Acta Botanica Brasilica, 2025, 39: e20240204
doi: https://doi.org/10.1590/1677-941X-ABB-2024-0204

Review

Implications of slash-and-burn agriculture with rotation and fallow lands in traditional agricultural systems: a review

Juliana Loureiro Almeida Campos[1,*], Fernanda Testa Monteiro[2], Gustavo Taboada Soldati[3], Claudenir Fávero[4],

[1] Universidade Federal dos Vales do Jequitinhonha e Mucuri, Faculdade Interdisciplinar de Humanidades, Diamantina, MG, Brazil.
[2] Universidade de São Paulo, Laboratório de Geografia Agrária, São Paulo, SP, Brazil.
[3] Universidade Federal de Juiz de Fora, Departamento de Botânica, Juiz de Fora, MG, Brazil.
[4] Universidade Federal dos Vales do Jequitinhonha e Mucuri, Departamento de Agronomia, Diamantina, MG, Brazil.
*Corresponding author: loureiroju@hotmail.com

ABSTRACT

Many cultures around the world manage a great diversity of agroecosystems through traditional practices like 'slash-and-burn agriculture'. Our review systematizes research on these systems, focusing on the rotation and fallow of lands managed over time and space by Indigenous Peoples and Local Communities in different parts of the world. We discuss the implications of these systems for the dynamics of biodiversity, agrobiodiversity, food security, soil characteristics, biomass, and carbon fluxes in the soil, vegetation, and atmosphere. We conclude that this agricultural practice has positive impacts on maintaining biological diversity and agrobiodiversity, also playing a significant role in reducing soil erosion and restoring soil natural fertility, raising pH, the dynamics of nutrient cycling, and carbon accumulation. The length of fallow is the main predictor of carbon stocks and their rate of accumulation in secondary forests, since repeated burning and more intensive cultivation can extend the time required for this accumulation and are not recommended. Understanding and strengthening this agriculture and improving it with agroecological approaches is more beneficial than simply criminalizing and diminishing its importance for the traditional groups that practice it, for the conservation of agrobiodiversity, and for the delivery of agroecosystem services to society at large.

Keywords: Agroecosystems; Fire management; Food security; Shifting cultivation; Swidden.

Received August 26, 2024; Accepted June 14, 2025
Editor-in-Chief: Thaís Elias Almeida; Associate Editor: Taline Silva

Data availability:
Data sharing is not applicable to this article.

How to cite:
Campos JLA, Monteiro FT, Soldati GT, Fávero C. 2025.Implications of slash-and-burn agriculture with rotation and fallow lands in traditional agricultural systems: A review. Acta Botanica Brasilica 39: e20240204. doi: 10.1590/1677-941X-ABB-2024-0204

This is an open-access article distributed under the terms of the Creative Commons Attribution License.

Introduction

For generations, social groups in different parts of the world have interacted with the environment to produce food and other raw materials such as wood, fibers, and vegetable oils. Over time/space, generations of human groups have developed agro-food strategies and diversified agricultural production logics adapted to their local soils, climates, and socio-cultural and economic contexts (Mazoyer & Roudart, 2010). As a result, we now enjoy significant biodiversity, much knowledge associated with the many uses comprising the soil-biodiversity-water relationship, and a high capacity for agricultural production throughout the world (Gupta, 2000; Raman, 2001; Ross, 2011). In today's world, according to Ploeg (2009), agricultural systems can be roughly grouped into three 'politic-economic models', of which we highlight two: 'entrepreneurial agriculture' and 'peasant agriculture'. The first of them refers to systems geared towards the productive industrialization of commodities, dependent on financial capital and industrial inputs, and in which higher yields demand large-scale territorial expansion (Ploeg, 2009). On the other hand, 'peasant agriculture', encompassing most of the world's rural population, is characterized by struggles for territorial and productive autonomy, which entails dependence on 'ecological capital', defined as non-market processes of co-production and exchange with ecosystems (Ploeg, 2009). Ploeg (2009) uses the term 'ecossystem'; however, as denoting the inseparability between 'nature' and 'cultures' (see Descola, 2013). We prefer the term 'agroecosystems' to represent the flow of matter and energy in a given location, considering humans' interaction with their environment to carry out agriculture.

Different environments and cultures around the world have thus given rise to a great diversity of agroecosystems with different forms of peasant/traditional agriculture, capable of presenting different local solutions for the best use of ecological capital in a coproduction between human groups and ecosystems (see Agnoletti, 2011; García & Santivañez, 2021), for example through 'slash-and-burn agriculture' (Conklin, 1961; Posey, 1984; Eden & Andrade, 1987; Kleinman *et al*., 1995; Pedroso Júnior *et al*., 2008; Mazoyer & Roudart, 2010). This is an ancient cultivation system, dating back to the Neolithic period and is still practiced today (Mazoyer & Roudart, 2010; Colin, 2021).

There are several formulations in the literature around the term 'slash-and-burn agriculture' (Pedroso Júnior *et al*., 2008; Gliessman, 2009; Mertz *et al*., 2009; Mazoyer & Roudart, 2010; Garavito *et al*., 2021). Mertz *et al*. (2009) highlighted the widespread use of terms in scientific literature as possible synonyms, such as 'swidden agriculture', 'shifting cultivation', and 'slash-and-burn agriculture', which must, however, be differentiated. The first case refers to systems that use fire to clear an area to be cultivated in rotation over the landscape. Yet there are rotational systems that do not use fire and are better defined by the term shifting cultivation (Mertz *et al*., 2009).

From another perspective, slash-and-burn agriculture is also referred to as 'shifting agriculture' and 'topple-and-fire agriculture', and can be defined as any agricultural system with continuity over time (ecological cycles) and space (visible throughout the landscape), in which clearings in forest phytophysiognomies are opened to be cultivated for short periods, followed by a longer fallow period, which is important to regenerate biodiversity and to reconstitute the edaphic characteristics required for a new cycle of agricultural production (Conklin, 1961; Posey, 1984; Eden & Andrade, 1987; Kleinman *et al*., 1995; Pedroso Júnior *et al*., 2008; Mazoyer & Roudart, 2010). Considering the rotational nature of this type of system,'slash-and-burn agriculture' creates a landscape composed of a mosaic of crop fields, fallow areas of different ages at different stages of regeneration, and areas of remnant vegetation (Finegan & Nasi, 2004; Arroyo-Kalin, 2012).

Given this diversity of concepts and contexts, we must specify the phenomenon, or the agriculture to which we are referring, in the reality we are analyzing. In our understanding, slash-and-burn agriculture is a socio-cultural and ecologically contextualized agricultural logic within a broader agricultural system, and not just the slash-and-burn technique itself. It refers to a form of agri-culture that slashes and burns biomass in a given area, necessarily combined with rotation and fallowing of lands, in order to recycle bases and to increase the natural fertility of the soil, as well as to raise the pH of naturally acidic and dystrophic tropical soils. In addition, it is practiced by traditional peasant families (or local communities), Indigenous Peoples, and *quilombolas* (Maroon Afro-descendants), in community territorial settings that provide conditions for the rotation and fallowing of lands. For this reason, there is an intrinsic relationship between agricultural practices and culture, considering the political and economic context in which this agricultural logic operates (Monteiro *et al*., 2019).

Our study presents a theoretical review of research on traditional agricultural systems featuring slash-and-burn agriculture with rotation and fallow of lands, concerning management practices over time (ecological processes) and space (expressed in the landscape), made by Indigenous Peoples and Local Communities. We outline the global distribution of these systems, including the phytophysiognomies and biomes where they occur, and discuss their implications for the dynamics of biodiversity, agrobiodiversity and food security, soil characteristics, biomass, and carbon fluxes in the soil, vegetation, and atmosphere. These aspects were selected for their centrality to the contributions of slash-and-burn agriculture.

Material and Methods

For this review, we searched for scientific articles in the Scopus, Web of Science, and Scielo databases using four different search keys, depending on the topic being researched:

i. (i): TS=((traditional OR local OR indigen*) AND (carbon OR biomass OR soil OR fertility) AND (shifting NEAR/4 (agriculture OR cultivation) OR (slash and burn) OR (swidden)));
ii. (ii): TS=((traditional OR local OR Indigen*) AND (biodiversity OR fallow OR diversity OR forest OR species) AND (shifting NEAR/4 (agriculture OR cultivation) OR (slash and burn) OR (swidden)));
iii. (iii) TS=((traditional OR local OR Indigen*) AND (agrobiodiversity OR crop OR species) AND (shifting NEAR/4 (agriculture OR cultivation) OR (slash and burn) OR (swidden))).

For searches in the Scopus database, instead of the NEAR/4 command, we used W/4.

The choice of search keys was based on categories of analysis/themes pertinent to slash-and-burn agricultural systems with rotation and fallow of lands. This methodology allows us to gather available results/studies, highlighting consensual results as well as gaps to be filled on this topic.

Results and Discussion

Worldwide distribution of slash-and-burn agriculture

Landscapes dominated by slash-and-burn agriculture occupy approximately 280 million hectares worldwide and are mainly located in tropical regions, with the majority in Africa, followed by the Americas and Asia (Heinimann *et al*., 2017). An estimated 200-500 million people, about 7% of the world's population, practice this form of agriculture (Colin, 2021). In the Amazon alone, slash-and-burn agriculture with rotation and fallow land feeds around 600,000 families in local communities (Homma *et al*., 1998).

Table 1 shows that, in most cases, fire management for slash-and-burn agriculture occurs in forest phytophysiognomies to establish more favorable environments for agricultural production. When operating in savanna domains, this agricultural practice occurs in forest enclaves, combining the creation of favorable environments with the use of more humid and productive microenvironments. In most rural situations, fire is used to clear fields, to facilitate human passage, or to renew pastures or natural resources. Please note that some authors – shown in Table 1 as 'not mentioned' – did not describe the characteristic vegetation of their study regions.

Different traditional agricultural systems in various parts of the world where slash-and-burn practices have been found are given very different names in the places where they are practiced: tavy (Madagascar), ladang (Indonesia and Malaysia), ray (Indochinese Peninsula), swidden (England), rai (Sweden), roça de toco, coivara, conuco, milpa, roza, chacra, chaco, chagra, roçado (Latin America), shamba, chitemene, lougan (Africa), jhum (India), kaingin (Philippines), shwe pyaung taungya (Myanmar) (Pedroso Júnior *et al*., 2008; Gliessman, 2009; Mertz *et al*., 2009; Mazoyer & Roudart, 2010; Thet & Tokuchi, 2020; Garavito *et al*., 2021). Table 1 summarizes the geographic and ecological scope of the reviewed research, including the continents, countries, and phytophysiognomies (morphological characteristics of plant communities; Grabherr & Kojima, 1993) or biomes (Coutinho, 2006) where the studies included in this review were conducted.

Despite this wide distribution and the significant contribution of slash-and-burn agriculture to the conservation of agrobiodiversity and maintenance of ecosystem services, as will be shown below, studies show that this practice has declined in several locations around the world (Gupta, 2000; Van Vliet *et al*., 2012). Projections indicate that the area now cultivated under such an agricultural approach is expected to decline considerably in the coming decades, probably due to the expansion of corporate agriculture (see Ploeg, 2009; Heinimann *et al*., 2017).

Impacts on biodiversity

Human activities in forest succession processes, caused by slash-and-burn agriculture with rotation and fallow of lands, have been a source of variability, helping to maintain or even promote regional biodiversity (Gupta, 2000; Raman, 2001; Ross, 2011). Scientists have found that secondary forests - plant communities in states of regeneration, following successional processes caused by anthropic or natural disturbances (Brown & Lugo, 1990; Finegan, 1992) - have been created, cultivated, and maintained through such agriculture (Raman, 2001) and that high biological diversity has been the outcome of such practices (Diegues *et al*., 1999; Gupta, 2000; Furlan, 2005). Evidence supporting this argument shows that dominant species in mature Central and South American forests are useful species protected by past human societies (Gómez-Pompa *et al*., 1972; Clement, 1999; Steege *et al*., 2013; Levis *et al*., 2018).

Traditional slash-and-burn farming practices are similar to disturbances that occasionally occur in forests from natural causes (Brown & Lugo, 1990; Raman *et al*., 1998). Through the creation of vegetation mosaics made possible by the rotation and fallowing of lands, this agricultural approach maintains a higher amount of early successional vegetation and edge areas than mature forests. This creates a social-ecological system in which human activity is crucial for the maintenance of local and regional biodiversity (Gupta, 2000; Raman, 2001).

Table 1. Continents, countries, and phytophysiognomies or biomes covered in the literature review.

Continent	Country	Phytophysiognomies or biomes	References
Asia	Bhutan	Subtropical forest and alpine meadows	Namgyel *et al.*, 2008
	India	Dry tropical forest; tropical rain forest; tropical evergreen forest; deciduous forest; semideciduous tropical forest; subtropical high altitude broadleaf forest; subtropical pine forest; temperate mountainous rain forests	Gupta & Kumar, 1994; Raman *et al.*, 1998; Gupta, 2000; Gupta *et al.*, 2001; Pandey *et al.*, 2019; Gogoi *et al.*, 2020; Gouda *et al.*, 2020; Manjunatha & Singh 2020; Thong *et al.*, 2020; Laskar *et al.*, 2021; Pandey *et al.*, 2022
	Thailand	Not mentioned	Rerkasem *et al.*, 2002
	China	Seasonal tropical forest; tropical rain forest	Fu *et al.*, 2003; Lu *et al.*, 2016
	Malaysia	Lowland tropical forest; tropical rain forest; mixed hill dipterocarp rain forest	Bruun *et al.*, 2006
	Myanmar	Mixed deciduous forest	Thet & Tokuchi, 2020
Oceania	Papua New Guinea	Rain forest	Bowman *et al.*, 1990
	Vanuatu	Not mentioned	Blanco *et al.*, 2016
Central America	Mexico	Tropical montane forest; tropical dry forest, tropical evergreen forest, rain forest	Medellin & Equihua 1998; Dalle *et al.*, 2011; Aryal *et al.*, 2014; Pérez-García & Castillo, 2016; Salinas-Melgoza *et al.*, 2017
South America	Brazil	Rain forest (Amazon); Atlantic rain forest (tropical forest and restinga); Savanna (Cerrado)	Posey, 1984; Sommer *et al.*, 2000; Peroni & Hanazaki, 2002; Metzger, 2003; Siminski & Fantini, 2007; Arroyo-Kalin, 2012; Borges *et al.*, 2016; NAC/UFVJM, 2017; Fávero, 2018
	Paraguay	Subtropical forest, deciduous forest, and mesophytic forest	Kammesheidt, 1998
	Peru	Rain forest (Amazon)	Smith *et al.*, 1999
	Colombia	Rain forest (Amazon)	Garavito *et al.*, 2021; Marentes *et al.*, 2021
Africa	Mozambique	'*Miombo*' forest (tropical and subtropical forests and savannas)	Magalhães & Mamugy, 2020
	Ethiopia	"Natural forests".	Terefe & Kim, 2020
Europe	Estonia	Savannas, gallery forests	Tomson *et al.*, 2015

The vegetation characteristic of early successional stages (annual plants and young perennial shoots) may in turn provide more forage for herbivorous animals, thus increasing the number of carnivores that feed on these prey (Namgyel *et al*., 2008). This also occurs in other managed tropical forest areas in the world, such as in the Amazon region (Denevan, 2001; Woods & Glaser, 2004; Mann, 2005), Mexico (Gómez-Pompa & Kaus, 1999), Central Africa (Weber *et al*., 2001), Thailand (Kealhofer, 2003), Papua New Guinea (Denham *et al*., 2003; Haberle, 2007), and the Solomon Islands, in Oceania (Bayliss-Smith *et al*., 2003).

In Bhutan, Asia, the prohibition of the age-old practice of slash-and-burn agriculture with rotation and fallow lands, which was aimed at preserving forest areas, could put at risk the biodiversity of local flora and fauna that were already adapted to a cycle of disturbances (Namgyel *et al*., 2008). In this regard, Gupta (2000) described the differences between conventional (industrial input-based) and traditional slash-and-burn agriculture in India and found that the transition to conventional cropping systems has reduced biodiversity. Many of the features that make up slash-and-burn agriculture with rotation and fallowing of lands, as traditionally practiced by local communities in India (soil conservation, controlled use of fire, maintenance of forest areas and large trees around the crop), have been eliminated in conventional cropping systems, with impacts on the region's floristic and faunal diversity (Gupta, 2000).

In traditional slash-and-burn agriculture, the fallow period length is a key factor in sustaining biological diversity, influencing how landscapes retain biodiversity components (Raman *et al*., 1998; Smith *et al*., 1999; Gupta, 2000; Finegan & Nasi, 2004; Thong *et al*., 2020). Research in India shows that fallow areas recover the plant species richness in direct proportion to the duration of the fallow, with fallows at lower altitudes exhibiting higher species richness than those at higher ones (Thong *et al*., 2020). A similar result was observed by Gogoi *et al*. (2020) in a survey also done in India, which showed that tree diversity rebounded with a longer fallow period, with the Shannon diversity index in the shortest fallow (up to 5 years) 1.69, 2.69 in the longest fallow (20-25 years) and 4.2 in the mature forest (Gogoi *et al*., 2020).

In southwestern China, Fu *et al*. (2003) identified the presence of 76 plant species collected from fallow areas of various ages, belonging to 38 botanical families and 64 genera. Most plants were used for household consumption, but when available in abundance they were transported to local markets for sale. Of the useful plants, most species were medicinal, followed by species used for wood, food, and animal feed. The study found that 28% of the plants raised in home gardens also grew in fallow areas, and 17% were transferred to these areas by the farmers themselves. The authors consider that in this transfer process, wild plants become cultivated or semi-domesticated species and that this practice can be an important way not only to ensure food security and health care for the families but also to conserve the region's economically important species, many of which are rare or threatened with extinction locally (Fu *et al*., 2003).

As for animal biodiversity, in India, the stage of forest regeneration of set-aside areas in successive years after fallowing correlated with the richness of plants used for food by different primate species (Gupta & Kumar, 1994; Gupta, 2000). Generalist primate species may alter their diets by ingesting dominant plants in the fallow phases. A total of 66% to 100% of tree species present in the fallow lands of cultivated areas were food species for the primates *Trachypithecus phayre* (Blyth, 1847) and *Macaca mulata* (Zimmermann, 1780). Slash-and-burn agriculture is practiced traditionally, with rotation and long fallow cycles, thus allowing adequate regeneration of secondary forests featuring food plants desired by those species.

On the other hand, five primate species with specialist diets (e.g. *Trachypithecus pileatus* (Blyth, 1843), *Macaca nemestrina* (Linnaeus, 1766), *Macaca arctoides* (I. Geoffroy Saint-Hilaire, 1831), *Hoolock hoolock* (Harlan, 1834) and *Nycticebus coucang* (Boddaert, 1785) may fail to survive changes to their habitats when their ecology and behavior do not allow them to adapt to rapid changes in plant cover occurring during fallow periods (Gupta & Kumar, 1994; Gupta, 2000). It is important, therefore, to reconsider the approach of analyzing the totality of a managed area and its mosaic of successional stages amidst the forested areas observed in landscapes inside community lands under such management. Although certain groups of animals do not forage in fallow areas, they find their ecological niches in the complexity of the regional mosaic produced by human management (Gupta & Kumar, 1994; Gupta, 2000).

Along those same lines, in Mexico, Medellin & Equihua (1998) compared the overall richness and abundance of six mammal species between four approximately 6-year fallow areas (former croplands) and four continuous tropical forest sites in Chiapas. Species richness was no different between the continuous forest and fallow areas, indicating that forest-dependent mammals visit fallow areas due to their forest cover and resource availability. Even species that strongly selected forest habitats (*Heteromys desmarestianus* (Gray, 1868) and *Didelphis marsupialis* (Linnaeus, 1758) were also present in fallow areas, and only one species (*D. marsupialis*) showed a significant decline in the number of captures as a function of distance from the forest edge. The authors concluded that slash-and-burn agriculture practices involving rotation and fallow lands carried out by the region's Indigenous Peoples increase spatial heterogeneity and promote mammal diversity. They defend the maintenance of these practices in the region's biodiversity conservation policy and management (Medellin & Equihua, 1998).

As for woody plants and birds, Raman *et al*. (1998) found that areas with longer fallow periods after slash-and-burn agriculture practice showed higher species

CC BY

richness, abundance, and vertical stratification for woody plant species in India. Similarly, bird species richness, diversity, and abundance also increased with the length of the fallow period. The authors concluded that areas with fallow periods shorter than 25 years and shorter than 50 years caused substantial changes (decreased richness, diversity, and abundance) in the bird and woody plant communities, respectively (Raman *et al*., 1998). These results help strengthen the argument that areas with long fallow periods can mimic, on a small scale, high-intensity disturbances that occur from natural causes, and thus secondary forests can contribute to the conservation of bird and plant communities (Brown & Lugo, 1990; Raman *et al*., 1998).

Habitat diversification promoted by traditional agricultural systems practicing slash-and-burn agriculture (Jhum) has also been critical to mammal movement in northeastern India (Gouda *et al*., 2020). Fallow areas of two to five years evidenced visits by large herbivores, such as sambar deer (*Rusa unicolor* (Kerr, 1792), barking deer (*Muntiacus muntjak* (Zimmermann, 1780), and wild boars (*Sus scrofa* (Linnaeus, 1758), while the frequency of feces decreased in fallows older than 5 years. Roads, trails, and stretches of mature forest near the fallow areas were actively visited by leopards (*Neofelis nebulosa* (Griffith, 1821). The abundance of old and active rodent burrows was higher in areas recently left to fallow. The authors suggest that proximity between fallow areas and crop fields favors the distribution of mammals and that greater spatial heterogeneity did not compromise faunal movement in the area studied (Gouda *et al*., 2020).

Similar research done in Papua New Guinea by Bowman *et al*. (1990) analyzed the diversity of birds, butterflies, and reptiles in slash-and-burn agriculture sites with different stages of ecological succession on fallow lands. Their results show that the diversity of the species studied increased along the successional gradient. Secondary forests showed similar numbers of bird, butterfly, and reptile species as mature forests, and many of these species were common between the two habitats. The niche range of reptile species declined however, at later successional stages, while at early regrowth sites the fauna assemblages showed little similarity to the mature forest (Bowman *et al*., 1990).

That study also found that in areas of slash-and-burn agriculture with rotation and fallow of lands, the landscape becomes a mosaic of forests of different ages in a continuum of forest succession (Bowman *et al*., 1990; Aweto, 2013). In this sense, the faunal similarity between disturbed and undisturbed forests should be treated with some caution, since the result may be due to a mosaic with the diverse habitats used by those animals (Bowman *et al*., 1990).

In a study done in Paraguay, Kammesheidt (1998) found that tree shoots play an important role in forest restoration during early successional stages in fallow areas, with shoot abundance decreasing at later stages. The rate ranged from 59.5% (for stems with DBH between 1-4.9 cm) and 21.0% (for stems with DBH of 5 cm) at early successional stage sites (2-5 years) to 32.9% and 19.6%, respectively, at later successional stage sites (10-15 years).

The rate of forest recovery in terms of stem density, basal area, and tree height class distribution was high, while the restoration of species composition progressed more slowly. At early successional stage sites, shoots accounted for approximately 60% of the total number of stems, while at advanced successional sites, about one-third of all stems grew from shoots (Kammesheidt, 1998). Therefore, the presence of mature trees within the fallow lands and in the surrounding mature forest patches may contribute significantly to the regeneration process, which also depends on the impact of other human disturbances in the fallow areas during this process (Gupta, 2000).

The studies analyzed show that the reason why the fallow phase contributes to the maintenance of biodiversity in traditional agricultural systems is related to ecological succession processes in those environments. The key factor for biodiversity conservation in such agricultural systems is the period that fallow lands need to regenerate (Gupta, 2000). In general, this process is related to the seed bank in the soil after the vegetation is cut down, as well as to the preservation of tree resprouts, which enable vegetative regeneration (Kammesheidt, 1998).

Agrobiodiversity, food, and nutritional security

Agrobiodiversity can be defined as the result of dynamic and complex relationships between human and non-human societies (a variety of animals, plants, and microorganisms used directly or indirectly for food and agriculture, including crops, livestock, forestry, and fisheries environments in which they interact and coexist) (FAO, 1999). This has an impact on policies to conserve cultivated ecosystems and to promote food and nutritional security for human populations, social inclusion, and sustainable rural development (Santilli, 2012a). Agrobiodiversity is thus the variety of biological components arising from the choices and practices of farmers and local communities who follow their logics in a given socioeconomic, environmental, and cultural context (Vandermeer & Lawrence, 2002; Blanco *et al*., 2016). The fruit of ancestral and modern-day management of agricultural systems has thus been the dynamic (on-farm) conservation and continuous genetic improvement of agrobiodiversity, the food basis of all human societies (FAO, 1999).

An example can be seen in the *milpa*, a traditional agricultural system that exists in tropical Mesoamerica, more precisely in Mexico. This system incorporates crops of maize (*Zea mays* L.), beans (*Phaseolus* spp.), and squash (*Cucurbita* spp.), which have been domesticated and diversified in the region (Watters, 1971). In addition to different types of crops, *milpas* also incorporate non-agricultural species, non-timber forest products, and understory vegetation (Finegan & Nasi, 2004). The species forming the undergrowth are used by local communities and their seeds are kept for the next planting season (Chacón & Gliessman, 1982). This is how the *milpa* helps maintain agrobiodiversity (Pérez-García & Castillo, 2016).

Several studies have sought to identify the agrobiodiversity in traditional agricultural systems using slash-and-burn with rotation and fallow of lands (Peroni & Hanazaki, 2002; Rerkasem *et al*., 2002; Rerkasem *et al*., 2009; Blanco *et al*., 2016; Borges *et al*., 2016; Pérez-García & Castillo, 2016; Pandey *et al*., 2019; Pandey *et al*., 2022; Garavito *et al*., 2021; Marentes *et al*., 2021). In Vanuatu, Oceania, Blanco *et al.* (2016) identified a total of 127 plant species in 273 home gardens, with 59% of these species made up of trees and shrubs, followed by fruits and vegetables (15%), and roots and tubers (13%). The average species richness per garden was 10.1, with an average of 11.6 varieties, in areas with an average size of 423 m^2. Richness and variety, as expected, decreased during cultivation periods, compared to the other phases of the cycle (Blanco *et al*., 2016).

When investigating the traditional knowledge of local *chagra* communities in the Colombian Amazon, Garavito *et al*. (2021) recorded 38 cultivated species belonging to 28 botanical families, most of which were used for food purposes. The seven most abundant species amounted to approximately 1000 individuals per hectare. Through a literature review, Rerkasem *et al*. (2009) identified a high abundance of spontaneous plants and agrobiodiversity associated with slash-and-burn agriculture with rotation and fallow of lands in Thailand and Indonesia, Southeast Asia. Declines in diversity have been observed, however, in areas where rotation has been replaced by permanent land use. Similarly, in northern Thailand, a study that identified 15 rice varieties, of which each farmer grows from two to five varieties, illustrates the contribution of traditional slash-and-burn farming systems to the conservation of traditional local varieties (Rerkasem *et al*., 2002).

Another study done in six states of India observed a high diversity of species and varieties in 12 different farming systems where slash-and-burn agriculture is practiced by local communities (Pandey *et al*., 2019). Thirty-five species of grains, fruits, vegetables, pulses, and spices were identified, with 25 vegetable varieties and 22 fruit varieties. The most abundant species in the crop fields were rice (*Oryza sativa* L.), maize (*Zea mays* L.,) and finger millet (*Eleusine coracana* (L.) Gaertn). Vegetables included pumpkins (*Cucurbita pepo* L.), potatoes (*Solanum tuberosum* L.), and water pumpkins (*Benincasa hispida* (Thunb.) Cogn), among others. Fruits included banana (*Musa* spp.), pineapple (*Ananas sativus* Schult. & Schult.f.,) and citrus fruits, while spices found were ginger (*Zingiber officinale* Roscoe), pepper (*Capsicum* spp.), turmeric (*Curcuma longa* L.), and others (Pandey *et al*., 2019).

Also in India, a survey of 481 families using slash-and-burn agriculture with rotation and fallow lands recorded a total of 55 plant species, as well as 47 varieties of rice (*Oryza sativa* L.), 19 varieties of maize (*Zea mays* L.) and six species of domestic animals, the most abundant being chickens (*Gallus gallus domesticus* (Linnaeus, 1758) and pigs (*Sus scrofa domesticus* (Erxleben, 1777) (Pandey *et al*., 2022). According to the authors, the northeastern region of India accounts for 83% of the total area where such agriculture is conducted in the country and plays a central role in providing agroecosystem goods and services that sustain the well-being of the region's residents. However, the fallow periods in many of these systems have become increasingly shorter, threatening local varieties and integrated landscape planning (Pandey *et al*., 2022).

In the Monochoa Indigenous Land, located in the Colombian Amazon, 132 cultivated species varieties have been recorded among the Indigenous Uitoto people, and 131 among the Muiname people (Marentes *et al*., 2021). Cassava (*Manihot esculenta* Crantz), coca (*Erythroxylum coca* Lam.,) and tobacco (*Nicotiana tabacum* L.) were the main crops grown by both ethnic groups. For cassava, 18 different varieties were found, of which four were classified as local ecotypes that are produced only at this location worldwide. There is also a local ecotype of coca called '*q+ícue jibieña*' in Huitoto or '*gaño meku*' in Muiname (Marentes *et al*., 2021). The great variety of crops found in the Monochoa Indigenous Land indicates that Indigenous farming systems based on slash-and-burn agriculture with rotation and fallow of plots are an opportunity to conserve agrobiodiversity and maintain these peoples' food security, while also making a globally important contribution to on-farm conservation.

After changes in the agricultural system in southern Mexico, researchers found that the transition from slash-and-burn to semi-permanent cropping systems caused transformations in agrobiodiversity, favoring some varieties over others (Pérez-García & Castillo, 2016). The density of annual herbs increased (9.0±1.5 to 22.0 ±1.5), as did their richness (9.2± 1.5 to 21.8 ± 1.5), in contrast to perennial herbs, which experienced a decrease in density (5.5 ± 0.6 to 2.9± 0.6), with no significant change in richness (3.1±0.4 to 2.1± 0.4). The study showed that the traditional *milpa* system is the best reservoir of agrobiodiversity, less prone to invasion by weeds than semi-permanent systems, which can increase the probability of invasion by such weeds, dependence on agrochemicals, and reduced capacity for soil regeneration during fallow periods (Pérez-García & Castillo, 2016).

In southeastern Brazil, 33 local *caiçara* communities cultivate 261 varieties belonging to 53 species, of which the most cited crop was cassava (*Manihot esculenta* Crantz), followed by yams (*Dioscorea* spp.), sweet potatoes (*Ipomoea batatas* Poir.), pumpkins (*Cucurbita pepo* L.), sugar cane (*Saccharum officinarum* L.), and beans (*Phaseolus vulgaris* L.) (Peroni & Hanazaki, 2002). The study showed that the exchange of varieties among local communities builds a network that decreases the loss of diversity managed on the regional scale and that characteristics such as cycles of itinerancy (cultivation and fallowing) and traditional agroecological knowledge contribute to the increase of this agricultural diversity. The selection of traditional varieties and the exchange of seeds between communities have always occurred throughout history (Van de Wouw *et al*., 2010) and are key elements for the conservation of this agricultural diversity and the traditional knowledge associated with it (Perreault, 2005; Emperaire & Peroni, 2007; Santilli, 2012b). However, restrictive environmental laws, rural exodus, and the rampant increase in local tourism have been factors contributing to the decline of agrobiodiversity (Peroni & Hanazaki, 2002).

It is important to note that the agrobiodiversity found in slash-and-burn agriculture under traditional agricultural systems is directly related to the different phases of this system's cycles. In Tocantins, northern Brazil, Borges *et al*. (2016) identified differences with respect to the species cultivated in each phase of different types of traditional agricultural systems that practice slash-and-burn agriculture, called '*roça de toco*' (cultivated in a dry environment) and '*roça de esgoto*' (cultivated in a wetland environment). Both go through the processes of felling, burning, and the fallow phase with rotation of lands, typical of slash-and-burn agriculture, but display differences in the species they raise and the duration of each phase, since the '*roça de toco*' has a faster cultivation phase and a longer fallow phase, because it is practiced in areas with less moisture.

Studies identified 45 cultivated varieties in these systems, of which 28 were found exclusively in the '*roça de esgoto*' (Borges *et al*., 2016), whose *capoeiras* (areas in the process of regeneration during fallow) have greater agrobiodiversity than recently active fields, which mostly grow cassava (*Manihot esculenta* Crantz). This data confirms, therefore, that slash-and-burn agriculture with rotation and fallow can provide important tools to restore native tropical forests and conserve agricultural species that are also important for food and nutritional security because the different forms of management within these systems enhance biodiversity and landscape management. Replacing traditional agricultural systems with slash-and-burn approaches that are less diverse, with more permanent crops, has been found to reduce those opportunities (Huijun *et al*., 2002).

Spatial heterogeneity and ecological processes in managed landscapes

Given the role played by slash-and-burn agriculture in traditional agricultural systems in landscape dynamics, some studies have looked into how these changes can affect various ecological processes taking place in landscapes over time and space. Spatial heterogeneity is the result of millenary agricultural practices, and the different spaces created by those traditional management activities are called cultural landscapes by some researchers (Jääts *et al*., 2011; Fernandes *et al*., 2013; Tomson *et al*., 2015; Ekblom & Gillson, 2017). However, there are cases where this design has been altered by more intense cultivation and shorter fallow periods (Metzger, 2003; Siminski & Fantini, 2007; Dalle *et al*., 2011), with potential impacts on biodiversity and carbon dynamics in soils and vegetation.

With that in mind, Metzger (2003) tested the effects of shorter fallow periods on landscape structures in the Brazilian Amazon and found that this decrease made it more homogeneous, and largely dominated by secondary vegetation. Patches of mature forest and secondary vegetation were reduced in the landscape and these structural changes appeared to be more common. The main mechanism behind homogenization was the more intensive use of secondary vegetation to establish crops, at four times the rate in short as opposed to longer fallow areas. This suggests that such structural changes can lead to slower regeneration processes, compromising related ecological processes.

Research in Mexico found that local communities perceived a shift in a landscape that once possessed a heterogeneous matrix composed of different successional stages, including mature forests, to a landscape dominated by young fallow areas (Dalle *et al*., 2011). This transformation was associated with the intensification of slash-and-burn agriculture with rotation and fallowing of plots at these sites, with *milpas* established on young fallow areas. The resulting landscape, as a dynamic agroecosystem composed of different interconnected and interdependent parts, was found to provide fewer resources to sustain livelihoods, demanding participatory land use planning (Dalle *et al*., 2011).

From another perspective, in Santa Catarina, southern Brazil, restrictions imposed by the state's strict environmental regulations on the use of Atlantic Forest woodland resources have led to changes in the landscape's composition, with a clear decrease in the area used for traditional slash-and-burn agriculture by local communities, in favor of a larger area of secondary forests. Cultivated areas have decreased by 65% in the last 10 years, leading to shorter fallow periods and more frequent rotations on each plot (Siminski & Fantini, 2007). However, a simulation of plot rotations revealed that from a land availability standpoint, the continuation of traditional slash-and-burn agriculture will still be possible in the long term for local communities, but only if such environmental standards are revised since it is critical for their food and nutrition security (Siminski & Fantini, 2007).

One of the factors contributing to landscape changes where slash-and-burn agriculture is practiced is the controlled use of fire. Studies indicate that traditional controlled fire practices play a central role in maintaining spatial heterogeneity and major ecological processes, as demonstrated in savannas in Africa (Brockett *et al*., 2001;

Laris, 2002), Australia (Bird *et al*., 2008), and Brazil (Klink & Machado, 2005; Pinheiro & Monteiro, 2010; Dodonov *et al*., 2014; Borges *et al*., 2016).

Besides being a natural disturbance, prescribed burning is the main management practice used by local communities in savannas within their traditional agricultural systems. It is employed to stimulate grass regrowth for cattle grazing, to support hunting activities, to facilitate access to resource-gathering areas (Mistry, 1998; Bond *et al*., 2005; Klink & Machado, 2005; Furley *et al*., 2008; McGregor *et al*., 2010; Yibarbuk *et al*., 2001), and to enable the gathering and management of non-timber forest products (Mistry, 1998; Bede, 2006; Varghese & Ticktin, 2008; Schmidt *et al*., 2011).

In Amazonia, archaeological evidence from the Holocene provides important indicators suggesting that spatial heterogeneity arising from the adoption of specific cultivation techniques, including a history of controlled fire use could, explain some of the regional variability in its vegetation (Arroyo-Kalin, 2012). In Europe, an analysis of maps since 1870 shows how the controlled use of fire as part of traditional slash-and-burn agricultural practices transformed landscapes in Estonia, where approximately 79% of agricultural areas have returned to a forested state (Tomson *et al*., 2015). Notably, time-series studies demonstrate the importance of understanding landscape dynamics over time (Metzger, 2003). However, studies to understand the effects of landscape transformations on biodiversity and on ecosystem services should be done separately, to complement each other.

In order to understand the effect of this management practice in the Brazilian Cerrado (savanna), the benefits of fire were first observed by Coutinho (1976; 1982; 1990) and Pivello & Coutinho (1996), especially in grassland formations. Over the years, research has identified that plant and animal species living in fire-prone ecosystems have evolved under the selective pressure of frequent burning, recurrently eliminating non-adapted genotypes (Bond & Keeley, 2005; Pausas & Parr, 2018). Natural selection has resulted in fire-related plant adaptations (Coutinho, 1976; Coutinho, 1977; Keeley *et al*., 2011; Simon & Pennington, 2012), as well as animal strategies to escape or survive fire (Pausas & Parr, 2018).

Plant adaptations in this biome include, for example, C4 grasses (Keeley & Rundel, 2005), trees with insulating cork and bark (Lawes *et al*., 2011; Simon & Pennington, 2012), small plants with robust roots, high resilience to regrow many times after fire (Coutinho, 1982; Pausas & Keeley, 2009), and fire-stimulated reproduction (Coutinho, 1977; Pilon *et al*., 2018; Fidelis *et al*., 2019). Fidelis *et al*. (2019) observed that flowering of the species *Bulbostylis paradoxa* (Spreng.) Lindman (Cyperaceae) in rupestrian field environments in the Cerrado occurs 24 hours after a burning event, with individuals showing more than 30 inflorescences in this period, which open fully 15 days after a fire. The researchers found that the species depended on fire to flower, since no individuals with inflorescences were seen in sites that had not been burned, nor in sites that were visited a few months after having been burned (Fidelis *et al*., 2019).

Another study in Portugal found that bird assemblages benefit from changes in landscape due to controlled fire use, which increases its richness and diversity along a vegetational gradient, ranging from shrub vegetation to deciduous forests and agricultural areas, which showed the highest biodiversity indices (Moreira *et al*., 2001). In this case, the authors identified the use of fire in traditional agriculture, although they did not mention the practice of slash-and-burn in the region. Nevertheless, the results show that fire regimes have contributed to maintaining bird diversity in landscapes and recommend that management actions focus on maintaining deciduous forests and agricultural land, where it was possible to observe several specialist bird species (Moreira *et al*., 2001).

Effects on chemical and physical characteristics of the soil

Research has confirmed that slash-and-burn practices in traditional agricultural systems do not compromise soil fertility (Kleinman *et al*., 1995; Johnson *et al*., 2001; Mendoza-Vega *et al*., 2003; Pedroso Júnior *et al*., 2008). Prescribed fire is used in the mineralization phase of part of the felled organic material, to prepare the soil for planting, leaving it less acidic, with greater nutrient availability (Kleinman *et al*., 1995), and accelerating the decomposition of organic matter due to the elevation of temperature at the soil surface after burning (Devendra & Thomas, 2002). Thus, a considerable portion of the nutrients stored in the vegetation that was burned (biomass) will be made available to be used by the plants in the cultivation phase (Ribeiro-Filho *et al*., 2013). After a few years of cultivation, the area enters the fallow phase. With the progress of the ecological succession that occurs during the fallow, nutrients are cycled and organic matter contributes to the restoration of soil fertility (Ribeiro-Filho *et al*., 2013).

The increased availability of nutrients in the soil after the burning of vegetation is due to the addition of nutrient-rich ash and the effects of the burning itself. The amount of mineral nutrients found in the ash depends mainly on the total nutrient content of the biomass, the temperature limits for each nutrient to pass to the gaseous state, and the quality of burning, which is related to the moisture content of the vegetation and the distribution of fine and coarse fuels (Bruun *et al*., 2006).

In an area of the traditional farming system of the everlasting flower gathering communities (Brazilian Globally Important Agricultural Heritage Systems - GIAHS), where slash-and-burn agriculture is practiced with rotation and fallow lands, soil analyses were performed in different environmental units (NAC/UFVJM, 2017). It was observed

CC BY

that in a recently opened area (after clearing and burning) the levels of total organic matter, pH, and the amounts of available nutrients in the soil were higher than in the area that has been in fallow for five years, the permanent pasture area, and the area where '*roça de toco*' was not practiced (*Cerrado Estrito*), the latter being an area dedicated to agroextractivism. It is significant that the area with five years of fallow, despite having lower levels of total organic matter, pH, and nutrients than the newly opened area due to extraction of crops, still has values close to or higher than the permanent pasture area and the *Cerrado Estrito*.

Evaluating the correlation between nutrient availability and fallow duration in traditional rice farming systems in Malaysia, researchers found that plant-available nitrogen stocks were positively correlated with fallow duration (increasing by 166.7%, $p<0.05$), unlike available phosphorus, which increased little (8.1%) and showed no significant correlation (Bruun *et al*., 2006). As for productivity, a significant and positive correlation ($R=0.751$, $p=0.02$) was found between fallow duration and rice yields (ranging from 169 kg/ha^{-1} to 3,466 kg/ ha^{-1}) when the most recent fallow plot (0 years) was included in the analyses.

A similar study in India, which analyzed soil samples at different depths in fallow areas from 12 to 15 years old, showed a finer fraction (silt and clay) compared to 3-year fallow areas (Manjunatha & Singh, 2020). The amount of available nitrogen increased significantly in 9-year fallow areas, with a maximum concentration in 12-year fallow areas, while the availability of phosphorus and potassium was minimal in 3-year fallow areas and increased from 6 years onwards. The availability of exchangeable calcium, on the other hand, increased in 9-year fallow areas. The study concluded that the minimum fallow period under those conditions should be 6 to 7 years for soil nutrient concentrations to be maintained at levels suitable for plants (Manjunatha & Singh, 2020).

In Papua New Guinea, meanwhile, the burning of a felled secondary forest (conversion phase) increased levels of soil phosphorus, available calcium, cation exchange capacity, electrical conductivity, and nitrogen compared to these concentrations in mature forest soils (Bowman *et al*., 1990). In that study, the vegetation groups were divided as follows: Group A was a recently established Garden and had the highest grass cover (24%) recorded and a correspondingly low basal area and canopy cover. Group B was composed of three gardens with a very open canopy (5%) less than 2 m in height, with mostly non-woody stems. Group C consisted of four plots with a mean age of 4 years since cultivation. Group D was composed of seven plots with a mean age of 8 years since cultivation. Group E were secondary forests with a mean age of 26 years since clearing and Group F was three uncleared forest plots.

In traditional slash-and-burn agricultural systems, it has also been observed that soil erosion is less severe compared to conventional agricultural systems (Pérez-García & Castillo, 2016). Soil aggregates have been widely used as quality indicators in studies on soil degradation and restoration (Six *et al*., 2000; Varela *et al*., 2010; Rojas *et al*., 2016). As major structural components of soil, aggregates influence water movement and retention, pore size and number, gas exchange, nutrient balances, root growth, and crop yield (Kasper *et al*., 2009).

From this analytical perspective, in India, Laskar *et al*. (2021) evaluated variations in soil aggregates at different depths and parts of landscapes, including a mature forest area, fallow areas of different ages, and a cultivated area whose main crops were rice (*Oryza sativa* L.), maize (*Zea mays* L.), ginger (*Zingiber officinale* Roscoe), and turmeric (*Curcuma longa* L.). At all soil depths, the forest area obtained the highest proportion of macroaggregates (75.6%), while the cultivated area obtained the lowest proportion (51.1%). The research provided evidence of significant changes in soil compaction and aggregate stability with the transition from mature forest to cultivated and fallow areas, suggesting that a minimum 20-year fallow period is required under those conditions to achieve a proportion of macroaggregates similar to what occurs in mature forest soils (Laskar *et al*., 2021).

With the progression of secondary succession in fallow areas in China, the soil's organic matter and phosphorus content showed an overall downward trend, while the soil's water content generally moved upward (Lu *et al*., 2016). Soil pH, potassium content, and nitrogen content reached maximum values at intermediate successional stages (30 and 60 years of fallow). Nutrients showed the lowest values in early succession stages and mature forests, evidence that intermediate succession stages are more favorable to soil fertility (Lu *et al*., 2016).

These results can be explained based on the intermediate disturbance hypothesis, proposed by Connell (1978), who demonstrated that in sites where disturbances are either too rare or too frequent, it is possible that species diversity may never reach the apex. In the case of very frequent disturbances, species succession will always stabilize in the initial phase, and only the pioneer species will colonize the site. In the case of very rare disturbances, only those species that are very competitive will stand out and achieve greater success and stability, eliminating other species of lesser competitive power. However, as the interval between disturbances increases (so-called intermediate disturbances), new species will develop and reach maturity. It is likely that higher soil fertility indices in sites with intermediate successional stages may be related to the occurrence of intermediate disturbance frequencies, favoring the growth and development of species in those sites.

Along those lines, a study in Mozambique, Africa, compared soil attributes between forested areas and areas under slash-and-burn agriculture practiced by local communities (Magalhães & Mamugy, 2020).

The results confirm that the conversion of forested areas to cropland did not impact soil organic matter and total nitrogen stocks, since there was no significant difference between the values measured in the different areas. The authors relate their findings to the traditional form of slash-and-burn agriculture practiced in the region, which involves plot rotation and fallowing, the controlled use of fire, the return of unused plant parts to the soil after harvest, and the maintenance of a significant number of tree species in cultivated areas (107 species, compared to 53 species found in the miombo woodlands) (Magalhães & Mamugy, 2020).

In Ethiopia, Terefe & Kim (2020) compared the pH, texture, soil density, and total nitrogen contents in mature forest areas, fallow areas of different ages (3, 5, and 7 years), and a field permanently cultivated for 10 years, which was a former slash-and-burn agriculture area that had been converted to grain crops such as tef (*Eragrostis tef* (Zucc.) Trotter), maize (*Zea mays* L.), or sorghum (*Sorghum biocolor* (L.) Moench), depending on the time of year. This area, called a monocrop in the paper, was 10 hectares in size and was treated with a mixture of inorganic fertilizers (urea and diammonium phosphate). Their results found no significant differences in soil pH between the forest area and all areas of slash-and-burn agriculture with rotation and fallow lands. The permanent crop field, however, showed significantly lower soil pH (3.9 ± 0.1) compared to the 3-year (5.5 ± 0.4) and 5-year (6.3 ± 0.4) fallow areas ($p<0.05$). Soil texture and density, on the other hand, varied little among the sites studied. Thus, the conversion of slash-and-burn agriculture areas to monoculture decreased soil nitrogen stocks, at an average loss rate of 0.6 ± 0.1 Mg N ha^{-1} year (Terefe & Kim, 2020).

Carbon dynamics in the soil, vegetation, and atmosphere

Debates on increasing greenhouse gas emissions in the atmosphere and their consequences for climate change have intensified in recent years. Recognized for its role in mitigating these changes, the accumulation of carbon performed by tropical ecosystems has been highlighted as an important factor (Stephens *et al*., 2007; Asner, 2011; Lal *et al*., 2015). In ecosystems, carbon and other nutrients such as nitrogen, phosphorus, etc., are available to plants as simple organic molecules, as ions in the atmosphere (e.g., carbon dioxide), or as ions dissolved in water (nitrate, phosphate, potassium, etc.) (Townsend *et al*., 2010). Each of these nutrients can be incorporated into complex carbon compounds in the biomass, decomposed, and returned to the system through biogeochemical cycles (Townsend *et al*., 2010). Understanding these flows, or fluxes, allows for a better understanding of the role of each nutrient in the agroecological dynamics of traditional agricultural systems.

Soil organic carbon is considered one of the most important indicators of productivity in agricultural systems (Nye & Greenland, 1960; Bruun *et al*., 2006). In slash-and-burn systems with rotation and fallow lands, carbon accumulates mainly during fallow phases, as vegetation regenerates through ecological succession events (Ribeiro-Filho *et al*., 2013). The burning of that secondary vegetation for conversion into cropland releases CO_2 and other waste gases into the atmosphere.

Authors argue that if traditional slash-and-burn agriculture is in equilibrium, the CO_2 released by fire in the conversion phase will be reincorporated into the biomass of secondary vegetation in the system's fallow phases, and thus will not contribute in the long term to variations in the atmospheric concentration of this gas (Fearnside, 2000; Lehsten *et al*., 2009). For this to be achieved, it is essential that fire be applied in a controlled manner and that the fallow period be properly maintained. Reincorporation of carbon occurs both above ground (in plant biomass) and below ground (Silver *et al*., 2000).

Several studies address the challenges and opportunities of agricultural systems using slash-and-burn agriculture with rotation and fallow lands in the context of reducing carbon emissions and increasing carbon accumulation (Mertz, 2009; Hett *et al*., 2012; Ribeiro-Filho *et al*., 2013; Aryal *et al*., 2014). Depending on the length of cropping and fallow cycles and the growth rate of plant species during fallow periods, slash-and-burn agriculture does not lead to a decline in carbon stocks, but rather to a lower level when compared to mature forest (Salinas-Melgoza *et al*., 2017).

However, data collected in dry tropical forest areas in Mexico show that biomass density in slash-and-burn agriculture reached levels similar to those of mature forests, with old fallow areas (over 20 years old) showing higher carbon stocks than mature forests (which have never been used for slash-and-burn cultivation) (Salinas-Melgoza *et al*., 2017). This is because there is no permanent removal of tree cover (Salinas-Melgoza *et al*., 2017), thus keeping stocks at adequate levels and highlighting the strong potential of these traditional agricultural systems for carbon accumulation.

Measurements of carbon storage in traditional slash-and-burn agriculture soils in the Brazilian Amazon show that the amount of carbon (185 t ha^{-1}) measured up to 6 meters deep did not differ significantly from the amount measured in mature forest areas (196 t ha^{-1}) but decreased significantly in semi-permanent crop areas (146-167 t ha^{-1}) (Sommer *et al*., 2000). Maintaining secondary vegetation as part of the agricultural land-use system in traditional slash-and-burn systems is crucial, as the trees' root systems are conserved and thus carbon also accumulates farther underground.

A study in Mexico analyzed changes in carbon stocks and accumulation rates associated with tree growth, recruitment, and mortality in fallows of different forest succession ages and different cropping intensities (Aryal *et al*., 2014).

CC BY

The rate of carbon accumulation in the biomass of live trees was higher in early successional stages (2.9-3.0 Mg C ha^{-1} 1 year^{-1}) (almost 100% annual addition of carbon to the live biomass), compared to older secondary forests (1.1-1.6 Mg C ha^{-1} year^{-1}). This was explained by high relative tree growth and high recruitment rates in early successional stages. However, mature forests (35 years old) showed higher carbon stocks compared to 4-year-old secondary forests (99.56 Mg C ha^{-1} and 11.72 Mg C ha^{-1}, respectively). The main predictor of carbon stocks and accumulation rates in secondary forests was the age of the fallow since repeated burning and more intensive cultivation can prolong the time required for this accumulation to take place (Aryal *et al*., 2014).

Laskar *et al*. (2021) found that soil organic carbon contents in macroaggregates increased with fallow age and decreased with soil depth in northern India. The highest content (1.95%) was found in the topsoil layer (10 cm) in the 20-year fallow area, while the lowest content (0.39%) was found at the depth of 21-30 cm in the 5-year fallow area. The researchers found that a minimum 20-year fallow period, under the soil and climate conditions they analyzed, is required to achieve carbon contents comparable to mature forest lands (Laskar *et al*., 2021).

Terefe & Kim's (2020) study in Ethiopia also found that traditional slash-and-burn agriculture did not affect soil carbon stocks compared to mature forest areas. Conversion of slash-and-burn areas to permanent monocrops, however, decreased soil organic carbon (by 45-50% over 10 years, a loss of 11.6 ± 0.2 Mg C ha^{-1} year). Their study shows that conversion from traditional slash-and-burn agriculture to monocropping, besides reducing soil fertility, can contribute to global climate change since less soil carbon and nitrogen can mean more greenhouse gas emissions, of both carbon dioxide (CO_2) and nitrous oxide (N_2O) (Snyder *et al*., 2009; Kim & Kirschbaum, 2015).

A study of several agricultural systems in the semiarid region of Minas Gerais, Brazil – an area where slash-and-burn agriculture is practiced with rotation and fallow lands in a traditional agricultural system of everlasting (starflower) gathering communities on a Brazilian GIAHS site – reported an accumulation of total organic carbon in the soil, from 0 to 40 cm depth, in amounts that were from 28% to 114% higher than a monocrop eucalyptus plantation (Favero, 2018). The situation with the highest soil carbon accumulation had been freshly opened (after clearing and burning) for cultivation (Fávero, 2018).

Gupta *et al*. (2001) calculated methane gas (CH_4) emissions from biomass burned in deciduous tropical forests cleared for traditional slash-and-burn agriculture by local communities at two sites in India. The results identified CH_4 emission rates of 1.29% and 1.59% at each of the two sites evaluated, which are close to accepted estimates for tropical forests elsewhere in the world (1.2±0.5%). The results showed that about 0.99 Tg of methane is emitted annually by slash-and-burn agriculture in India (Gupta *et al*., 2001), a low value compared to the global annual estimate of 11-53 Tg/yr calculated by Andreae (1991).

Another study conducted in India shows that the age of fallow in traditional slash-and-burn agriculture plays a key role in recovering aboveground carbon biomass in living woody species (Thong *et al*., 2020). The total carbon of living woody biomass ranged from 0.98 Mg ha^{-1} in 5 years of fallow to 142.58 Mg ha^{-1} in 20 years of fallow. The recovery of aboveground carbon biomass in the oldest fallow area was 39% to 40% that of a mature forest, and the estimated time for the fallow to reach the level of a mature forest under the analyzed soil and climate conditions was approximately 40 years (Thong *et al*., 2020).

In Southeast Asia, Palm *et al*. (2005) observed that average aboveground carbon stocks decreased by about 90% when long fallow periods were reduced to 4 years. The soil's organic carbon stock in permanent palm plantation sites was 0 to 40% lower than stocks in areas of traditional slash-and-burn agriculture, with the greatest losses occurring in mechanically established palm plantations. Thus, conversion from slash-and-burn agriculture with rotation and fallow lands to continuous cropping systems causes substantial losses of aboveground carbon stocks and generally leads to a decline in their quality (Palm *et al*., 2005).

A research literature review by Ribeiro-Filho *et al*. (2013) conclusively showed that longer fallow periods allow not only the recovery of soil fertility but also the recovery under natural conditions of the soil's organic carbon emitted into the atmosphere during the conversion phase. It should be noted that the necessary fallow period is directly related to the soil and climate conditions of each situation.

Final Considerations

The breadth of available research highlight the importance of many aspects of slash-and-burn agriculture with rotation and fallow lands as practiced in Indigenous Peoples and Local Communities' traditional agricultural systems. Their agricultural logic has positive impacts on maintaining biological diversity and agrobiodiversity. It plays a significant role in restoring natural fertility, raising pH, the dynamics of nutrient cycling, and carbon accumulation. It also has an effect on soil erosion, shown to be less severe under such management when compared to conventional farming systems. Furthermore, this form of agriculture has proven its importance for these groups' food and nutritional security, contributing to the formation of social relationships and cultural practices that are inseparable from the traditional agricultural systems where it is practiced.

The relationship between traditional slash-and-burn agriculture and biodiversity conservation is mainly due to the process of diversification of ecological niches associated with ecological succession, which regenerates the secondary forest, along with species of flora and, consequently, fauna. It is significant that although certain groups of animals do not forage in fallow areas, they find their ecological niches in the complexity of the regional mosaic produced by human management.

However, there are gaps in our knowledge of the role of important ecological processes in these environments, such as pollination and dispersal, which are critical for the establishment of plant species in these locations. We also underscore the importance of research on the effects of this agriculture on fauna, since such studies are rare.

Slash-and-burn agriculture with rotation and fallow lands can play an important role in conserving agricultural species essential to the food and nutritional security of Indigenous Peoples and Local Communities in different parts of the world. Significantly, many of the traditional agriculture situations analyzed here have been replaced by monocultures and permanent crops, causing changes in the ways of life of communities and a reduction in the variety of species they raise. In other words, such shifts have negative impacts on agricultural and sociocultural diversity. On the other hand, public policies to conserve agrobiodiversity and its associated traditional knowledge have important roles to play in maintaining this agricultural approach.

The controlled use of fire is a central factor for managing these crops and is used during the mineralization phase of part of the chopped organic material, as an essential step to make arable the acidic and dystrophic soils so common in tropical areas of the planet. This is an ancient technique that still enables food production for Indigenous Peoples and Local Communities around the world. The marketing of such produce also contributes to food security in the regions where it is grown. Yet this practice has been banned by restrictive environmental regulations, leading to homogenized landscapes and reducing the supply of many different products from these agroecosystems.

Research to date does indicate that longer fallow periods not only recover soil fertility but also allow for the recovery of the soil's organic carbon, re-accumulated under natural conditions after having been emitted into the atmosphere during the conversion phase. The length of fallow is, therefore, the main predictor of carbon stocks and their rate of accumulation in secondary forests, since repeated burning and more intensive cultivation can extend the time required for this accumulation. On the other hand, crops can have negative effects on the climate when their cultivation is intensified and they start releasing more carbon gases.

Thus, in order to mitigate potential negative effects, crop management should provide enough fallow time to ensure a favorable carbon balance, as a strategy for carbon storage and for the necessary regeneration of forests. This also contributes directly to keeping the productive capacity of this agriculture synchronized with its natural cycles and elements (soil, biodiversity, and water).

In turn, ensuring the proper fallow period for each soil and climate situation depends directly on the size of the area that a community needs to maintain the dynamic balance of its slash-and-burn agriculture with rotation and fallow lands on its ancestral lands. In other words, it is essential to maintain enough community land to be able to synchronize territorial management with the community's underlying socio-ecological dynamics. Political and economic dynamics are therefore directly related to the sustainability of this traditional agriculture in each sociocultural and ecological context where it is practiced. This means that understanding and strengthening this agriculture and improving it with agroecological approaches, is more beneficial than simply criminalizing and/or diminishing its importance for these groups, for the conservation of agro-biodiversity and the delivery of agro-ecosystem services to society at large.

Acknowledgements

We acknowledge the GIAHS (Globally Important Agricultural Heritage Systems) Program Secretariat of the Food and Agriculture Organization of the United Nations (FAO/UN) for the funding support.

Authors' Contributions

Juliana Loureiro Almeida Campos: Methodology, Writing - Original Draft. Fernanda Testa Monteiro: Conceptualization, Writing - Reviewing and Supervision. Gustavo Taboada Soldati: Writing - Reviewing. Claudenir Fávero: Conceptualization, Writing - Reviewing and Supervision.

Conflicts of Interest

The authors have no conflicts of interest to declare.

References

Agnoletti M. 2011. Paesaggi rural storici, Per un catalogo nazionale. Historical rural landscapes for a National Register. Rome, Laterza.

Andreae MO. 1991. Biomass burning - its history, use, and distribution and its impact on environmental quality and global climate. In: Levie JS (ed.). Global Biomass Burning: Atmospheric, climatic, and biospheric implications. Cambridge, MIT Press. p. 445-456.

Arroyo-Kalin M. 2012. Slash-burn-and-churn: Landscape history and crop cultivation in pre-Columbian Amazonia. Quaternary International 249: 4-18. doi: 10.1016/j.quaint.2011.08.004

Aryal DR, De Jong BH, Ochoa-Gaona S, Esparza-Olguin L, Mendoza-Vega J. 2014. Carbon stocks and changes in tropical secondary forests of southern Mexico. Agriculture, Ecosystems and Environment 195: 220-230. doi: 10.1016/j.agee.2014.06.005

Asner GP. 2011. Painting the world REDD: Addressing scientific barriers to monitoring emissions from tropical forests. Environmental Research Letters 6: 021002. doi: 10.1088/1748-9326/6/2/021002

Aweto AO. 2013. Shifting cultivation and secondary succession in the Tropics. Wallingford, CABI International.

CC BY

Bayliss-Smith Y, Hviding E, Whitmore T. 2003. Rainforest composition and histories of human disturbance in Solomon Islands. *Ambio* 32: 346-352. doi: 10.1579/0044-7447-32.5.346

Bede LC. 2006. Alternativas para o uso sustentado de sempre-vivas: efeitos do manejo extrativista sobre *Syngonanthus elegantulus* Ruhland (Eriocaulaceae). PhD Thesis, Universidade Federal de Minas Gerais, Brazil.

Blanco J, Vandenbroucke H, Carrière SM. 2016. A novel index to quantify agrobiodiversity in a biocultural perspective: The case of shifting cultivation gardens in Vanuatu (Pacific). Agroecology and Sustainable Food Systems 40: 190-214. doi: 10.1080/21683565.2015.1127307

Bird RB, Bird DW, Codding BF, Parker CH, Jones JH. 2008. The "fire stick farming" hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. Proceedings of the National Academy of Sciences of the United States of America 105: 14796-14801. doi: 10.1073/pnas.0804757105

Bond WJ, Keeley JE. 2005. Fire as a global 'herbivore': The ecology and evolution of flammable ecosystems. Trends in Ecology and Evolution 20: 387-394. doi: 10.1016/j.tree.2005.04.025

Bond WJ, Woodward FI, Midgley GF. 2005. The global distribution of ecosystems in a world without fire. New Phytologist 165: 525-538. doi: 10.1111/j.1469-8137.2004.01252.x

Borges SL, Eloy L, Schmidt IB, Barradas ACS, Santos IAD. 2016. Fire management in veredas (palm swamps): New perspectives on traditional farming systems in Jalapão, Brazil. Ambiente e Sociedade 19: 269-294. doi: 10.1590/1809-4422ASOC20150020R1V1932016

Bowman DM, Woinarski JCZ, Sands DPA, Wells A, McShane VJ. 1990. Slash-and-burn agriculture in the wet coastal lowlands of Papua New Guinea: Response of birds, butterflies and reptiles. Journal of Biogeography 17: 227-239. doi: 10.2307/2845121

Brockett BH, Biggs HC, Van Wilgen BW. 2001. A patch mosaic burning system for conservation areas in southern African savannas. International Journal of Wildland Fire 10: 169-183. doi: 10.1071/WF01024

Brown S, Lugo AE. 1990. Tropical secondary forests. Journal of Tropical Ecology 6: 1-32. doi: 10.1017/S0266467400003989

Bruun TB, Mertz O, Elberling B. 2006. Linking yields of upland rice in shifting cultivation to fallow length and soil properties. Agriculture, Ecosystems and Environment 113: 139-149. doi: 10.1016/j.agee.2005.09.012

Chacón JC, Gliessman SR. 1982. Use of the non-weed concept in traditional tropical agroecosystems of south-eastern Mexico. Agro-Ecosystems 8: 1-11. doi: 10.1016/0304-3746(82)90010-5

Clement CR. 1999. 1492 and the loss of Amazonian crop genetic resources. I. The relation between domestication and human population decline. Economic Botany 53: 188-202. doi: 10.1007/BF02866498

Colin S. 2021. Slash and Burn Agriculture Explained. https://thoughtco.com/slash-and-burn-agriculture-p2-1435798. 24 Mar. 2022.

Conklin HC. 1961. The study of shifting cultivation. Current Anthropology 2: 27-61. doi: 10.1086/200160

Connell JH. 1978. Diversity in tropical rain forests and coral reefs. Science 199: 1302-1310. doi: 10.1126/science.199.4335.1302

Coutinho LM. 1976. Contribuição ao Conhecimento do Papel Ecológico das Queimadas na Floração de Espécies do Cerrado. Associate Professor´s Thesis, Universidade de São Paulo, Brazil.

Coutinho LM. 1977. Aspectos ecológicos do fogo no cerrado: II. As queimadas e a dispersão de sementes. Boletim de Botânica 5: 57-64. doi: 10.11606/issn.2316-9052.v5i0p57-63

Coutinho LM. 1982. Ecological effects of fire in Brazilian cerrado. In: Huntley BJ, Walker BH (eds.). Ecology of Tropical Savannas. Berlin, Springer-Verlag. p. 273-291.

Coutinho LM. 1990. Fire in the ecology of the Brazilian Cerrado. In: Goldammer JG (ed.). Fire in the Tropical Biota: Ecosystem Processes and Global Challenges. Berlin, Springer-Verlag. p. 82-105.

Coutinho, LM. 2006. O conceito de bioma. Acta Botanica Brasilica 20: 13-23. doi: 10.1590/S0102-33062006000100002

Dalle SP, Pulido MT, Blois SD. 2011. Balancing shifting cultivation and forest conservation: Lessons from a "sustainable landscape" in southeastern Mexico. Ecological Applications 21: 1557-1572. doi: 10.1890/10-0700.1

Descola P. 2013. Beyond Nature and Culture. Chicago, The University of Chicago Press.

Denevan W. 2001. Cultivated landscapes of native Amazonia and the Andes. New York, Oxford University Press.

Denham T, Haberle S, Lentfer C *et al.* 2003. Origins of agriculture at Kuk swamp in the highlands of New Guinea. Science 301: 189-193. doi: 10.1126/science.1085255

Devendra C, Thomas D. 2002. Smallholder Farming Systems in Asia. Agricultural Systems 71: 17-25. doi: 10.1016/S0308-521X(01)00033-6

Diegues AC, Arruda RS, Silva VCD, Figols FA, Andrade D. 1999. Biodiversidade e comunidades tradicionais no Brasil. São Paulo, NUPAUB-USP/PROBIO-MMA/CNPq.

Dodonov P, Xavier RO, Tiberio FCS, Lucena IC, Zanelli CB, Matos DMS. 2014. Driving factors of small-scale variability in a savanna plant population after a fire. Acta Oecologica 56: 47-55. doi: 10.1016/j.actao.2014.02.003

Eden MJ, Andrade A. 1987. Ecological aspects of swidden cultivation among the Andoke and Witoto Indians of the Colombian Amazon. Human Ecology 15: 339-359. doi: 10.1007/BF00888030

Emperaire L, Peroni N. 2007. Traditional management of agrobiodiversity in Brazil: A case study of manioc. Human Ecology 35: 761-768. doi: 10.1007/s10745-007-9121-x

Ekblom A, Gillson L. 2017. The Importance of paleoecology in the conservation andrestoration of Cultural landscapes. PAGES Magazine 25: 88-89. doi: 10.22498/pages.25.2.88

FAO. 1999. Agricultural Biodiversity, Multifunctional Character of Agriculture and Land Conference, Background Paper 1. https://www.fao.org/3/y5609e/y5609e02.htm#TopOfPage. 13 Apr. 2022.

Fávero C. 2018. Acúmulo de carbono no solo por sistemas agroecológicos na região do semiárido de Minas Gerais. Cadernos de Agroecologia 13: 1-7.

Fearnside PM. 2000. Global warming and tropical land-use change: Greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. Climate Change 46: 115-158. doi: 10.1023/A: 1005569915357

Fernandes PM, Davies GM, Ascoli D *et al*. 2013. Prescribed burning in southern Europe: Developing fire management in a dynamic landscape. Frontiers in Ecology and Environment 11: e4-e14. doi: 10.1890/120298

Finegan B. 1992. The management potential of neotropical secondary lowland rain forest. Forest Ecology and Management 47: 295-321. doi: 10.1016/0378-1127(92)90190-E

Finegan B, Nasi R. 2004. The biodiversity and conservation potential of shifting cultivation landscapes in tropical landscape. In: Schroth G, Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (eds.). Agroforestry and Biodiversity Conservation in Tropical Landscapes. Washington DC, Island Press. p. 153-197.

Fidelis A, Rosalem P, Zanzarini V, Camargos LS, Martins AR. 2019. From ashes to flowers: A savanna sedge initiates flowers 24 h after fire. The Scientific Naturalist 100: e02648. doi: 10.1002/ecy.2648.

Fu Y, Guo H, Chen A, Cui J, Padoch C. 2003. Relocating plants from swidden fallows to gardens in southwestern China. Economic Botany 57: 389-402. doi: 10.1663/0013-0001(2003)057[0389:RPFSFT]2.0.CO;2

Furlan SA. 2005. Florestas culturais: manejo sociocultural, territorialidades e sustentabilidade. AGRÁRIA (São Paulo, Online) 3: 3-15. doi: 10.11606/issn.1808-1150.v0i3p3-15

Furley P, Rees RM, Ryan CM, Saiz G. 2008. Savanna burning and the assessment of long-term fire experiments with particular reference to Zimbabwe. Progress in Physical Geography 32: 611-634. doi: 10.1177/0309133308101383

Garavito G, Clavijo R, Luengas P, Palacios P, Arias MH. 2021. Assessment of biodiversity goods for the sustainable development of the chagra in an indigenous Community of the Colombian Amazon: Local values of crops. Journal of Ethnobiology and Ethnomedicine 17: 23. doi: 10.1186/s13002-021-00453-0

García MA, Santivañez T. 2021. Hand in hand with nature – Nature-based solutions for transformative agriculture: A revision of NBS for the Europe and Central Asia Region, supported by Globally Important Agricultural Heritage Systems (GIAHS) examples. Budapest, Food and Agriculture Organization of the United Nations.

Gliessman SR. 2009. Agroecologia: processos ecológicos em agricultura sustentável. 4. ed. Porto Alegre, Editora Universidade UFRGS.

Gogoi A, Sahoo UK, Saikia H. 2020. Vegetation and ecosystem carbon recovery following shifting cultivation in Mizoram-Manipur-Kachin rainforest eco-region, Southern Asia. Ecological Processes 9: 1-13. doi: 10.1186/s13717-020-00225-w

Gómez-Pompa A, Kaus A. 1999. From pre-Hispanic to future conservation alternatives: Lessons from Mexico. Proceedings of the National Academy of Sciences of the United States of America 96: 5982-5986. doi: 10.1073/pnas.96.11.5982

Gómez-Pompa A, Vasquez-Yanes C, Guevara S. 1972. The tropical rainforest: A nonrenewable resource. Science 177: 762-765. doi: 10.1126/science.177.4051.762

Gouda S, Decemson HT, Parida A, Solanki GS. 2020. Impact of shifting cultivation on mammalian diversity and distribution in fringe areas of Dampa tiger reserve, Mizoram, India. Environment Conservation Journal 21: 103-115. doi: 10.36953/ECJ.2020.211212

Grabherr G, Kojima S. 1993. Vegetation Diversity and Classification Systems. In: Solomon AM, Shugart HH (eds.). Vegetation Dynamics & Global Change. New York, Chapman & Hall. p. 218-232.

Gupta AK. 2000. Shifting cultivation and conservation of biological diversity in Tripura, Northeast India. Human Ecology 28: 605-629. doi: 10.1023/A: 1026491831856

Gupta AK, Kumar A. 1994. Feeding ecology and conservation of the Phayre's leaf monkey Presbytis phayrei in Northeast India. Biological Conservation 69: 301-306. doi: 10.1016/0006-3207(94)90430-8

Gupta PK, Krishna Prasad V, Sharma C, Sarkar AK, Kant Y, Badarinath KVS, Mitra AP. 2001. CH4 emissions from biomass burning of shifting cultivation areas of tropical deciduous forests – experimental results from ground-based measurements. Chemosphere - Global Change Science 3: 133-143. doi: 10.1016/S1465-9972(01)00003-4

Haberle S. 2007. Prehistoric human impact on rainforest biodiversity in highland New Guinea. Philosophical Transactions of the Royal Society B 362: 219-228. doi: 10.1098/rstb.2006.1981

Heinimann A, Mertz O, Frolking S *et al*. 2017. A global view of shifting cultivation: Recent, current, and future extent. PLoS One 12: e0184479. doi: 10.1371/journal.pone.0184479

Hett C, Castella JC, Heinimann A, Messerli P, Pfund JL. 2012. A landscape mosaics approach for characterizing swidden systems from a REDD plus perspective. Applied Geography 32: 608-618. doi: 10.1016/j.apgeog.2011.07.011

Homma AKO, Walker RT, Scatena FN *et al*. 1998. Redução dos desmatamentos na Amazônia: política agrícola ou Ambiental. In: Homma AKO (ed.). Amazônia: meio ambiente e desenvolvimento agrícola. Brasília, Editora Embrapa-SPI.

Huijun G, Padoch C, Coffey K, Aiguo C, Yongneng F. 2002. Economic development, land use and biodiversity change in the tropical mountains of Xishuangbanna, Yunnan, Southwest China. Environmental Science & Policy 5: 471-479. doi: 10.1016/S1462-9011(02)00093-X

Jääts L, Konsa M, Kihno K, Tomson P. 2011. Fire Cultivation in Estonian Cultural Landscapes. In: Peil T, Lang V, Kull K (eds.). The Space of Culture – The Place of Nature: Approaches to Culture Theory I. Tartu, Tartu Universtity Publishers. p. 1-19.

Johnson CM, Vieira ICG, Zarin DJ, Frizano J, Johnson AH. 2001. Carbon and nutrient storage in primary and secondary forests in eastern Amazonia. Foreste, Ecology and Management 147: 245-252. doi: 10.1016/S0378-1127(00)00466-7

Kasper M, Buchan GD, Mentler A, Blum WEH. 2009. Influence of soil tillage systems on aggregate stability and the distribution of C and N in different aggregate fractions. Soil and Tillage Research 105: 192-199. doi: 10.1016/j.still.2009.08.002

Kammesheidt L. 1998. The role of tree sprouts in the restoration of stand structure and species diversity in tropical moist forest after slash-and-burn agriculture in Eastern Paraguay. Plant Ecology 139: 155-165. doi: 10.1023/A: 1009763402998

Kealhofer L. 2003. Looking into the gap: Land use and the tropical forests of southern Thailand. Asian Perspectives 42: 72-95. doi: 10.1353/asi.2003.0022

Keeley JE, Pausas JG, Rundel PW, Bond WJ, Bradstock RA. 2011. Fire as an evolutionary pressure shaping plant traits. Trends Plant Sci 16: 406-411. doi: 10.1016/j.tplants.2011.04.002

Keeley JE, Rundel PW. 2005. Fire and the Miocene expansion of C4 grasslands. Ecology Letters 8: 683-690. doi: 10.1111/j.1461-0248.2005.00758.x

Kim DG, Kirschbaum MUF. 2015. The effect of land-use change on the net exchange rates of greenhouse gases: A compilation of estimates. Agriculture, Ecosystems and Environment 208: 114-126. doi: 10.1016/j.agee.2015.04.026

Kleinman PJ, Pimentel D, Bryant RB. 1995. The ecological sustainability of slash-and-burn agriculture. Agriculture, Ecosystems and Environment 52: 235-249. doi: 10.1016/0167-8809(94)00531-I

Klink CA, Machado RB. 2005. Conservation of the Brazilian Cerrado. Conservation Biology 19: 707-713. doi: 10.1111/j.1523-1739.2005.00702.x

Lawes MJ, Richards A, Dathe J, Midgley JJ. 2011. Bark thickness determines fire resistance of selected tree species from fire-prone tropical savanna in north Australia. Plant Ecology 212: 2057-2069. doi: 10.1007/s11258-011-9954-7

Lal R, Negassa W, Lorenz K. 2015. Carbon sequestration in soil. Current Opinion in Environmental Sustainability 15: 79-86. doi: 10.1016/j.cosust.2015.09.002

Laris P. 2002. Burning the seasonal mosaic: Preventive burning strategies in the wooded savana of southern Mali. Human Ecology 30: 155-186. doi: 10.1023/A: 1015685529180

Laskar SY, Sileshi GW, Pathak K *et al*. 2021. Variations in soil organic carbon content with chronosequence, soil depth and aggregate size under shifting cultivation. Science of the Total Environment 762: 143114. doi: 10.1016/j.scitotenv.2020.143114

Lehsten V, Tansey K, Balzter H *et al*. 2009. Estimating carbon emissions from African wildfires. Biogeosciences 6: 349-360. doi: 10.5194/bg-6-349-2009

Levis C, Flores BM, Moreira PA *et al*. 2018. How people domesticated Amazonian forests. Frontiers in Ecology and Evolution 5: 171. doi: 10.3389/fevo.2017.00171

Lu X, Zang R, Ding Y, Huang J. 2016. Changes in biotic and abiotic drivers of seedling species composition during forest recovery following shifting cultivation on Hainan Island, China. Biotropica 48: 758-769. doi: 10.1111/btp.12392

Marentes MAH, Venturi M, Scaramuzzi S, Focacci M, Santoro A. 2021. Traditional forest-related knowledge and agrobiodiversity preservation: the case of the chagras in the Indigenous Reserve of Monochoa (Colombia). Biodiversity and Conservation 31: 2243-2258. doi: 101007/s10531-021-02263-y

Magalhães TM, Mamugy FPS. 2020. Fine root biomass and soil properties following the conversion of miombo woodlands to shifting cultivation lands. Catena 194: 104693. doi: 101016/jcatena2020104693

Manjunatha RL, Singh NJ. 2020. Effect of fallow age on soil properties of Jhum fields in West Garo Hills District Meghalaya. Journal of Pharmacognosy and Phytochemistry 9: 591-597.

Mann C. 2005. 1491: New revelations of the Americas before Columbus. New York, Knopf.

Mazoyer M, Roudart L. 2010. Histórias das agriculturas no mundo: do neolítico à crise contemporânea. São Paulo, UNESP.

Medellin RA, Equihua M. 1998. Mammal species richness and habitat use in rainforest and abandoned agricultural fields in Chiapas, Mexico. Journal of Applied Ecology 35: 13-23. doi: 101046/j1365-2664199800272x

Mendoza-Vega J, Karltun E, Olsson M. 2003. Estimations of amounts of soil organic and fine root carbon in land use and land cover classes and soil types of Chiapas highlands, Mexico. Forest Ecology and Management 177: 1-16. doi: 101016/S0378-1127(02)00439-5

Mertz O. 2009. Trends in shifting cultivation and the REDD mechanism. Current Opinion in Environmental Sustainability 1: 156-160. doi: 101016/jcosust200910002

Mertz O, Padoch C, Fox J *et al*. 2009. Swidden change in Southeast Asia: Understanding causes and consequences. Human Ecology 37: 259-264. doi: 101007/s10745-009-9245-2

Metzger JP. 2003. Effects of slash-and-burn fallow periods on landscape structure. Environmental Conservation 30: 325-333. doi: 101017/S0376892903000341

McGregor S, Lawson V, Christophersen P *et al.* 2010. Indigenous wetland burning: conserving natural and cultural resources in Australia's World Heritage-listed Kakadu National Park. Human Ecology 38: 721-729. doi: 101007/s10745-010-9362-y

Mistry J. 1998. Fire in the cerrado (savannas) of Brazil: An ecological review. Progress in Physical Geography: Earth and Environment 22: 425-448. doi: 101177/030913339802200401

Monteiro FT, Fávero C, Filho AC, Oliveira MNS, Soldati GT, Teixeira RDBL. 2019. Sistema Agrícola Tradicional da Serra do Espinhaço Meridional MG: transumância, biodiversidade e cultura nas paisagens manejadas pelos(as) apanhadores(as) de flores semprevivas. In: Eidt JS, Udry C (eds.). Sistemas Agrícolas Tradicionais no Brasil. Brasília, Embrapa. p. 93-139.

Moreira F, Ferreira PG, Rego FC, Bunting S. 2001. Landscape changes and breeding bird assemblages in northwestern Portugal: The role of fire. Landscape Ecology 16: 175-187. doi: 101023/A: 1011169614489

NAC/UFVJM – Núcleo de Estudos em Agroecologia e Campesinato da UFVJM. 2017. Monitoramento de Agroecossistemas de Referência Agroecológica na Região do Semiárido de Minas Gerais - Ciclo de Monitoramento 2015/2016 - Agroecossistema da família de Preta e Imir, Comunidade de Vargem do Inhaí, Diamantina, Alto Jequitinhonha. Diamantina, NAC/UFVJM.

Namgyel U, Siebert SF, Wang S. 2008. Shifting cultivation and biodiversity conservation in Bhutan. Conservation Biology 22: 1349-1351. doi: 101111/j1523-1739200801019x

Nye PH, Greenland DJ. 1960. The Soil Under Shifting Cultivation. Harpenden, Commonwealth Bureau of Soils.

Palm CA, van Noordwijk M, Woomer P *et al.* 2005. Carbon losses and sequestration after land use changes on the humid tropics. In: Palm CA, Vosti SA, Sanchez PA, Ericksen PJ (eds.). Slash-and-Burn Agriculture - The Search for Alternatives. New York, Columbia University Press. p. 41-63.

Pandey DK, Adhiguru P, Devi SV, Dobhal S, Dubey SK, Mehra TS. 2019. Quantitative assessment of crop species diversity in shifting cultivation system of Eastern Himalaya. Current Science 117: 00113891. doi: 1018520/cs/v117/i8/1357-1363

Pandey DK, Dobhal S, De HK, Adhiguru P, Devi SV, Mehra TS. 2022. Agrobiodiversity in changing shifting cultivation landscapes of the Indian Himalayas: An empirical assessment. Landscape and Urban Planning 220: 104333. doi: 101016/jlandurbplan2021104333

Pausas JG, Keeley JE. 2009. A burning story: The role of fire in the history of life. Bioscience 59: 593-601. doi: 101525/bio200959710

Pausas JG, Parr CL. 2018. Towards an understanding of the evolutionary role of fire in animals. Evolutionary Ecology 32: 113-125 doi: 101007/s10682-018-9927-6

Pedroso Júnior NN, Murrieta RSS, Adams C. 2008. A agricultura de corte e queima: um sistema em transformação. Boletim do Museu Paraense Emílio Goeldi Ciências Humanas 3: 153-174. doi: 101590/S1981-81222008000200003

Pérez-García O, Castillo RF. 2016. The decline of the itinerant milpa and the maintenance of traditional agrobiodiversity: Crops and weeds coexistence in a tropical cloud forest area in Oaxaca, Mexico. Agriculuture, Ecosystems and Environment 228: 30-37. doi: 101016/jagee201605002

Peroni N, Hanazaki N. 2002. Current and lost diversity of cultivated varieties especially cassava under swidden cultivation systems in the Brazilian Atlantic Forest. Agriculuture, Ecosystems and Environment 92: 171-183. doi: 101016/S0167-8809(01)00298-5

Perreault T. 2005. Why chacras (swidden gardens) persist: Agrobiodiversity food security and cultural identity in the Ecuadorian Amazon. Human Organization 64: 327-339. doi: 1017730/humo644e6tymmka388rmybt

Pilon NA, Hoffmann WA, Abreu RC, Durigan G. 2018. Quantifying the short-term flowering after fire in some plant communities of a cerrado grassland. Plant Ecology & Diversity 11: 259-266. doi: 101080/1755087420181517396

Pinheiro MHO, Monteiro R. 2010. Contribution to the discussions on the origin of the cerrado biome: Brazilian savanna. Brazilian Journal of Biology 70: 95-102. doi: 101590/S1519-69842010000100013

Pivello VR, Coutinho LM. 1996. A qualitative successional model to assist in the management of Brazilian cerrados. Forest, Ecology and Management 87: 127-138. doi: 101016/S0378-1127(96)03829-7

Ploeg JD. 2009. Sete teses sobre a agricultura camponesa. In: Petersen P (ed.). Agricultura familiar camponesa na construção do futuro. Rio de Janeiro, AS-PTA.

Posey D. 1984. Os Kayapó e a natureza. Ciência Hoje 2: 35-41.

Raman TRS. 2001. Effect of Slash-and-Burn Shifting Cultivation on Rainforest Birds in Mizoram, Northeast India. Conservation Biology 15: 685-698. doi: 101046/j1523-17392001015003685x

Raman TRS, Rawat GS, Johnsingh AJT. 1998. Recovery of tropical rainforest avifauna in relation to vegetation succession following shifting cultivation in Mizoram north-east India. Journal of Applied Ecology 35: 214-231. doi: 101046/j1365-2664199800297x

Rerkasem K, Yimyam N, Korsamphan C, Thong-Ngam C, Rerkasem B. 2002. Agrodiversity lessons in mountain land management. Mountain Research and Development 22: 4-9. doi: 101659/0276-4741(2002)022[0004:ALIMLM]20CO;2

Rerkasem K, Lawrence D, Padoch C, Schmidt-Vogt D, Ziegler AD, Bruun TB. 2009. Consequences of swidden transitions for crop and fallow biodiversity in Southeast Asia. Human Ecology 37: 347-360. doi: 101007/s10745-009-9250-5

Ribeiro-Filho AA, Adams C, Murrieta RSS. 2013. The impacts of shifting cultivation on tropical forest soil: A review. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas 8: 693-727. doi: 101590/S1981-81222013000300013

Rojas JM, Prause J, Sanzano GA, Arce OEA, Sánchez MC. 2016. Soil quality indicators selection by mixed models and multivariate techniques in deforested areas for agricultural use in NW of Chaco, Argentina. Soil and Tillage Research 155: 250-262. doi: 101016/jstill201508010

Ross NJ. 2011. Modern tree species composition reflects ancient Maya "forest gardens" in northwest Belize. Ecological Applications 21: 75-84. doi: 101890/09-06621

Salinas-Melgoza MA, Skutsch M, Lovett JC, Borrego A. 2017. Carbon emissions from dryland shifting cultivation: A case study of Mexican tropical dry forest. Silva Fennica 51: 1553. doi: 1014214/sf1553

Santilli J. 2012a. A Lei de Sementes brasileira e os seus impactos sobre a agrobiodiversidade e os sistemas agrícolas locais e tradicionais. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas 7: 457-475. doi: 101590/S1981-81222012000200009

Santilli J. 2012b. Agrobiodiversity and the Law: Regulating genetic resources food security and cultural diversity. Routledge, Abingdon.

Siminski A, Fantini AC. 2007. Slash-and-burn agriculture: Use of forest resources and dynamics of rural landscape in Santa Catarina State, Brazil. Ciência Rural 37: 690-696. doi: 101590/S0103-84782007000300014

Schmidt IB, Sampaio MB, Figueiredo IB, Ticktin T. 2011. Fogo e artesanato de capim-dourado no Jalapão – usos tradicionais e consequências ecológicas. Biodiversidade Brasileira 1: 67-85. doi: 1037002/biobrasilv%25vi%25i116

Silver WL, Ostertag R, Lugo AE. 2000. The Potential for Carbon Sequestration Through Reforestation of Abandoned Tropical Agricultural and Pasture Lands. Restoration Ecology 8: 394-407. doi: 101046/j1526-100x200080054x

Simon MF, Pennington T. 2012. Evidence for adaptation to fire regimes in the tropical savannas of the Brazilian Cerrado. International Journal of Plant Science 173: 711-723. doi: 101086/665973

Six J, Elliott ET, Paustian K. 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biology and Biochemistry 32: 2099-2103. doi: 101016/S0038-0717(00)00179-6

Smith J, Van De Kop P, Reategui K, Lombardi I, Sabogal C, Diaz A. 1999. Dynamics of secondary forests in slash-and-burn farming: interactions among land use types in the Peruvian Amazon. Agriculture, Ecosystems & Environment 76:85-98. doi: 101016/S0167-8809(99)00075-4

Snyder CS, Bruulsema TW, Jensen TL, Fixen PE. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture, Ecosystems & Environment 133: 247-266. doi: 101016/jagee200904021

Sommer R, Denich M, Vlek PLG. 2000. Carbon storage and root penetration in deep soils under small-farmer land-use systems in the Eastern Amazon region. Brazil Plant Soil 219: 231-241. doi: 101023/A:1004772301158

Stephens BB, Gurney KR, Tans PP *et al*. 2007. Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO2. Science 316: 1732-1735. doi: 101126/science11370

Steege H, Pitman NCA, Sabatier D *et al*. 2013. Hyperdominance in the Amazonian tree flora. Science 342: 1243092. doi: 101126/science1243092

Terefe B, Kim DG. 2020. Shifting cultivation maintains but its conversion to mono-cropping decreases soil carbon and nitrogen stocks compared to natural forest in Western Ethiopia. Plant Soil 453: 105-117. doi: 101007/s11104-019-03942-0

Thet APP, Tokuchi N. 2020. Traditional knowledge on shifting cultivation of local communities in Bago Mountains, Myanmar. Journal of Forest Research 25: 347-353. doi: 101080/1341697920201764166

Thong P, Sahoo UK, Thangjam U, Pebam R. 2020. Pattern of forest recovery and carbon stock following shifting cultivation in Manipur, North-East India. PLoS One 15: e0239906. doi: 101371/journalpone0239906

Tomson P, Bunce RGH, Sepp K. 2015. The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. Landscape and Urban Planning 137: 54-63. doi: 101016/jlandurbplan201412015

Townsend CR, Begon M, Harper JL. 2010. Fundamentos em Ecologia. Porto Alegre, Artmed.

Van de Wouw M, Kik C, van Hintum T, van Treuren R, Visser B. 2010. Genetic erosion in crops: Concept research results and challenges. Plant Genetic Resources 8: 1-15. doi: 101017/S1479262109990062

Van Vliet N, Mertz O, Heinimann A *et al*. 2012. Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. Global Environmental Change 22: 418-429 doi: 101016/jgloenvcha201110009

Vandermeer J, Lawrence D. 2002. Effect of biodiversity on ecosystem functioning in managed ecosystems. In: Loreau M, Naeem S, Inchausti P (eds.). Biodiversity and ecosystem functioning: Synthesis and perspectives. New York, Oxford University Press. p. 221-236.

Varela ME, Benito E, Keizer JJ. 2010. Wildfire effects on soil erodibility of woodlands in NW Spain. Land Degradation and Development 21: 75-82. doi: 101002/ldr896

Varghese A, Ticktin T. 2008. Regional variation in non-timber forest product harvest strategies trade and ecological impacts: The case of Black Dammar (*Canarium strictum* Roxb) use and conservation in the Nilgiri Biosphere Reserve, India. Ecology and Society 13: 2. doi: 105751/ES-02555-130211

Watters RF. 1971. Shifting Cultivation in Latin America. Rome, Food and Agriculture Organization of the United Nations.

Weber B, White L, Vedder A, Naughton-Treves L. 2001. African rain forest ecology and conservation: An Interdisciplinary Perspective. Connecticut, Yale University Press.

Woods W, Glaser B. 2004. Towards an understanding of Amazonian dark earths. In: Glaser B, Woods W (eds.). Amazonian dark earths: Explorations in space and time. New York, Springer Verlag. p. 1-10.

Yibarbuk D, Whitehead PJ, Russell-Smith J *et al*. 2001. Fire ecology and aboriginal land management in Central Arnhem Land Northern Australia: A tradition of ecosystem management. Journal of Biogeography 28: 325-343. doi: 101046/j1365-2699200100555x

CC BY