42% and 51% of the total SOC), as underlined by Alías et al. (2015). SOC was followed by the aerial biomass (Tree trunk), that supplied the 9.45-15.22% of the total C sequestration of the system. Ciais et al. (2013) showed that SOC contained two to five times as much C as above-ground biomass. Thereafter, our system contained less proportion of C sequestration in aerial biomass than other studies, maybe due to the youth and low density of the trees.

Many researchers assume that the belowground biomass constitutes a fixed portion of the aboveground biomass and such values range from 25 to 40%, depending on factors like the nature of the plant and its root system and the ecological conditions (Alías et al. 2015), but no data were found about fine roots in these systems. Our analyses indicated that 52.9-58.8% of the C sequestered in vegetation came from the aerial part and the rest (41.2-47.1%) from the roots, mostly thick roots. Fine roots suppose from 15 to 32% of the total root biomass. Nevertheless, they account a very low proportion of the total C accumulated in the system (between 1.6 and 2.9% of the total C). It should be noted that the response of SOC to the different treatments was more important than other analysed parameters, suggesting SOC is more sensible to management techniques. Thus, avoiding soil disturbances is important for the formation of stable organic-mineral complexes which, in turn, are crucial elements in the process of C soil sequestration (Jandl et al. 2007).

Regarding the control of herbaceous competition, mowing yielded the highest values of SOC due the mineralization of plant litter, followed by grazing and ploughing. Accordingly, Soussana and Lemaire (2014) found that intensive site preparation, such as ploughing, may favour the loss of soil C, because it stimulates the decomposition of the forest floor, in spite of favouring biomass production at least in the short term, since soil C is a principal source of energy for the nutrient-recyclers (Nave et al. 2010). We hypothesize that tree growth increment detected with ploughing could be not maintained in the long term due to the depletion of SOC. The opposite trend was found with grazing, that enhanced the SOC. Soussana and Lemaire (2014) highlighted that, at low stocking density, like in this case, herbivores can enhance soil N cycling and net primary productivity, leading to an increment in the soil C sequestration. In addition, it is expected that grazing will improve the biomass of aboveground mass in the longer term, as a result of the enhancement of tree diameter increment observed the second and third year of the essay (data not included). Improvement of tree growth was not observed in the representation of C sequestration in the aerial biomass because the different initial tree sizes masked the effect of treatments on trees.

Regarding fertilization treatments, inorganic fertilization and legume sowing increased the total organic sequestration compared to control, especially due to the improvement of SOC, although it was only a trend. Several authors (O'Dea et al. 2015) reported that, in general, N addition increases C sequestration in grasslands by slowing the decomposition of SOC, especially on nutrient-limited sites (Jandl et al. 2007). Moreover, N fertilization stimulates tree growth, as a result of the increment of C inputs into soils through litter fall and rhizodeposition (O'Dea et al. 2015). During the last year, it was detected that the legume implantation enhanced the tree diameter increment. Since legumes supply N gradually (Marinari et al. 2010), it is expected that the improvement of C sequestration seen with the legume sowing will be further increased in the long term. By contrast, inorganic fertilization yielded a positive response from the first year (data not presented).

In conclusion, grazing, as control of herbaceous vegetation, and legume implantation, as N supply, are adequate techniques for optimizing soil C sequestration, leading to an adequate tree growth in the longer term.

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