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Slash-and-burn agriculture and tropical cyclone activity in Madagascar: Implication for soil fertility dynamics and corn performance

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ABSTRACT

On the western coast of Madagascar, the dry tropical forest of Kirindy may disappear in the next 50 years because of its rapid conversion into agricultural land by slash-and-burn cultivation. The slash-and-burn fields are cultivated during 3 years in average and are further abandoned because of soil depletion, weed invasion and finally lower crop yields. As a consequence, new forest areas are regularly cleared from the primary forest, causing deforestation. In addition, Madagascar is situated in a region with high cyclonic activity. Violent storms hit the western coast every 3–4 years, leading to intense rainfalls and floods. These events may enhance soil physical degradation and nutrient leaching, thereby accentuating the soil depletion by slash-and-burn agriculture and with it, the forest conversion rate. Focusing on the combined effects of historic land management and prevailing climatic conditions, this paper investigates: (1) the temporal evolution of soil fertility along with crop performance from cultivation up to field abandonment, and (2) the relative effects of land use (crop cultivation) and extreme climatic events (heavy rain, cyclonic storms) on soil and crop properties. We used a space-for-time substitution approach in slash-and-burn corn (*Zea mays* L.) fields to describe dynamics of soil fertility and crop performance. We sampled soils and plants during two seasons: (a) a normal rainy season, in 2014, and (b) a cyclonic rainy season, in 2015. We found that under the cyclonic storm, soil becomes not only N and P deficient, but the K concentration also steeply drops. Overall, this leads to a dramatic reduction of corn performance. While a decrease in grain yield due to slash-and-burn agriculture reaches about 37.5% after three years of cultivation on the same field (from 4 to 2.5 t ha^{-1}), it decreases up to 75% after a single cyclonic rainy season (from 4 to 1 t ha^{-1}). On the sidelines of the study, a locust pest also damaged half of the corn fields in 2014, driving the corn yield down to zero on those particular fields. Given what precedes, the study points out the fragility of traditional agricultural techniques against natural hazards. Along with global warming, the frequency and intensification of natural disasters are expected to increase, impacting negatively and strongly the livelihoods of rural farmers. This raises the urgent need to increase farmer's awareness to alternative and more sustainable agricultural practices.

1. Introduction

Primary forests of Madagascar are home to a rich and unique biodiversity, but they are endangered by severe deforestation. On the south-western coast of the island, in the Menabe region,

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deforestation rate of the dry deciduous forest has been estimated at 2.6% per year between 2008 and 2010, i.e. to 1890 ha per year (Zinner et al., 2014). At that rate, the forest and most, if not all, of its endemic species, will have entirely disappeared by 2050 (Zinner et al., 2014). Slash-and-burn shifting cultivation is the main cause of deforestation in Madagascar (Dirac Ramohavelo, 2009). In this traditional cultivation practice, forest is converted into agricultural land by partial clearing and subsequent burning of the cut trees. The ashes are used then to amend the soil. However, after three years, crop yield already decreases and weeds invade the field, forcing the farmers to abandon the land and to burn new areas of primary forest (Raharimalala et al., 2010; Styger et al., 2007). Therefore, whilst convenient to the farmers, shifting cultivation contributes largely to the rapid ongoing deforestation (Dirac Ramohavelo, 2009; Genini, 1996).

The duration of cultivation and of fallow, together with population density, are key factors when determining the impact of slash-and-burn practices on forest cover (Kleinman et al., 1995; Ziegler et al., 2009). An increase in population density often forces an extension of cultivation duration whilst fallow periods are reduced. Across Madagascar, average fallow duration has decreased from 8 to 4 years over the last century (Jarosz, 1993). As a result, fallow periods became too short to allow recovery of the soil nutrient status, leading to soil depletion and ultimately to secondary successions of savannahs (Raharimalala et al., 2012, 2010). In most tropical ecosystems, forest regeneration can only be successful with a strict minimum of 10 years of fallow (Thomaz et al., 2014). Yet, Raharimalala et al. (2010) showed that in the dry deciduous forests of Menabe, fallow duration should be at least doubled to 20 years.

Slash-and-burn agriculture affects both soil chemical and physical properties. Ashes are strongly alkaline, and therefore increase soil pH, favouring microbial activity and therefore soil nutrient availability (Demeyer et al., 2001). This is particularly useful on tropical acid soils, where nutrient availability is low due to leaching, translocation or binding in strong metal-anion complexes (Frossard et al., 1995). However, large ash inputs can impact upon soil macronutrient stoichiometry, as ash is generally N-poor, mainly due to volatilisation during combustion (Demeyer et al., 2001). Hence, ash input most likely leads to N limitation in the soil, which is problematic for sustainable crop growth. Nutrient limitation becomes even more prominent as corn (*Zea mays* L.), an especially N-demanding plant, is one of the most cultivated crops in Madagascar, after rice. Not surprisingly, corn yield is very low in Madagascar, with a national average of 1.5 to 2 t ha^{-1} (FAO, 2013). Consequently, fertilization rates are not sufficient to compensate for the high nutrient uptake by corn, resulting in soil nutrient depletion (Folberth et al., 2013).

In addition to the effect on soil chemical properties, slash-and-burn agriculture tends to degrade soil structure, mainly as a consequence of wind and rain erosion (Comte et al., 2012; Thomaz, 2013). Indeed, soil physical degradation is of main concern for the western coast of Madagascar. Heavy rains are common under tropical cyclone activity, leading to soil saturation and overland flow, which further causes soil erosion even on slightly sloping terrains. During the rainy season (November–April), up to nine

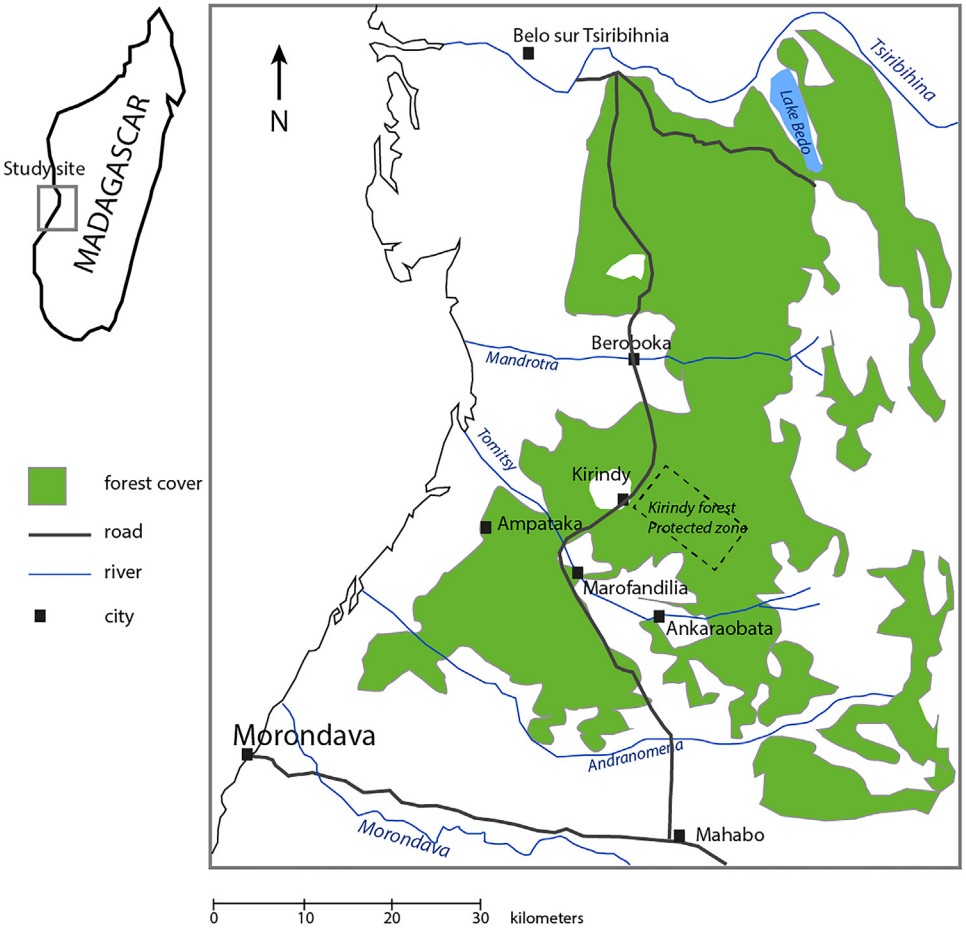

Fig. 1. Geographical location of the study site in the Kirindy forest (adapted from Scales (2012)).