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Native coffee agroforestry in the Western Ghats of India maintains higher carbon storage and tree diversity compared to exotic agroforestry

Joannès Guillemot[a,b,c,*], Guerric le Maire[a,b,d], Manjunatha Munishamappa[e], Fabien Charbonnier[a,b,f], Philippe Vaast[a,b,g]

[a] CIRAD, UMR Eco&Sols, 34060 Montpellier, France
[b] Eco&Sols, Univ Montpellier, CIRAD, INRA, IRD, Montpellier SupAgro, 34060 Montpellier, France
[c] Universidade de São Paulo-ESALQ, 13418-900 Piracicaba SP, Brazil
[d] NIPE, UNICAMP, 13083-896 Campinas, Brazil
[e] EMPRI, Bangalore, India
[f] CONACyT research fellow, El Colegio de la Frontera Sur, San Cristóbal de las Casas, Mexico
[g] World Agroforestry Centre (ICRAF), Southeast Asia Regional Program, Hanoi, Viet Nam

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ABSTRACT

The ongoing introduction of the exotic *Grevillea robusta* tree species into agroforestry systems (AFS) of the Indian Western Ghats could become a threat to both climate change mitigation and tree diversity conservation.

Here, we quantified carbon (C) storage and shade tree diversity in native forests and coffee AFS under contrasted management (native versus exotic shade trees, Robusta versus Arabica systems) at 67 plots along a 3500 mm precipitation gradient in the Cauvery watershed, India.

Despite a substantial reduction of shade tree cover in native AFS compared to forest (from 90% to 32% in the high precipitation area), native AFS and forests displayed high and comparable C stocks (max. 228 MgC ha^{-1} and 234 MgC $ha^{-1,}$ respectively) and tree diversity (max. 44 and 45 species, respectively). Both variables were negatively impacted by the introduction of *G. robusta*, especially in Robusta coffee systems (max. 158 MgC ha^{-1}, 12 species).

The current trend toward the introduction of *G. robusta* in coffee AFS of the study area (exotic agroforestry) negatively affects C storage and tree diversity, especially in Robusta coffee systems. Policy makers should take advantage of the carbon-tree diversity positive correlation found in the agroforestry landscape of the Western Ghats of India to promote conservation and climate change mitigation.

1. Introduction

The ongoing deforestation and biodiversity decline caused by human disturbance is strongly affecting the functioning of tropical forests, which may hamper their ability to sustain ecosystem services in the future (Hooper et al., 2012). Indeed, recent studies (e.g. De Beenhouwer et al., 2013; Gibson et al., 2011) highlighted that both biodiversity and ecosystem services are reduced by management intensification (i.e. from native forest to mono-specific plantation or full-sun crops). In this context, agroforestry systems (AFS), where crops or pasture are grown in association with trees, have been proposed as a way to reconcile biodiversity conservation and crucial ecosystem services such as food supply and carbon (C) storage (De Beenhouwer et al., 2016; Nair et al., 2009). In such systems, tree shade is commonly finely tuned through tree planting, thinning and pruning, in order to obtain favourable light and humidity conditions for coffee production (Beer et al., 1997; Tscharntke et al., 2011).

Coffee is an important example of crop traditionally cultivated under native tree shade, with strong benefit for biodiversity conservation and C storage (Perfecto et al., 2014). A current trend toward the use of fast-growing exotic tree monocultures, instead of native canopies, is however currently observed in coffee AFS worldwide (Ehrenbergerová et al., 2016; Nath et al., 2011; Schmitt-Harsh et al., 2012). This simplification of coffee AFS canopies may affect AFS functioning and biodiversity conservation. Tree species identity and diversity has indeed been reported to affect forest carbon and water cycling (Castro-Díez et al., 2012; Kunert et al., 2012; Potvin et al., 2011), as well as the richness and community compositions of other ecosystem components such as birds (Gil-Tena et al., 2007), insects (Sobek et al., 2009) and soil organisms (Tedersoo et al., 2016).

* Corresponding author at: USP-ESALQ, Departamento de Ciências Florestais, Av. Pádua Dias, 11 - Cx. Postal 9, Piracicaba, SP, CEP 13418-900, Brazil.
E-mail address: joannes.guillemot@cirad.fr (J. Guillemot).

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The simplification of coffee AFS tree species composition has been particularly acute in the Kodagu district, which accounts for one-third of the Indian coffee production (Garcia et al., 2010), and is located in the Western Ghats biodiversity hotspot. Kodagu district landscape has strongly evolved over the last decades, with an important rate of forest degradation and deforestation due to coffee estate expansion toward the western forested area (Lo Seen et al., 2010), and the introduction of the fast-growing species *Grevillea robusta* in the canopies of coffee AFS (Garcia et al., 2010; Nath et al., 2016). The natural distribution area of *G. robusta* is located in Australia, but this species has been introduced in a large part of Asia and in Africa, where it is considered as an exotic species (http://www.worldagroforestry.org/treedb2/). Farmers' preference for *G. robusta* in the Western Ghats is thought to be mainly driven by the economic and legal advantages conferred on it by the existing policy framework, even though native trees have higher multipurpose utility and potential economic value (Garcia et al., 2010; Nath et al., 2016). Exotic species can indeed be harvested freely whereas native species require official permit to be harvested, which may not be granted under certain forms of land tenure where the government claims ownership rights over current and future native trees (Garcia et al., 2010; Nath et al., 2016). As a consequence, *G. robusta* was replanted five time more often than native trees over the 2011–2016 period in coffee AFS of the Western Ghats (Nath et al., 2016). Furthermore, coffee plants of the area have undergone pest attacks (stem borer, *Xylotrechus quadripes*) that have led farmers to convert their Arabica coffee (*Coffea arabica*) plantations into more resistant Robusta coffee (*Coffea canephora*) plantations (Garcia et al., 2010). The consequences of these management changes for C storage and biodiversity of the Western Ghats remain however poorly documented.

Kodagu district has extremely contrasted ecological conditions, with mean annual precipitation (MAP) ranging from 1200 mm in the East to more than 5000 mm in the West within about 50 km (Fig. 1). Such environmental gradients can be advantageously used to study the response of AFS to changes in precipitations, which integrate both the responses of plant functioning and farmer's management to contrasted environmental conditions. Therefore, it is possible to study synergies, antagonisms and trade-offs among the ecosystem services provided by AFS in contrasted environmental contexts. In this study, we aimed at quantifying how C storage and tree shade diversity vary among land-use systems (from native forest, to native shade tree AFS, to exotic shade tree AFS) along a 3500 mm MAP gradient in the Kodagu district. Moreover, we additionally aimed at quantifying the impact of Arabica to Robusta conversion in terms of C storage and tree shade diversity in this area.

We specifically tested the following hypotheses: 1) the management of AFS (planting of exotic trees in AFS, selective logging and pruning in native AFS) decreases C storage and tree species diversity compared to native forest; 2) the introduction of the fast-growing species *G. robusta* in AFS increases above-ground C storage compared to native AFS, but decreases soil C storage because of a reduction in soil biological activity; and 3) carbon storage and tree diversity are lower in Robusta coffee than in Arabica coffee AFS, as the higher light and high temperature tolerance of Robusta coffee plants allows for a low canopy density management. The impacts of our findings for management guidelines and conservation policies of coffee AFS in the Indian Western Ghats were discussed in a concluding section.

2. Materials and methods

2.1. Study area and sample design

The study area was the Cauvery watershed zone of the Kodagu district, Karnataka state, India (Fig. 1). Altitude ranges from 850 m in the East of the district to 1875 m in the West. Precipitation is strongly seasonal, with a maximum occurring during the monsoon, between June and August (Elouard and Guilmoto, 2000). Mean annual precipitation ranges from 1200 mm to more than 5000 mm within about 50 km from East to West. Forest cover of the study area is comprised of "low elevation wet evergreen forests" in the West and "moist to dry deciduous forests" in the East (Elouard and Guilmoto, 2000).

The watershed was surveyed in order to find locations with a native forest patch close to an AFS with native shade trees (called hereafter "native AFS") and / or close to an AFS with exotic shade trees ("exotic AFS"). Study plots were then established in each land-use system, in such way that i) plots were at a maximum distance of 300 m from each other, and had comparable topographical and soil characteristics (especially soil texture, Table 1) ii) native tree species represented more than 90% of the shade tree basal area in native AFS plots, and *Grevillea robusta* represented more than 60% of the shade tree basal area in exotic AFS plots.

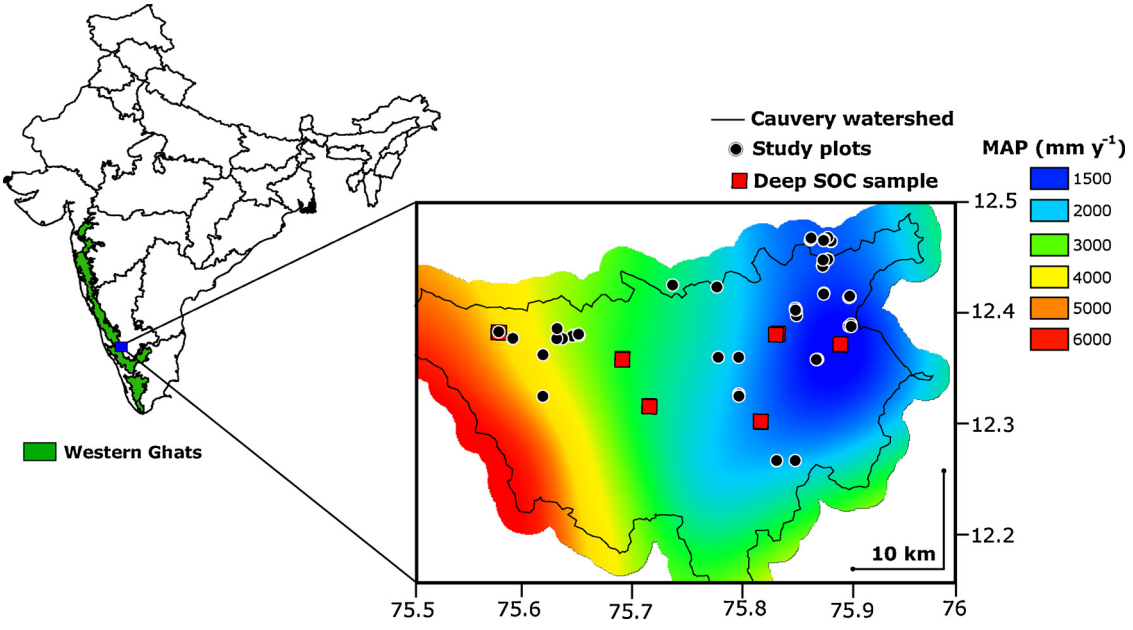

Fig. 1. Locations of the study sites, throughout the Cauvery watershed (Kodagu district, Karnataka state, India). MAP: Mean annual precipitation; SOC: Soil organic carbon.