USING ECOYIELDSAFE TO COMPARE SOIL CARBON DYNAMICS UNDER FUTURE CLIMATE IN TWO CONTRASTING AGROFORESTRY SYSTEMS

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Abstract

In recent decades, modern agroforestry systems have been proposed at European level as land use alternatives for conventional agricultural systems. The potential range of benefits that modern agroforestry systems can provide includes farm product diversification, soil and biodiversity conservation and carbon sequestration. This paper compares simulations of the EcoYieldSAFE model, integrated with the widely used soil carbon model RothC, a model simulating soil organic carbon turnover. Two case study systems are examined: a cork oak system in south Portugal and a poplar system in the UK, in current and future climate. Simulations suggest, under future climate for the Mediterranean case study, a reduction in carbon storage of about 2 Mg ha^{-1} and 5 Mg ha^{-1} in the agroforestry and arable systems, respectively. In the Atlantic environment, climate change, although having a negative impact, was not as dramatic as in the Mediterranean case. The agroforestry resiliency under future climate is discussed.

Keywords: modeling; Mediterranean; Atlantic; ecosystem services; benefits, sequestration

Introduction

Agroforestry, while present in Europe on 15.4 million hectares of land covering almost 10% of the utilized agricultural area (den Herder et al. 2017), is also a promising option for designing new systems of sustainable agriculture. These systems sequester carbon at higher rates than if the trees and crops are grown separately, they store carbon also in standing biomass or introduce carbon to the soil through, for example, leaf fall, root turnover or crop residues, reducing carbon in the atmosphere, which is essential for mitigating the effects of global warming (Schroeder 1994; Montagnini and Nair 2004; Upson 2014).

This work explores state of the art modelling tools to compare two different land use systems (agriculture and agroforestry) in two different environments (Mediterranean and Atlantic) in current and future climate.

The usage of EcoYieldSAFE model, that includes a soil carbon module (Palma et al. 2017) in the original YieldSAFE model (van der Werf et al. 2007), to compare different land use systems (agriculture and agroforestry) in different environments (Mediterranean and Atlantic) in current and future climate.

Materials and methods

We used the EcoYieldSAFE model, a recent update of the daily time step YieldSAFE model (van der Werf et al. 2007) that included a soil carbon module (Palma et al. 2017). A comparison between conventional arable and agroforestry land use alternative was made for two different locations and different growth rate tree species for a simulation horizon of 80 years. The first was in a Mediterranean climate, and compared an arable system with a wheat-wheat-fallow rotation to an agroforestry system with the same rotation and a density of 78 trees ha^{-1} (holm oak – *Quercus rotundifolia* L.) over a 80 year time horizon. The second was in an Atlantic climate, and compared an arable system with a wheat-wheat-barley-oilseed rotation to an agroforestry system with the same rotation and a density of 78 trees ha^{-1} (poplar – *Populus* sp) over a 20 year time horizon. The daily climate input for the simulations was obtained through Clipick (Palma 2017) – AR5 RACMO evaluation and RCP8.5 datasets (van Meijgaard 2012) - for locations near Montemor (South Portugal) and Silsoe (Central UK). Evaluation and RCP8.5 were considered climate for current or future climate respectively.

Results and discussion

The simulations predicted that in both environments, agroforestry would increase soil organic content when compared to conventional arable agriculture. Although this is somewhat expected through previous studies (Schroeder 1994; Montagnini and Nair 2004), the ability to assess soil carbon dynamics and quantify carbon storage in the long-term through dedicated agroforestry models is an improvement to the set of tools that are available for assessing agroforestry land use changes.

In the Mediterranean scenario, the effect of the cork oak trees was to increase SOC by about 1 Mg ha^{-1}, but when compared to conventional agriculture, after 80 years, there was a difference of 2.5 Mg ha^{-1} because agricultural land use tends to decrease the carbon content of the soil (Figure 1), with or without conservation measures (Hermle et al. 2008; Oberholzer et al. 2014). Similar results for similar systems are reported by Francaviglia et al. (2012) in Sardinia where input plant materials for a cork oak forest were of 3.74 Mg ha^{-1} (and considering 0.5 Mg ha^{-1} of manure from livestock) giving an increase of 10% of SOC in about 90 years. However, simulations seem conservative when compared to results obtained by Cardinael et al. (2017) that found carbon being accumulated in about 0.24 Mg C ha^{-1} y^{-1} (9.6 Mg C ha^{-1} for 40 years).

In the Atlantic scenario, during the 80-year simulation horizon, there was additional carbon added by coarse roots of the poplar when each 20-year tree rotation ended. These fluctuations in soil carbon increased the mean carbon content of the soil over the 80-year simulation time horizon. However, even when not considering the carbon peaks created by the coarse roots input, the results still showed a difference, after 80 years, of about 10 Mg ha^{-1} between the arable and agroforestry systems.

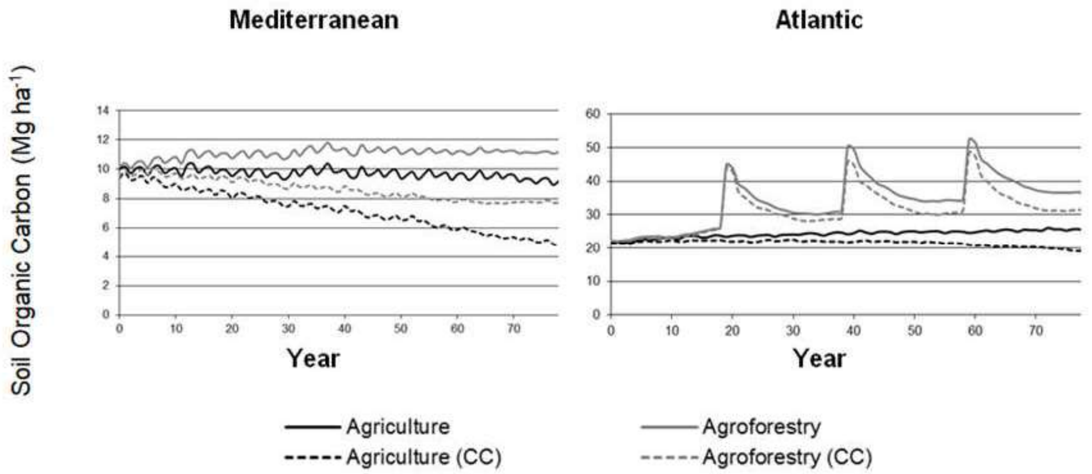

Figure 1: Comparison of simulated soil organic carbon between agroforestry and conventional agriculture in Mediterranean and Atlantic environments without and with climate change (CC). Both agroforestry systems are simulated with 78 trees ha^{-1}. Mediterranean system has a rotation of wheat-wheat-fallow and the agroforestry system has a perennial tree (*Quercus rotundifolia* L.). Atlantic system has a rotation of wheat-wheat-barley-oilseed and the agroforestry system has a deciduous tree (*Populus* sp) harvested each 20 years. Future climate is the Representative Concentration Pathway 8.5 simulated by the KNMI RACMO climate model (see Palma 2017 for details).

Under future climate change, the simulations suggested that, in Mediterranean areas, soil carbon storage was more resilient under agroforestry systems. The model suggested a reduction in carbon storage of about 2 Mg ha-1 and 5 Mg ha-1 in the agroforestry and arable systems, respectively (Figure 1A). The reduction of yields where rain fed yields are already low, was mainly due to increased water scarcity, a projected characteristic of future climate for Mediterranean areas, which will need adaptive management (Christensen et al. 2007; Palma et al. 2015). In the Atlantic environment, climate change, although having a negative impact, was not as dramatic as in the Mediterranean case (Figure 1). Furthermore, the agroforestry scenario still increased carbon in the soil showing, as in the Mediterranean case, that in terms of soil carbon storage, agroforestry land use was more resilient to climate change than arable land use.

Conclusions

The integration of a carbon dynamics module (RothC) into YieldSAFE has improved our ability to assess long-term soil carbon storage under different land uses, including agroforestry land uses, which could have an important role to play in mitigation of climate change impacts.

This assessment indicated that agroforestry is a more resilient land use system under future climate change, and will retain and input higher levels of carbon in the soil in comparison with conventional arable agriculture. The trends in our simulated results is consistent with existing data and theory but now, integration of RothC and YieldSAFE, can allow quantitative predictions to be made to assess how land use systems, including agroforestry systems, will impact carbon storage levels in the long-term.

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