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Collapse of ecosystem carbon stocks due to forest conversion to soybean plantations at the Amazon-Cerrado transition

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ABSTRACT

Deforestation to establish monocrops in the tropics is causing massive reductions in ecosystem C stocks. Amazonia is a principal targets of this process, owing to the expansion of the agribusiness frontier throughout the transition with the Cerrado biome, the zone known as the "Arc of Deforestation". In this vast contact region between the two largest South American biomes, the conversion of primary forest to soybean and pasture systems has led to the deforestation of nearly five million hectares since 1980. Despite this, we lack precise understanding of the effects of land use on ecosystem C stocks and pools in this region. Addressing this knowledge gap is crucial to improve predictions and fit models for different land use scenarios in Amazonia. To reduce uncertainty regarding the magnitude of the impacts of deforestation on the C cycle, we evaluated ecosystem C stocks in contrasting land-use systems across a topographically, climatically, and edaphically near-homogeneous landscape in southern Amazonia. We investigated the soil, litter, fine root and aboveground biomass (AGB) C stocks of soybean plantations and compared them to those of remnant native forests and rubber plantations; the latter is considered *a priori* as a cropping system with low impact on the C cycle. We found that the conversion of native forest to soybean plantation caused a 130.5 Mg C ha^{-1} loss, about threefold higher than the loss when forest is converted to rubber plantations, 48.5 Mg C ha^{-1}. While 30-year old rubber plantations had recovered 84% of forest carbon stocks, all plantation types induced sustained losses of at least one-third of the original soil carbon. Fine root allocation changed sharply in the two crops following conversion, indicating an alteration in plant nutrient dynamics. Our results show that perennial and annual monocrops have very different impacts on the C cycle, which need to be accounted for in carbon-climate models as well as in public policies regulating land use in Amazonia. Our results show that while silviculture has the potential to restore most of the above-ground C stocks of previously forested areas, but neither silviculture nor conventional agriculture may ever restore Amazon soil C stocks once they become vulnerable and oxidized after deforestation. If such conversion-driven soil carbon losses were scaled across the Amazon they would induce a cumulative loss of more than 5 Pg in soil carbon by 2050.

1. Introduction

One of the greatest uncertainties surrounding land use in the tropics is the impact of agriculture on Amazon Forest C stocks. Additionally, we are unsure about the sustainability threshold of traditional agricultural systems established in the savannas of central Brazil once applied in Amazonia (Petter et al., 2017). Brazilian agriculture has worldwide importance; it is mainly based on cereal crops and covers nearly 59 million hectares (CONAB, 2016), 60% of which is located in the Cerrado biome (IBGE, 2016). Amazonia borders this agribusiness belt from northwest to northeast, and, due to the scarcity of new agricultural land, is being pressured by the intense conversion of native forests to pasture and annual cropping systems, especially that of soybean (Persson et al., 2014; Farias et al., 2016). The largest supply of land is located exactly at the transition zone between Amazonia and Cerrado, the world's largest ecotonal complex. The confluence of the two floras

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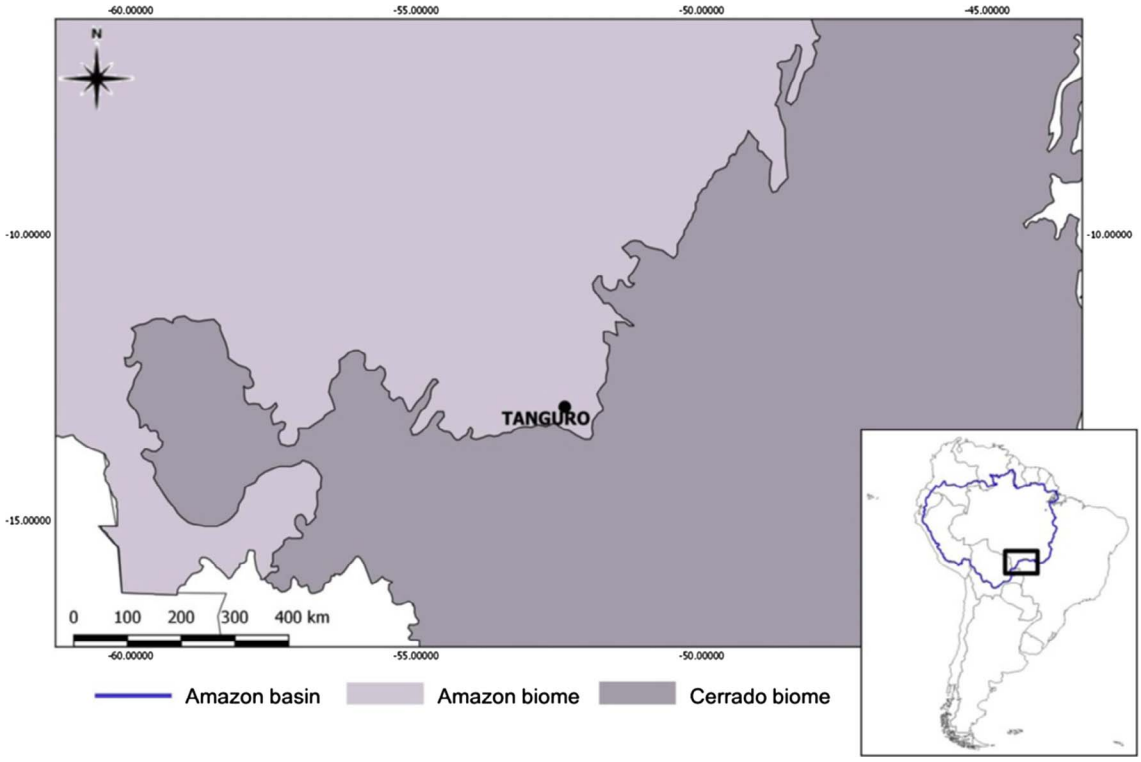

Fig. 1. Location of the Tanguro Farm, Querência, MT.

in addition to the largest and most dynamic agricultural frontier in the tropics result in a vast area of agribusiness occupation extending for nearly six thousand kilometers and known as the "Arc of Deforestation".

The native vegetation remnants in this ecotonal complex contain greater species diversity than each biome separately in unique physiognomies such as *cerradão* and transitional forests. However, the expansion of agribusiness in this contact zone has led to a series of massive environmental impacts (Costa & Pires, 2010), such as a rapid loss of biodiversity (Wearn et al., 2012) and soil and water degradation (Maia et al., 2010; Neill et al., 2013). Another impact of regional land use is substantial C transfer from soil-plant systems to the atmosphere (Friedlingstein et al., 2010; Coe et al., 2013), initially one of the results of deforestation and fire and, later, intensive land use, especially in the traditional soybean cropping system.

This scenario of land-use change is reflected on the C cycle and may lead to significant alterations in ecosystem structure, composition and functioning (Ojima et al., 2013). The conversion of native vegetation to agricultural and pasture lands compromises nutrient cycling (Davidson et al., 2004), alters organic matter dynamics (Don et al., 2011), and consequently has negative effects on the integrity of biogeochemical cycles, especially that of C. As estimated by Buckeridge (2008), the conversion of Brazilian forests in crop/pasture systems over the past 140 years has led to a net release of 121 Pg C to the atmosphere. This C increase alters not only the climate but also biodiversity patterns (Strassburg et al., 2010), considerably modifying ecosystems.

However, uncertainty still predominates in estimating the effects of land use on biogeochemical cycles and their consequences on the regional C balance. Current knowledge gaps exist regarding the impacts of native vegetation conversion to soybean plantations on CO_2 emissions in the Arc of Deforestation. Moreover, there has been no detailed research on the ways in which the substitution of native ecosystems by agroecosystems could reduce and/or redistribute C stocks in the biosphere. In this case, seasonal patterns of biomass deposition and allocation may also change (Yang et al., 2004), thus affecting the balance of nutrients, water and C (Wilson et al., 2000; Kotowska et al., 2016). These modifications are the result of a reduction in vegetation structure and the simplification of trophic interactions (Moore et al., 2005). In addition, land-use change can alter C residence time in the system, increasing the necessity for repetitive fertilization (Drinkwater & Snapp, 2007), thus leading to instability and unsustainability.

Nevertheless, the magnitude of the effects of those changes can vary greatly among crops (Kotowska et al., 2015) and management systems (Petter et al., 2017). Annual and perennial monocrops, for instance, differ in C storage and cycling patterns (Baldotto et al., 2015). Successive harvests in short-cycle crops are responsible for significant C exportation (Zeri et al., 2013) and a consequent reduction in soil stocks, even when direct planting is used. This results mainly from the traditional agricultural management system based on soybean planting during the summer followed by corn during the interharvest season (Petter et al., 2017). On the other hand, perennial crops such as rubber tree can positively influence this scenario by incorporating large amounts of organic matter into the substrate, which consequently protects against erosion and leaching (Suddick et al., 2013) and favors biogeochemical cycles by maintaining C stocks. As a result, perennial crops need lower nutrient additions and interventions compared to annual crops.

Because cropping systems show distinct behaviors, we aimed to assess the impacts of native forest conversion to soybean plantations (high-impact annual monocropping systems), also comparing with rubber tree plantations (low-impact perennial monocropping systems), in terms of C stocks and dynamics in distinct ecosystem compartments in the Arc of Deforestation. To achieve this goals, we generate prior knowledge on the impacts of such conversion by addressing these questions:

(1) What is the magnitude of the difference in native forest conversion impacts on C stocks between annual (soy) and perennial (rubber) monocrops?
(2) In the conversion of native forest to rubber tree monocrops, do C stocks tend to become similar to the original stocks of native forest over time?