HOW DO AGROFORESTRY TREES AFFECT THE SUPPLY OF REGULATING ECOSYSTEM SERVICES?

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Abstract

Several studies have identified agroforestry systems as suppliers of additional environmental benefits for the society (also called regulating ecosystem services) while maintaining similar levels of productivity compared to agricultural and forestry alternatives. However, no general pattern can be drawn as these studies are very site specific. In order to offer more information on the role of trees in the enhancement of environmental benefits by agroforestry systems, the supply of three regulating ecosystem services (soil erosion, nitrate leaching and carbon sequestration) by four different agroforestry systems in Europe were quantified at: 1) increasing tree densities and 2) compared to its land-use alternatives ranging from agriculture (without trees) to forestry (high tree density). Methods included the use of a biophysical model (Yield-SAFE) where specific methodologies for the quantification of the environmental benefits were previously integrated. First results show different tendencies across Europe even if there was a general improvement of supply linked to an increase of tree density. The methodology also helped to improve management knowledge in order to reduce environmental impact associated to human activities.

Keywords: Yield-SAFE; agroforestry systems; carbon sequestration; soil erosion; nitrate leaching; tree density

Introduction

Agroforestry systems (AFS) are getting attention of land managers as they are able to produce food, energy, and materials in a more efficient way compared to mono-cropping land-use alternatives such as agriculture or forestry (Graves et al. 2007). This is mainly due to the overall higher and more diverse biomass production because of higher use efficiency of solar radiation and water by trees and crops (Cannell et al. 1996). In addition, agroforestry practices are often integrated into strategies for improving natural resources management as they are: 1) linked to less environmental stressful activities and 2) because the multilayer composition makes the system provides more Regulating Ecosystem Services (RES) (Torralba et al. 2016) as it can host more living organisms that can mediate or regulate harmful environment impacts.

The study presented by García de Jalón et al. (2017) showed that, when key actors in the agriculture and forestry sectors (including farmers, landowners, agricultural advisors, researchers and/or environmentalists) are enquired about the potential implementation of agroforestry, the main benefit they see is the reduction of the environmental impacts compared to farming or forestry. In recent years, several studies gave scientific support to this opinion by showing that agroforestry is a practice that can offer similar yields while reducing soil erosion (Nair 2007), nitrate leaching (Jose 2009) net greenhouse gas emissions (Godfray et al. 2012),improve biodiversity conservation (Klaa et al. 2005) and enhance climate change mitigation by sequestering more carbon (Cardinael et al. 2015). However, Moreno et al. (2017) stated that there is evidence that these positive environmental effects are very location specific and that there is a need of a better geographical coverage in order to generalize these patterns at broader scales.

The main objective in this study was to analyze how tree-crop interactions for water and radiation interact with the supply of three Regulating Ecosystem Services: soil erosion, nitrate leaching and carbon sequestration. The study covered four different agroforestry systems in Europe representing diverse biogeographical environments. The Yield-SAFE model described in Palma et al. (2016) was used to predict RES outputs from the four systems. To this end, the model was completed by specific methodologies for the estimation of the three RES. For each system, six different land use alternatives of increasing tree densities were considered: a crop rotation or only pasture (zero tree density); four agroforestry (intermediate tree densities) and forestry (high tree density).

Materials and methods

The integration of methodologies for the assessment of RES into Yield-SAFE allowed to assess the effects of tree density and crop area covered on the supply of RES. A comparison is done to the performance of 4 AFS under increasing tree density alternatives (depending on the system) ranging from agriculture (without trees) to forestry (high tree density). The 3 RES estimated were: 1) soil composition and structure by the estimation the soil eroded by water; 2) water quality through the estimation of the nitrates leached and 3) air composition and climate regulation via the estimation of carbon sequestered by above and belowground biomass and soil carbon storage.

The soil eroded by water was estimated using the revised universal soil loss equation (RUSLE). The equation estimates long-term average annual soil loss by sheet and rill erosion and has been the most frequently used soil erosion model (Panagos et al. 2015). The RUSLE equation was implemented into Yield-SAFE model following the approach used in Palma et al. (2007) with the exception of the cover management factor (C factor) that in this study varies depending on the type and age of vegetation and on the disposition of the trees related to the crop.

For the estimation of the nitrate leached, the approach suggested by Palma et al. (2007) was followed and implemented into the Yield-SAFE model. In this approach it is considered that the quantity of nitrate leached ($kgNO_3^-$ ha^{-1} yr^{-1}) can be estimated depending on the nitrogen balance of the system and the relationship between the flow to groundwater and the soil water content at field capacity. The nitrogen balance considers as nitrogen inputs coming from fertilization, atmospheric deposition, biotic fixation and mineralization and as nitrogen outputs, the processes of denitrification, volatilization, crop and tree uptake and immobilization.

The carbon sequestered by the systems was estimated through the capacity of above and belowground biomass and soil to store carbon. The improved version of Yield-SAFE model (Palma et al. 2017) used integrates a soil carbon model (RothC, Coleman and Jerkinson 2014) that simulates soil organic turnover. The integration focused on the estimation of input plant material from tree and crop into soil including leaf fall and root mortality. For this study products extracted from crops as wheat grain, sugar-beet, or meat (through grass) were not included in the carbon sequestration estimation due to their short durability (timber on the other hand, was included as it immobilizes carbon for many years). For the silvo-pastoral systems (montado and Swiss pastures) the excrements of the livestock grazing were considered to be organic input material for the soil model.

The model was applied to four systems in Europe representing different components and climate regions: 1) Montado wood pastures in Portugal; 2) Grazed cherry tree pastures in Switzerland; 3) Poplar for timber production with cereals alleys in the UK and 4) Poplar short rotation coppice with cereals in Germany. For each system 6 different tree densities were considered including: arable (no trees), forestry (high tree density) and 4 agroforestry alternatives ranging from the arable to the forestry option. The Yield-SAFE model was previously parametrized for all the tree and crop components of the systems and the weather, soil, crop, tree and livestock management inputs required by the model were collected.

The simulation period used was of 80 years. In case of shorter rotation periods (20 years in silvoarable systems in the UK and 4 years in short rotation coppice in Germany), the rotation period was repeated until 80 years were achieved (4 and 20 times respectively).

Results and discussion

First results showed different tendencies across the 4 study regions, even if there was a general improvement of RES supply linked to tree presence. In terms of soil eroded (Figure 1A), most of the parameters included in the RUSLE equations are constant and depend on the physical and weather conditions of the site and just the cover management factor (C_{factor}) varies depending on the growth of the tree, the crop present and the disposition of trees related to crops. The C_{factor} is defined as how crop management causes soil loss compared to bare ground. The higher susceptibility of soil to erode (K_{factor}) presented in Switzerland results in higher values of soil eroded after the simulation period whereas due to the lower rainfall erosivity factor (R_{factor}) in the UK results are the opposite. On the other hand, the lower C_{factor} value presented by natural grasslands in Portugal or Switzerland diminishes the importance of tree presence in avoiding soil erosion. In the UK and Germany, where cereals and sugar beet present higher C_{factor} values, the absence of trees (arable alternatives) lead to higher soil losses.

In Mediterranean areas precipitation rarely exceeds evapotranspiration meaning there is a low flow to groundwater to transport nitrates. In addition, it is assumed that natural grasslands in Switzerland are not fertilized meaning for both systems (montado and Swiss pastures) nitrate leached can be considered negligible (Figure 1B). On the other hand, on the English site there is a clear effect of trees in avoiding nitrate leaching as with the same area and the same amount of fertilization dedicated to crop, the nitrate leached is reduced as tree density increases. Meanwhile no tree effect is initially observed in the German site as nitrate leaching is reduced but also is the crop dedicated area.

Carbon sequestration is estimated as a fixed percentage of living biomass (50%) and its content in soil, that on its turn depends on the inputs provided by the living biomass through root mortality and leaves fall. Therefore, the different levels of carbon sequestration encountered among the four agroforestry system reflect the different edapho-climatic conditions present in the different sites that limit the biomass growth potential of the systems. As expected, pure pastures and arable alternatives remain in an equilibrium state all along the simulation period (Figure 1C). Yet the presence of trees increases carbon sequestration, however this was not linear. Tree competition for water and solar radiation increased with tree density, reducing the quantity of biomass, and therefore the carbon sequestered by each tree. Also the final destination of the products offered by each system influences drastically carbon sequestration estimation. Biomass from German poplar plantations is not considered to sequester carbon as wood chips are burnt to produce energy. Timber from Swiss cherry trees and poplar in the UK are considered to have longer life expectancies as may be used for furniture and cheap wood materials (fruit boxes, pallets) respectively. Portuguese oaks have been also considered to sequester carbon as they remain standing even after the simulation period.

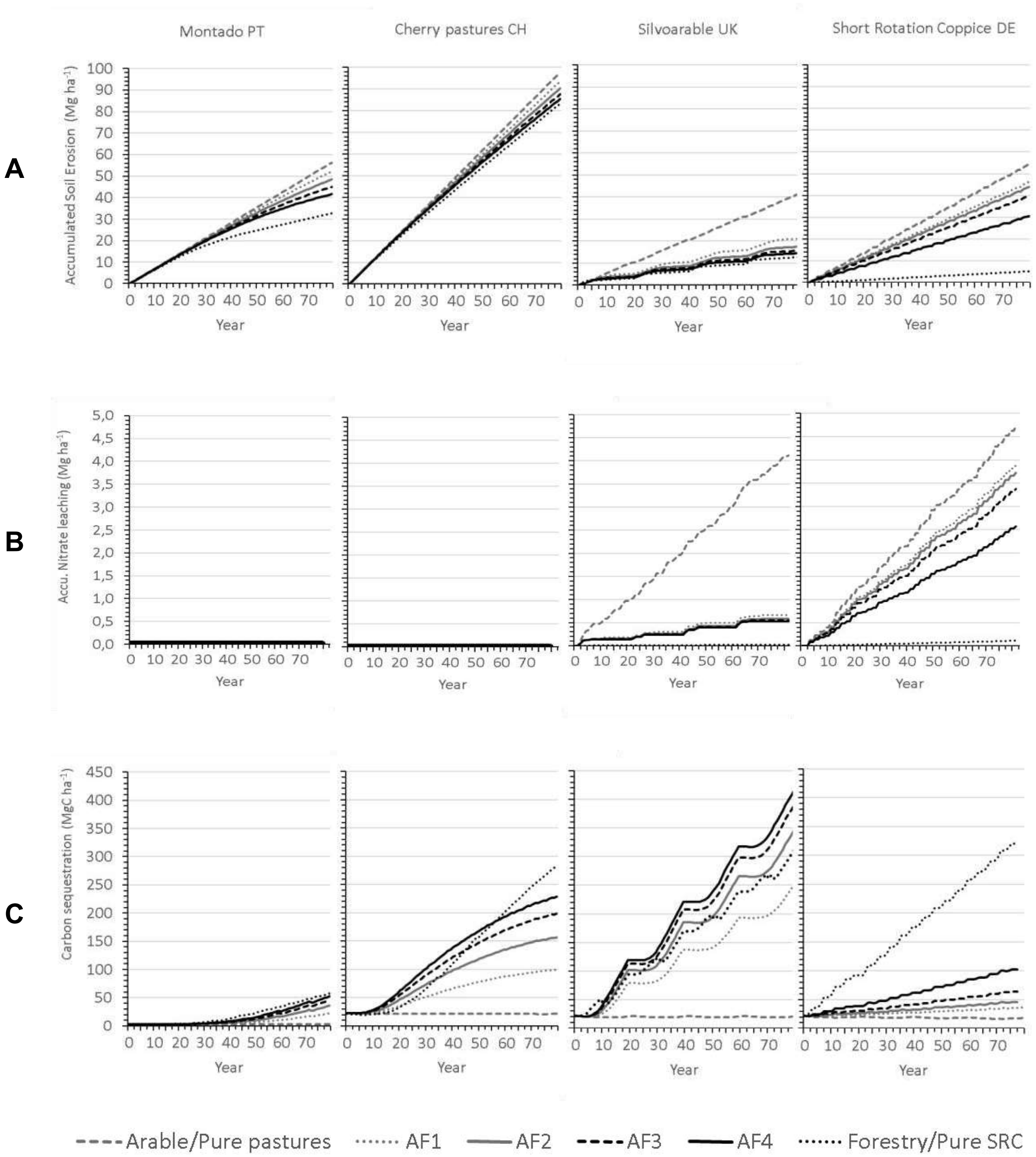

Figure 1: Yield-SAFE predictions of Regulating Ecosystem Services provided (A, soil erosion; B, Nitrate leaching; C, carbon sequestration) in 80 years for 6 different management alternatives in increasing tree densities across Europe. Montado in Portugal (Montado PT): 0 trees ha^{-1} (Pure pastures); 50 trees ha^{-1} (AF1); 100 trees ha^{-1} (AF2); 150 trees ha^{-1} (AF3); 200 trees ha^{-1} (AF4) and Forestry (Forestry/Pure SRC). Cherry tree pastures in Switzerland (Cherry pastures CH): 0 trees ha^{-1} (Pure pastures); 26 trees ha^{-1} (AF1); 52 trees ha^{-1} (AF2); 78 trees ha^{-1} (AF3); 104 trees ha^{-1} (AF4) and Forestry (Forestry). Silvoarable systems in the UK (Silvoarable UK): 0 trees ha^{-1} (Arable); 56 trees ha^{-1} (AF1); 78 trees ha^{-1} (AF2); 104 trees ha^{-1} (AF3); 156 trees ha^{-1} (AF4) and Forestry (Forestry). Short rotation coppice in Germany (Short rotation coppice DE): 0m (Arable); 96m (AF1); 72 m (AF2); 48 m (AF3); 24m (AF4) and pure short rotation coppice (Pure SRC).

References

Cannell MGR, Noordwijk M, Ong CK (1996) The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. Agrofor Syst 34:27–31. doi: 10.1007/BF00129630.

Cardinael R, Chevallier T, Barthès BG, Saby BPA, Parent T, Dupraz C, Bernoux M, Chenu C (2015) Impact of alley cropping agroforestry on stocks, forms and spatial distribution of soil organic carbon - A case study in a Mediterranean context. Geoderma 259–260: 288–299.

Coleman K, Jenkinson D (2014) RothC - A Model for the Turnover of Carbon in Soil - Model description and users guide. Rothamsted Research, Harpenden, UK.

García de Jalón S, Burgess PJ, Graves AR, Moreno G, McAdam J, Pottier E, Novak S, Bondesan V, Mosquera-Losada MR, Crous-Durán J, Palma JHN, Paulo J, Oloveira TS, Cirou E, Hannachi Y, Pantera A, Wartelle R, Kay S, Malignier N, Van Lerberghe P, Tsonkova P, Mirck J, Rois M, Grete Kongsted A, henail C, Luske B, Berg S, Gosme M, Vityi A (2017) How is agroforestry perceived in Europe? An assessment of positive and negative aspects by stakeholders. Agroforst Syst. doi: 10.1007/s10457-017-0116-3.

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Robinson S, Thomas SM, Toulmin C (2012) Food Security: the Challenge of Feeding 9 billion. Science 327: 812-818.

Graves AR, Burgess PJ, Palma JHN, Herzog F, Moreno G, Bertomeu M, Dupraz C, Liagre F, Keesman K, van der Werf W, Koeffemande de Nooy A, van den Briel JP (2007) Development and application of bio-economic modelling to compare silvoarable, arable, and forestry systems in three European countries. Ecol Eng 29:434–449. doi: 10.1016/j.ecoleng.2006.09.018.

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: An overview. Agroforst Syst 76: 1–10.

Klaa K, Mill PJ, Incoll LD (2005) Distribution of small mammals in an silvorable agroforestry system in Northern England. Agrofor Syst 63: 101–110.

Moreno G, Aviron S, Berg S, Crous-Duran J, Franca A, García de Jalón S, Hartel T, Mirck J, Pantera A, Palma JHN, Paulo JA, Re GA, Sanna F, Thenail C, Varga A, Viaud V, Burgess PJ (2017) Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. Agrofor Syst. doi: 10.1007/s10457-017-0126-1.

Nair PKR (2007) The coming of age of agroforestry. J Sci Food Agric 87: 1613–1619.

Palma JHN, Graves AR, Burgess PJ, Keesman KJ, van Keulen H, Mayus M, Reisner Y, Herzog F (2007) Methodological approach for the assessment of environmental effects of agroforestry at the landscape scale. Ecol Eng 29: 450–462.

Palma J, Graves A, Crous-Duran J, Upson MA, Paulo JA, Oliveira TS, García de Jalón S, Burgess P (2016) Yield-SAFE Model Improvements. Report for Milestone 29 (6.4) of the AGFORWARD project (Lisboa). http://hdl.handle.net/10400.5/12337 (accessed 24/04/2018).

Palma JHN, Crous-Duran J, Graves AR, García de Jalón S, Upson M, Oliveira TS, Paulo JA, Ferreiro-Domínguez N, Moreno G, Burgess PJ (2017) Integrating belowground carbon dynamics into Yield-SAFE, a parameter sparse agroforestry model. Agrofor Syst https://doi.org/10.1007/s10457-017-0123-4.

Panagos P, Borrelli P, Poesen J, Ballabio C, Lugato E, Meusburger K, Montanarella L, Alewell C (2015) The new assessment of soil loss by water erosion in Europe. Environ Sci Policy 54: 438–447.

Torralba M, Fagerholm N, Burgess PJ, Moreno G, Plieninger T (2016) Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agr Ecosyst Environ 230: 150-161.