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Variation in soil fertility influences cycle dynamics and crop diversity in shifting cultivation systems

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ABSTRACT

Smallholder farming in Amazonia is practised mostly through shifting cultivation, which under low population pressure is well adapted to the low-fertility soils that predominate in uplands and to the lack of external inputs. In this paper we investigate the effects of soil heterogeneity (in terms of fertility and texture) on shifting cultivation systems in Central Amazonia. We focus on the effect of soil variation between anthropogenic upland soils (Amazonian Dark Earths, ADE) and surrounding soils on the size and location of cultivation plots, on the cultivation cycle, and on the diversity and assemblage of crops. We found that more fertile soils are cultivated more intensively (with shorter fallow periods, higher frequency of cultivation, shorter cycles and higher labour requirements) and with different crop assemblages, and have similar or larger numbers of crop species and/or landraces. Current smallholder farming systems along soil gradients between ADE and non-anthropogenic soils show that enhanced soil fertility can favour synergies between intensification and diversification in shifting cultivation.

1. Introduction

Small-scale agriculture is the basis of the livelihoods of thousands of families in Amazonia, with smallholder farmers representing the vast majority of the rural population in the region (Godar et al., 2014). In Central Amazonia, smallholder agriculture is practised mainly through shifting cultivation, which at low population densities is well suited to the poor and acidic soils that predominate in the uplands (Nye and Greenland, 1960; Altieri, 2004). These systems use crops well adapted to poor soils and are mostly low input: the intensification of land use without extra inputs is usually associated with reduction in yields (Mertz et al., 2008), decrease in the availability of non-crop plant resources (Dalle and de Blois, 2006), increased labour requirements (Nielsen et al., 2006), and loss of resilience of secondary forests that regrow after abandonment (Jakovac et al., 2014). However, farmers' opportunities to intensify and/or diversify their shifting cultivation systems can be influenced by several factors, among which environmental heterogeneity is a central one (Denevan, 1984; Almekinders et al., 1995). In Central Amazonian uplands, patches of high-fertility anthropogenic soils are also found; these add considerable heterogeneity to landscapes and are associated with different opportunities for the intensification and/or diversification of shifting cultivation.

Amazonian Dark Earths (ADE, or Terra Preta) are anthropogenic soils created by the concentrated deposition of carbonized organic materials from the cultural activities of pre-Columbian populations between 500 and 2500 years ago (Neves et al., 2003; Glaser and Birk, 2012). It has been estimated that these soils occur in 0.1–0.3% of forested Amazonia (Sombroek et al., 2003), and they are more likely to be found along rivers in the central and eastern parts of the basin (McMichael et al., 2014). ADE exhibit on average high levels of most macro- and micro-nutrients (apart from potassium), as well as higher organic matter content and pH than surrounding soils (Glaser and Birk, 2012). Patches of ADE are currently used by local people for homegardens, agroforests, secondary and mature forests, and swiddens[1] in shifting cultivation (German, 2003; Hiraoka et al., 2003; German, 2004; Junqueira et al., 2010; Fraser et al., 2011a,b; Junqueira et al., 2011). Previous studies have

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[1] We use the term 'swidden' to refer to the cropping phase of a plot in shifting cultivation.

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indicated that ADE are associated with more intensified cultivation systems, with shorter fallow periods and focused on short-cycle manioc landraces (Fraser et al., 2012) and/or nutrient-demanding cash crops (Hiraoka et al., 2003; Kawa et al., 2011). These studies, however, have considered ADE as a defined soil category, which neither conforms to how farmers perceive and classify soils (data not shown), nor to the heterogeneity in soil properties found between ADE and adjacent soils (Fraser et al., 2011c).

In this paper, we look at the shifting cultivation strategies used by smallholder farmers (*i.e.*, how cultivation is practised and what is cultivated) in ADE and adjacent soils in Central Amazonia. We combine data from soil samples, botanical inventories and farmer interviews to investigate whether the gradients in soil properties between anthropogenic and adjacent soils influence (1) the size and location of cultivation plots, (2) the characteristics of the shifting cultivation cycle, and (3) the diversity and assemblage of crops and landraces cultivated. In contrast to previous studies about cultivation on ADE, we analyse the whole gradient in soil properties between ADE and adjacent soils, we investigate multiple aspects of the cultivation cycle (swidden size and distance, labour investment, cycle frequency and length of fallows and of cropping periods) and we consider the whole assemblage of crops cultivated, at both the species and the landrace level. This provides a more comprehensive understanding of how ADE is incorporated into local cultivation systems in Amazonia, and allows us to evaluate in a wider sense the effects of soil fertility and texture in shifting cultivation systems.

2. Methods

2.1. Study area

This study was carried out in riverside communities located along the middle and lower Madeira River, in Central Amazonia (Fig. 1). The local climate is a transition between “tropical rainforest climate” and “tropical monsoon climate” [Af and Am in the Köppen climate classification, respectively (Alvares et al., 2013)], with a short dry season between July and September, annual rainfall of 2600–2800 mm and mean temperatures between 27 and 28 °C. Despite increasing deforestation close to roads and small cities, forests and/or other apparently natural vegetation types occupy most of the landscape in this region. These are composed predominantly of evergreen *terra firme* forests and flooded forests along the rivers, with patches of savannahs further from the rivers (Rapp Py-Daniel, 2007).

Soils in the uplands (*i.e.*, in areas that are not subjected to the river floods) are generally poor and acidic ferralsols, with small patches of acrisols, lixisols and podzols; in the active floodplain of the Madeira River (and also on paleoriverine land forms) fertile gleysols occur [IBGE (2010); classification sensu WRB (2014)]. Anthropogenic soils (anthrosols) are commonly found in the landscape, particularly on bluffs along the Madeira River, its tributaries and lakes, and many of them are located under current villages or towns (Moraes and Neves, 2012). Patches of ADE are heterogeneous in colour, texture and chemical properties, and vary in size from 1 to ~50 ha (Fraser et al., 2011b; Fraser et al., 2011c; Moraes and Neves, 2012).

The local population is composed mostly of *caboclos*, descendants of the intermarriage between local indigenous people with migrants from other parts of Brazil in the late 19th and early 20th centuries (Adams et al., 2009). Main subsistence and economic activities include the cultivation of manioc and/or other annual crops in shifting cultivation systems, agroforestry, the extraction of forest products (e.g., Brazil nut *Bertholletia excelsia* Bonpl., rubber *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg.), hunting and fishing. Despite these commonalities, the *caboclos* form a heterogeneous group in which multiple historical trajectories coexist, as well as diverse forms of resource use and management, and different levels of interaction with cities and markets.

2.2. Sampling design

We selected seven villages along the middle and lower Madeira River and its tributaries, spread along a stretch of approximately 400 km (Fig. 1). Selected villages were located on or close to patches of ADE, were well-spaced along the river, and were located

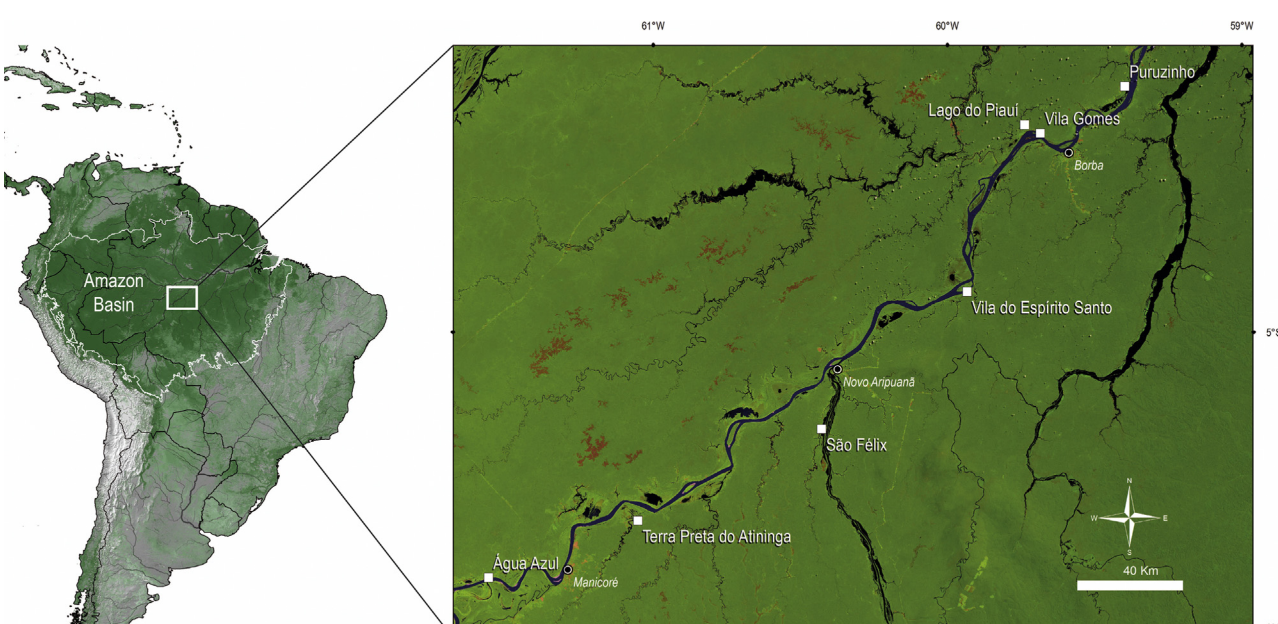

Fig. 1. Location of study sites (white squares) along the middle and lower Madeira River, Central Amazonia, Brazil. Dots indicate cities located along the river. The inset shows the placement of the study area as white rectangle in the Amazon Basin. The inset map is composed of a mosaic of LANDSAT images from 2009 to 2010, obtained from the U.S. Geological Survey; dark green areas represent old-growth forests, light green represents secondary regrowth and red/brown represents open areas.