The impacts of shifting cultivation on tropical forest soil: a review

Impactos da agricultura itinerante sobre o solo em florestas tropicais: uma revisão

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Abstract: The sustainability of shifting cultivation is presently a topic of debate in scientific and institutional communities; however, there is no current consensus. To address this debate, we performed a search of the pertinent literature that was published during the last 30 years on the impact of shifting agriculture on tropical soils. This search revealed that the nature of the impact depends on the shifting cultivation system (SCS) phase (conversion, cultivation, or fallow) and on the soil properties (physical, chemical, and biological). We also suggest soil quality indicators for evaluating this agricultural practice in tropical forests, which may be used as a basis for analyses on the tendencies of conservation and degradation of impacted soils. Future research should improve the choices of these indicators, relying mostly on practical criteria, so they can be used by shifting cultivators.

Keywords: Shifting agriculture. Shifting cultivation system. Swidden. Soil. Ecological impact. Sustainability.

Resumo: A sustentabilidade da agricultura itinerante é, atualmente, um tema bastante debatido no meio científico e institucional, sobre o qual ainda não existe consenso. Como forma de subsidiar este debate, realizamos um levantamento da literatura pertinente, publicada nos últimos 30 anos, a respeito dos impactos da agricultura itinerante sobre os solos tropicais. Este levantamento demonstrou que a natureza dos impactos depende da fase do sistema (conversão, cultivo ou pousio) e das propriedades do solo (físicas, químicas e biológicas). Também foram sugeridos indicadores de qualidade do solo para essa prática agrícola em florestas tropicais, que poderão servir como base para o acompanhamento das tendências de conservação e degradação de solos impactados. Pesquisas futuras devem aprimorar as escolhas destes indicadores, baseando-se em critérios principalmente práticos, para que possam ser utilizados pelos agricultores itinerantes.

Palavras-chave: Agricultura itinerante. Sistema agrícola itinerante. Derrubada-e-queima. Solo. Impacto ecológico. Sustentabilidade.

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INTRODUCTION

Shifting cultivation systems (SCS) and their impacts on soil and vegetation have been widely studied by many research groups (Juo and Manu, 1996; Palm *et al.*, 1996; Nandwa and Bekunda, 1998; Giardina *et al*., 2000; Lawrence and Foster, 2002; Bruun *et al*., 2009; Mertz *et al*., 2009). The current intensification of studies on the topic is likely related to problems linked to global warming (Lal *et al*., 1995; Kauffman *et al.*, 2009) and the deforestation of rainforests (Fearnside, 2005). This review article aims to identify and classify the impacts of SCS on the properties of tropical forest soils. Moreover, based on our results, we suggest soil quality indicators that may lead to new, more specific quantitative indicators for SCS and may also contribute to the sustainable management of these systems.

In the methods section, we present the methodological procedures used for this review. In the following section, we present and discuss the results of the identification and classification of the types of SCS impacts on the physical, chemical, and biological properties of the soil. In the fourth section, we suggest qualitative indicators (physical, chemical, and biological) for the evaluation of the impact of SCS on the soil and of trends in soil degradation and conservation. Finally, in the last section, we discuss our results and make some conclusions based on the sustainability of SCS.

SHIFTING CULTIVATION SYSTEMS AND FORESTS

Shifting cultivation (SC) is one of the main subsistence activities of small-scale societies and rural populations in tropical forests. This system has been practiced for thousands of years (Harris, 1971; Dove and Kammen, 1997; Altieri, 1999; Bellwood, 2005) and is based on the ecological processes of forest ecosystems (Boserup, 1965; Altieri, 1999; Long and Zhou, 2001; Vadez *et al*., 2004; Pedroso-Junior *et al*., 2008, 2009). Over the past three centuries, the practice of SC has been restricted to forested areas of the tropics, because the increase in population density has made this practice impossible in Europe (Boserup, 1989; Worster, 2003). Estimates of how many people worldwide currently depend on shifting agriculture systems for their subsistence vary from 35 million to 1 billion people (Lanly, 1982; Attiwill, 1994; Brady, 1996; Kleinman *et al*., 1996; IFAD *et al*., 2001; Sanchez *et al*., 2005).

The basic phases of SCS are the following: (1) conversion, (2) cultivation, and (3) fallow (Kleinman *et al*., 1995). Conversion includes the slash-and-burn of native vegetation. This practice physically exposes the soil for planting, eliminates competing plant cover, and improves soil fertility by leaving it less acidic and with a greater availability of nutrients (Kleinman *et al*., 1995). The length of the cultivation period varies depending on the region (one to three years), but is always shorter than the fallow period. The fallow period may be natural or managed and allows recovery from the soil degradation resulting from conversion and cultivation. The duration of the fallow period is variable, but it must be long enough for woody vegetation to become dominant (Eden and Andrade, 1987; Kleinman *et al*., 1995; Mertz *et al*., 2009). The SCS leads to the formation of mosaics of secondary forests in different stages of regeneration, contained within a mature forest matrix that helps to sustain them (Conklin, 1961; Harris, 1971; Hiraoka and Yamamoto, 1980; Egger, 1981; Altieri *et al*., 1987; McGrath, 1987; Adams, 2000a; Martins, 2005).

The similarities among shifting cultivation practices in different tropical forests exist because farmers mimic the characteristics and ecological processes of the forest system in their agricultural activities (Beckerman, 1983; Altieri, 1989; Adams, 2000b; Warner, 2001). This forest management system appears to maintain the genetic diversity of the crops and of the secondary forests in regeneration and avoids soil degradation by minimizing its exposure to erosive and drying elements. The period of disturbance is compensated by the recovery of the soil-vegetation system (McGrath, 1987; Kleinman *et al*., 1995; Pedroso-Junior *et al*., 2008, 2009).

SCS appear to be sustainable under specific conditions of low demographic densities and the use of low input technologies (Kleinman *et al*., 1995; Johnson *et al*., 2001; Pedroso-Junior, 2008, 2009). However, the rapid and important climatic and economic-political transformations that have occurred in recent decades (Mertz, 2002; Pedroso-Junior *et al*., 2008, 2009; Van Vliet *et al*., 2012) have produced a growing concern about the sustainability of SCS (Bruun *et al*., 2009) and the food security of subsistence farmers (Altieri *et al*., 1987; Adams *et al*., 2005).

Historically, the debate on the sustainability of shifting cultivation has been associated with the conservation of tropical forest ecosystems and characterized by antagonistic positions (Pedroso-Junior *et al*., 2008, 2009). During the 1950s, the Food and Agriculture Organization of the United Nations (FAO, 1957) requested that governments, research centers, and public and private associations invested in the modernization of agricultural practices and disregarded those associated with shifting cultivation. According to FAO, shifting cultivation represented a backward and inadequate system for the conservation of the tropical forest ecosystems in which it was practiced (Mertz *et al*., 2009).

However, a few decades later, studies of SCS showed that these practices displayed a certain economic and environmental rationality (Fox, 2000; Mertz, 2002) and increased interest in this system. The effect of these new studies was to support the hypothesis that the SCS techniques have traditional characteristics and that they consequently exhibit ecological sustainability (Kleinman *et al.*, 1995; Pedroso-Junior *et al*., 2008, 2009).

Also many are the opinions on the hole of SCS in tropical forest dynamics, shifting cultivation began to be considered one of the drivers of tropical deforestation in the 1990s (FAO, 1985; Myers, 1993; Bandy *et al*., 1993; Brady, 1996). SCS were blamed for 10% of the loss of forested areas in Latin America (Houghton *et al*., 1991), for between 30% to 35% of forest lost in the Amazon (Serrão *et al*., 1996), and for 50% in Indonesia (Jong, 1997). In addition to deforestation, there was also a concern that the impact on soils could compromise forest biodiversity (FAO, 1985; Myers, 1993; Bandy *et al*., 1993; Brady, 1996). Moreover, the areas used for shifting cultivation could function as a significant cause of global warming (Fearnside, 2005), and the soil could be considered a source of CO_2 emissions into the atmosphere (Brown and Lugo, 1990), which would not be compensated by secondary forest growth during the fallow period.

These negative concerns regarding the environmental sustainability of the SCS have guided public policies in many tropical countries towards eradicating this agricultural system (Ziegler *et al*., 2009). This system has been considered to be incompatible, for example, with biodiversity conservation and the management of protected areas (Namgyel *et al*., 2008).

Nevertheless, the number of scientists who argued in favour of in the positive environmental impacts of shifting cultivation also increased in the same period (Pedroso-Junior *et al*., 2008, 2009; Mertz *et al*., 2009; Padoch and Pinedo-Vasquez, 2010). The time scale of the human/tropical forest interactions led different authors to argue that some forest ecosystems might have coevolved with human activities such as shifting cultivation (Sanford *et al*., 1985; Balée and Campbell, 1990; Brown and Lugo, 1990; Denevan, 1992; Adams, 1994; Lindbladh and Bradshaw, 1998; Uotila *et al*., 2002; Willis *et al*., 2004) and thus could be called cultural forests (Balée, 1989). For example, Namgyel *et al*. (2008) suggested that the prohibition of the millennial practice of shifting cultivation in Bhutan (Asia), which aimed to preserve forested areas, would actually put at risk the biodiversity of the local flora and fauna that had already been adapted to a cycle of disturbances. The same has been argued for other tropical forest areas in the world (Willis *et al*., 2004; Bush and Silman, 2007).

SCS AND THE SOIL

With regard to the impact on soils, the target of this study, some studies have presented results that indicate degenerative processes in the soil (Borggaard *et al*., 2003;

Rasul *et al*., 2004). However, other scientists have disagreed and accused the former group of adopting a simple view of the topic that is based on a chronic lack of evidence (Mertz, 2002; Mertz *et al*., 2009; Bruun *et al*., 2009). Moreover, compared to other agricultural systems, several lines of evidence have supported the latter group of scientists. These lines of evidence include the decrease of erosive processes in SCS areas as well as the maintenance of various other environmental processes, including the following: hydrological (Ziegler *et al*., 2009), protection of biodiversity (Rerkasem *et al*., 2009), and potential sequestration of carbon (Bruun *et al*., 2009). However, a recent review of the literature has shown that the impacts of SCS over the environment and its populations may be either positive or negative, depending on the context (Pedroso-Junior *et al*., 2008, 2009).

Thus, the debate on the sustainability of shifting agriculture and its impact on soils remains inconclusive. The research question that guided this study is the following: is shifting cultivation a sustainable system with respect to the soil dynamics?

The main objectives of this study were the following: 1) to perform a search of the literature on the impacts (positive and negative) caused by shifting agriculture systems on the soils of tropical forests; and 2) based on the secondary data reviewed in the literature, to suggest qualitative indicators that are representative of these impacts, which will allow for an evaluation of the sustainability of the system in different contexts. To perform these tasks, the types of soil impacts (considering physical, chemical, and biological parameters) caused by the different components of shifting cultivation (conversion, cultivation, and fallow) were identified and classified.

METHODOLOGY

For this study, an impact was defined as any alteration of the physical, chemical, or biological properties of the soil that was caused by any form of matter or energy that resulted from activities related to the components of shifting cultivation (conversion, planting, and fallow).

Based on the method proposed by Brites (2010), the data collection consisted of two stages. In the first stage, a list was compiled of the impacts of the practice of shifting cultivation on tropical forest soils. The impacts were identified through an examination of review articles and compilations on the topic (Juo and Manu, 1996; Palm *et al*., 1996; Nandwa and Bekunda, 1998; Giardina *et al*., 2000; Lawrence and Foster, 2002; Milne *et al*., 2007; Pedroso-Junior *et al*., 2008, 2009; Bruun *et al*., 2009; Mertz *et al*., 2009).

In the second stage, a systematic literature search was performed to find empirical evidence for these impacts. The criteria that had been used by Brites (2010) were used in the search for and selection of publications: (i) studies of the impact of SCS on tropical forest soils; (ii) studies on the impact on one of the soil aspects (physical, chemical, and biological); (iii) studies with primary data, which excluded bibliographic reviews; and (iv) studies that presented parameters for the conservation or degradation of soils that were subjected to shifting cultivation practices. The use of these criteria allowed for the quantitative summary of the sources of research and a systematized comparison of the results from different studies.

The review was performed using the following databases: Scientific Electronic Library Online (SciELO, www.scielo.org), Web of Science (WOS, apps.isiknowledge.com), and Center for International Forestry Research (CIFOR, www.cifor.cgiar.org/publications). The keywords used in the search were the following: swidden, shifting cultivation, slash-and-burn, *agricultura itinerante*, *derrubada-e-queima* and *coivara*. The search was limited to articles published within the past 30 years (1980-2010).

The soils in the reviewed studies had been classified according to the North American system (Soil Survey Staff, 1999) and the FAO and UNESCO (1974) at the level of order. The types of impacts identified were classified in relation to the aspects of the soils (physical, chemical, and biological), the basic components of shifting cultivation (conversion, cultivation, and fallow), and the possible effects on the soil of tropical forests. The effects were classified as the following: (i) positive, when they promoted soil conservation; (ii) negative, when the soil exhibited degradation; and (iii) uncertain, when it was not possible to identify whether the effect was conservation or degradation.

Based on the review of the literature on the impact caused by SCS in tropical soils, variables related to the physical, chemical, and biological properties of the soil were selected. These properties provided the foundation for the indicators for evaluating the impact of the SCS. In addition, this study was based on a review of articles describing the construction of models and indicators of the quality of soils subject to agricultural management (Larson and Pierce, 1991; Andrews and Carroll, 2001; Yemefack *et al.*, 2006a, 2006b). We used the following inclusion criteria for the variables found in the literature review that comprised the indicators: 1) soil properties that experienced impacts detected in the majority of the studies we reviewed; and 2) soil properties (relevant variables) common to the various soil quality indices (SQI) (Larson and Pierce, 1991; Andrews and Carroll, 2001) and minimum data sets (MDS) (Yemefack *et al.*, 2006a, 2006b) – that had been developed for agricultural systems in general.

Next, we present our results and discussion section in text and tables. The results obtained in this review are referenced in Table 1, which shows the articles we reviewed. The types of identified impacts are found in the tables and are classified according to the aspects of the soil (physical, chemical, and biological), the basic components of shifting cultivation (conversion, cultivation, and fallow), and the possible effects on the soil of tropical forests. All impacts show their respective numbered references in Table 1. The articles cited in the body of the text in the following section are either not found in Table 1 or are being referred to because of specific aspects.

RESULTS AND DISCUSSION

A total of 80 research articles were collected (Table 1) as well as nine review articles on the topic (Juo and Manu, 1996; Palm *et al.*, 1996; Nandwa and Bekunda, 1998; Giardina *et al.*, 2000; Lawrence and Foster, 2002; Milne *et al.*, 2007; Bruun *et al.*, 2009; Mertz *et al.*, 2009). The earliest article was published in 1981. The 2000s have the greatest percentage of publications, with 61%, compared to 25% in the 1990s and 13% in the 1980s (Table 1). This increase is likely caused by the recent debate on global warming and the importance of carbon emissions derived from the burning of tropical forests (Lal *et al.*, 1995; Kauffman *et al.*, 2009). The reviewed studies were performed on three types of forests, according to the classification of biomes of Walter *et al.* (1975): 82% were Tropical Rain Forest, 11% were Seasonal Tropical Forest, and 7% were Seasonal Forest Savanna.

Our bibliographic review found that the geographic distribution of the studies on the impacts of SCS on the soil of tropical forests accompanies the importance of the continents with regard to the extent of the forested area and its biodiversity. The American continent was the site for almost half of the studies, with 28.8% in South America, 11.3% in North America, and 5.0% in Central America (Table 1).

Twenty-four percent of the reviewed studies were performed only in Brazil (Table 1), which was consistent with the Brazilian territorial extension and the importance of the Amazon Rainforest, which is still under a relative state of conservation. Moreover, the existence in these regions of indigenous and rural populations that practice various forms of forest management and, consequently, soil management, and the advancement of the agricultural frontier and its well-known outspread into tropical ecosystems, appear to contribute to an increased interest in the soil dynamics of this region.

In contrast, the limited number of studies about SCS in the Atlantic Forest (Table 1) likely reflects its currently reduced territorial extension and the existence of rather strict legal restrictions imposed on the clearing of remnant vegetation (Brasil, 2000, 2006, 2008; São Paulo, 2010). The Asian continent was the location for 30% of the collected studies, and Africa was the location for 12% (Table 1).

Table 1. References to primary data used in this review (the numbers of references are those given in the tables of impacts on soil properties). Legends: Ref = Reference; S/U = Sustainable/Untenable.

(Continue)

	References	Keyword	Source	Continent	Country	S/U
1	Bruun *et al.* (2006)	Shifting cultivation; Fallow periods; Yields; Plant-available N and P; Soil organic carbon	Web of Science	Asia	Borneo	S
2	Aboim *et al.* (2008)	Soil quality; Soil quality indicators; Microbial diversity; DGGE	Web of Science	South America	Brazil	S
3	Lessa *et al.* (1996)	Slash and burn; Ashes; Fine roots; Dynamics of exchangeable cations; Soil organic matter; Oxisol soils	Web of Science	South America	Brazil	S
4	Mamede and Araújo (2008)	Agricultural practices; Biodiversity; Fire; Seedling emergence; Semiarid tropical zone (SAT); Plant life-form	Web of Science	South America	Brazil	U
5	Salcedo *et al.* (1997)	Oxisol; Subtractive fertilizer trial; Additive fertilizer trial; N mineralization; C mineralization	Web of Science	South America	Brazil	S
6	Sommer *et al.* (2004)	AEC; Fallow vegetation; Leaching; Slash-and-burn; Variable-charge soil; Volatilization	Web of Science	South America	Brazil	U
7	Tiessen *et al.* (1992)	Not listed	Web of Science	South America	Brazil	S
8	Zarin *et al.* (1998)	Available phosphorus; Brazil; Exchangeable cations; Soil organic carbon; Terra firme; Várzea	Web of Science	South America	Brazil	S
9	Béliveau *et al.* (2009)	Soil mercury; Amazon deforestation; Slash-and-burn agriculture; Soil cations; Soil texture; Land use	Web of Science	South America	Brazil	U
10	Hughes *et al.* (2000)	Tropical deforestation; Regenerating forests; Biomass burning; Carbon and nutrient pools; Amazon Basin	Web of Science	South America	Brazil	S
11	Sampaio *et al.* (1993)	Brazil; Coppicing; Crown area; Dry forest; Fire; Slash and burn; Species survival; Sprouting	Web of Science	South America	Brazil	U
12	Farella *et al.* (2006)	Mercury; Cations; Deforestation; Amazon; Agriculture; Land-use	Web of Science	South America	Brazil	S
13	Hölscher *et al.* (1997)	Amazonia; Shifting cultivation; Soil chemistry; Nutrient dynamics	Web of Science	South America	Brazil	S

Table 1. (Continue)

	References	Keyword	Source	Continent	Country	S/U
14	Johnson *et al.* (2001)	Aboveground biomass; Plant nutrients; Soil nutrients; Slash-and-burn agriculture	Web of Science	South America	Brazil	S
15	Kato *et al.* (1999)	Land preparation; Mulch; Nutrient management; Secondary vegetation; Fallow	Web of Science	South America	Brazil	U
16	Lima *et al.* (2010)	Agricultura de queima e corte; Invertebrados do solo; Sistemas agroflorestais; Sistemas de uso do solo; Transição cerrado-floresta	SciELO	South America	Brazil	U
17	R. R. Oliveira (2008)	Slash-and-burn agriculture; Caiçaras; Turnover of nutrients; Litter layer; Secondary forest	SciELO	South America	Brazil	S
18	Sampaio *et al.* (2003)	Amazônia; Agricultura itinerante; Efeito residual; Conversão de florestas	SciELO	South America	Brazil	S
19	Menzies and Gillman (2003)	Land clearing; Nutrient leaching; Shifting agriculture	Web of Science	Africa	Cameroon	S
20	Obale-Ebanga *et al.* (2003)	Vertisols; Aggregates; Stability; Land use; Shifting cultivation; Cameroon	Web of Science	Africa	Cameroon	S
21	Yemefack *et al.* (2006a)	Empirical modelling; Soil dynamics; Chronosequence; Shifting cultivation; Fractional rational function; Sampling strategies; Southern Cameroon	Web of Science	Africa	Cameroon	S
22	Yemefack *et al.* (2006b)	Minimum data set (MDS); Shifting cultivation; Soil dynamics; Southern Cameroon; Soil quality; Multi-criteria decision-making	Web of Science	Africa	Cameroon	S
23	Ewel *et al.* (1981)	Carbon; Carbon dioxide; Cations; Costa Rica; Fire; Mycorrhizae; Nitrogen; Phosphorus; Seeds; Shifting agriculture; Slash and burn; Sulfur; Tropical forests	Web of Science	Central America	Costa Rica	S
24	Soto *et al.* (1995)	Not listed	Web of Science	Europe	Spain	S
25	Rossi *et al.* (2010)	Soil macrofauna; Species richness; Slash-and-burn agriculture; Agriculture intensification; Landscape; Biodiversity	Web of Science	South America	French Guiana	S
26	Topoliantz *et al.* (2006)	Not listed	Web of Science	South America	French Guiana	S

Table 1. (Continue)

	References	Keyword	Source	Continent	Country	S/U
27	Sirois *et al.* (1998)	*Erythrophleum guinensis*; Managed fallows; Nutrient cycling; *Parinari excelsa*; *Parkia biglobosa*; Shifting cultivation	Web of Science	Africa	Guinea	S
28	Paniagua *et al.* (1999)	Soil degradation and rehabilitation; Vegetation successions; Soil fertility indices; Honduras	Web of Science	Central America	Honduras	S
29	Fonte *et al.* (2010)	Agroforestry; Carbon storage; Earthworms; Phosphorus availability; Slash-and-burn agriculture; Soil aggregates	Web of Science	Central America	Honduras	S
30	Bhadauria and Ramakrishnan (1989)	Not listed	Web of Science	Asia	India	S
31	Gafur *et al.* (2003)	Shifting cultivation; Hydrology; Soil erosion; Nutrient depletion; Bangladesh	Web of Science	Asia	India	S
32	Mishra and Ramakrishnan (1983)	Not listed	Web of Science	Asia	India	S
33	Lawrence *et al.* (2005)	Indonesia; Rainforest; Secondary forest; Seed dispersal; Shifting cultivation; Species composition; Soil nutrients	Web of Science	Asia - Oceania	Indonesia	S
34	Ketterings and Bigham (2000)	Not listed	Web of Science	Asia - Oceania	Indonesia	S
35	Ketterings *et al.* (2000)	Not listed	Web of Science	Asia - Oceania	Indonesia	S
36	Ketterings *et al.* (2002)	Oxisols; Phosphorus; Slash-and-burn; Indonesia; Rubber agroforestry	Web of Science	Asia - Oceania	Indonesia	S
37	Ketterings *et al.* (1999)	Slash-and-burn; Shifting cultivation; Fire; Farmer's survey; Social/economic/ agronomic survey; Small rubber producers; Jambi; Province; Sumatra; Indonesia	Web of Science	Asia - Oceania	Indonesia	S
38	Lawrence and Schlesinger (2001)	Disturbance; Indonesia; Nutrient cycling; Phosphorus fractionation; Phosphorus organic; Phosphorus soil; Shifting cultivation; Tropical rain forest; Tropical soil	Web of Science	Asia - Oceania	Indonesia	S
39	Rodenburg *et al.* (2003)	Soil run-off; Slash-and-burn; Spatial variability; Soil pH; Resin-extractable P; Small-scale agriculture; Rubber plantation; Indonesia	Web of Science	Asia - Oceania	Indonesia	S

Table 1. (Continue)

	References	Keyword	Source	Continent	Country	S/U
40	McDonald *et al.* (2002)	Slash-and-burn agriculture; Surface runoff; Soil erosion; Soil fertility; Deforestation; Forest buffer zone; Agroforestry; Contour hedgerow; *Calliandra calothyrsus*; Jamaica	Web of Science	Central America	Jamaica	S
41	Chaplot *et al.* (2007)	Soil interrill erosion; Runoff; Soil crusting; Shifting cultivation; Sloping lands; Laos	Web of Science	Asia	Laos	S
42	Roder *et al.* (1997)	Shitting cultivation; Rice; Soil fertility; C-loss	Web of Science	Asia	Laos	S
43	Roder *et al.* (1995)	*Ageratum conyzoides*; *Chromolaena odorata*; Extractable P; Fallow period; *Lygodium flexuosum*; N; Organic matter; Shifting cultivation; Soil fertility; Upland rice	Web of Science	Asia	Laos	S
44	Rumpel *et al.* (2006a)	Tropical sloping land; Erosion; Organic matter; Black carbon	Web of Science	Asia	Laos	S
45	Rumpel *et al.* (2006b)	Tropical soil; Organic matter composition; Black carbon	Web of Science	Asia	Laos	S
46	Sakurai *et al.* (2005)	Northern Laos; Population capacity; Shifting cultivation; Sustainability; Upland rice	Web of Science	Asia	Laos	S
47	Brand and Pfund (1998)	Madagascar; Nutrient balance; Nutrient depletion; Shifting cultivation	Web of Science	Africa	Madagascar	S
48	Styger *et al.* (2009)	Tavy; Succession; Carbon sequestration; Slash-and-burn; Shifting cultivation; Biodiversity	Web of Science	Africa	Madagascar	S
49	Andriesse and Koopmans (1984/1985)	Not listed	Web of Science	Asia	Malaysia	S
50	Hattori *et al.* (2005)	Degraded forest; Mixed dipterocarp forest; Sarawak; Shifting cultivation; Soil characteristics	Web of Science	Asia	Malaysia	S
51	Kendawang *et al.* (2004)	Fire severity; Microbial biomass; C; Sarawak; Shifting cultivation; Soil organic matter	Web of Science	Asia	Malaysia	S
52	Kendawang *et al.* (2005)	Fire severity; Microbial biomass; Sarawak; Shifting cultivation; Soil burning effect	Web of Science	Asia	Malaysia	S
53	Tanaka *et al.* (2004)	Nutrient dynamics; Runoff water; Sarawak; Shifting cultivation; Soil acidity	Web of Science	Asia	Malaysia	S

Table 1. (Continue)

	References	Keyword	Source	Continent	Country	S/U
54	Tanaka *et al.* (2005)	Nutrient dynamics; Runoff water; Sarawak; Shifting cultivation; Soil acidity	Web of Science	Asia	Malaysia	S
55	Neergaard *et al.* (2008)	137Cs; Erosion; Upland rice; Black pepper; Soil carbon; Slash-and-burn; Swidden farming	Web of Science	Asia	Malaysia	S
56	Andriesse and Schelhaas (1987a)	Not listed	Web of Science	Asia	Malaysia; Sri Lanka; Thailand	S
57	Andriesse and Schelhaas (1987b)	Not listed	Web of Science	Asia	Malaysia; Sri Lanka; Thailand	S
58	Ellingson *et al.* (2000)	Deforestation; Fire ecology; Nitrification; Nitrogen mineralization/transformation; Tropical dry forest; Tropical pasture; Slash-and-burn agriculture	Web of Science	North America	Mexico	U
59	Diekmann *et al.* (2007)	Tropical dry forest; Geostatistics; Mexico; Shifting cultivation; Soil nutrients; Spatial heterogeneity	Web of Science	North America	Mexico	S
60	Castellanos *et al.* (2001)	Slash-and-burn; Fine roots; Tropical dry forest; Root biomass; Root productivity; Mexico	Web of Science	North America	Mexico	U
61	Døckersmith *et al.* (1999)	Fire; Nitrogen; Phosphorus; Soil nutrient heterogeneity; Tree effects; Tropical dry forest	Web of Science	North America	Mexico	S
62	Garcia-Oliva *et al.* (1999)	Soil carbon; Nitrogen; Forest burning; Soil aggregates; Pasture	Web of Science	North America	Mexico	S
63	Giardina *et al.* (2000)	Cations; Fire; Nitrogen; Nutrients; Phosphorus; Slash-and-burn; Soil; Tropical forests	Web of Science	North America	Mexico	S
64	Mendoza-Vega and Messing (2005)	Calcareous soils; Land use/land cover; Fallow length; Soil properties; Selva Lacandona	Web of Science	North America	Mexico	S
65	Weisbach *et al.* (2002)	Slash-burn cultivation; Calcareous soil; Milpa; Soil organic matter; Soil variability	Web of Science	North America	Mexico	S
66	Eaton and Lawrence (2009)	Carbon budget; Soil carbon; Biomass carbon; Tropical dry forest; Secondary forest; Shifting cultivation; Yucatán Peninsula; Mexico	Web of Science	North America	Mexico	S

Table 1. (Conclusion)

	References	Keyword	Source	Continent	Country	S/U
67	Are *et al.* (2009)	Slash and burn; Trash; Physical properties; Soil quality; Alfisol	Web of Science	Africa	Nigeria	S
68	Okore *et al.* (2007)	Cropping system; Deforestation; Soil organic matter; Cassava fallow; Particulate organic matter		Africa	Nigeria	S
69	Sillitoe and Shiel (1999)	Soil fertility; Shifting cultivation; Sweet potatoes; Abandoned land; Papua New Guinea	Web of Science	Oceania	Papua New Guinea	S
70	Alegre and Cassel (1996)	Slash-and-burn; Soil physical properties; Agroforestry; Alley cropping	Web of Science	South America	Peru	S
71	Stewart (1994)	*Colocasia esculenta*; Nutrient dynamics; Shifting cultivation; Soil physical properties; Unburnt bush fallow	Web of Science	South Pacific Ocean	Samoa	S
72	Mapa and Kumaragamage (1996)	Kriging; Shifting cultivation; Spatial variability	Web of Science	Asia	Sri Lanka	S
73	Aumtong *et al.* (2009)	Soil carbon; Soil carbon fractions; Carbon storage; Land-use change; Soil use and management; Ultisols; Sloping uplands	Web of Science	Asia	Thailand	S
74	Chidumayo and Kwibisa (2003)	Brachystegia-Julbernardia woodland; Fire; Grass biomass; Soil nutrients; Re-growth; Zambia	Web of Science	Africa	Zambia	S
75	Stromgaard (1988)	Not listed	Web of Science	Africa	Zambia	S
76	Kyuma *et al.* (1985)	Shifting cultivation; Soil fertility; Soil tilth; Effect of burning	Web of Science	Asia	Thailand	S
77	Tulaphitak *et al.* (1985a)	Shifting cultivation; Soil fertility; Soil tilth; Zero-tillage	Web of Science	Asia	Thailand	S
78	Tulaphitak *et al.* (1985b)	Shifting cultivation; Soil fertility; Nutrient balance; Nutrient release from organic matter	Web of Science	Asia	Thailand	S
79	Uhl and Jordan (1984)	Amazon Basin; Disturbance; Forest burning; Nutrient leaching; Plant replacement; Recovery; Secondary succession	Web of Science	South America	Venezuela	S
80	Uhl and Murphy (1981)	Not listed	Web of Science	South America	Venezuela	S

With regard to the types of soils that were researched, the studies can be grouped into five categories according to the FAO and UNESCO (1974) and the North American System (Soil Survey Staff, 1999): Ferric Acrisols (FAO) and Paleudult (Soil Taxonomy System - STS) (52%), Humic or Rhodic Ferrasols (FAO) and Acrohumox/Haplorthox (STS) (28%), Dystric Cambisols (FAO) and Dystrochrept (STS) (13%), Eutric or Humic Nitosols (FAO) and Paleudult (STS) (5%), and Lithosols (FAO) and Hapludoll or Udorthent (2%). The type of soil may determine the number of cultivation cycles and the fallow time that must be applied to the system to maintain the functional quality of the soil (Bruun *et al*., 2009).

The main characteristic of the Ferric Acrisols (FAO) or Paleudult (STS) is the presence of the B texture horizon immediately below the A or E horizon. In addition, this category has low clay activity and aluminum saturation equal to or greater than 50%, and/or saturation by bases of less than 50% in the majority of the B-horizon. This abrupt change in texture or the contrasting texture implies an increase in problems related to erosion, water stores, and the physiology of the plants (R. R. Oliveira, 2008). Boserup (1989) commented that these types of soils are susceptible to degradation under conditions of population increase or technological changes, which could lead to an increase of the crop cycles and/or a decrease of the fallow period.

The Humic or Rhodic Ferrasols (FAO) or Acrohumox/Haplorthox (STS) are soils that display an advanced stage of weathering, with colloidal material with a low cation exchange capacity and low or virtually absent levels of easily weatherable primary minerals. Thus, its nutrient reserves are reduced, which does not prevent them from being productive soils when properly managed (J. B. Oliveira, 2008).

Dystric Cambisols (FAO) or Dystrochrept (STS) consist of mineral material, with an incipient B-horizon underlying any type of surface horizon. These categories are not very deep and have relatively high levels of easily weathered primary minerals, with a clay fraction ranging from medium to high. The Dystric Cambisols (FAO) or Dystrochrept (STS), because they do not contain additions of clay in the B-horizon, are less susceptible to erosion (J. B. Oliveira, 2008).

This review found that the type of soil subjected to shifting cultivation systems does not indicate the tendency toward soil conservation or degradation. However, each soil type exhibits its own inherent characteristics that aid in determining the composition and structure of the plant formations.

As reported by Pedroso-Junior *et al*. (2008, 2009), studies on the impact of shifting cultivation on tropical forest soil may indicate that this impact is either positive or negative, depending on the spatial and temporal scale that is considered. Among the positive impacts that have been indicated, there is an increase in soil fertility after conversion, with an increase of P, Ca, and Mg that indicates that the stocks of these macronutrients are not affected (Brinkmann and Nascimento, 1973; Stromgaard, 1986; Andriesse and Schelhaas, 1987b; Juo and Manu, 1996; Zarin *et al*., 1998; McDonald *et al*., 2002; Johnson *et al*., 2001; Frizano *et al*., 2003; R. R. Oliveira, 2008). There is also a relatively rapid reconstitution (around five years) of the nutrient capture mechanisms of the dead organic matter on the forest floor and in the fine roots after the abandonment of the crop area (R. R. Oliveira, 2008).

Other studies point to negative impacts on soil fertility and an increase in the occurrence of erosion (Ewel *et al*., 1981; Kyuma *et al*., 1985; Andriesse and Schelhaas, 1987a, 1987b; Brand and Pfund, 1998; Nagy and Proctor, 1999; McDonald *et al*., 2002). The destabilization of the nutrient cycles of the soil/plant systems, based on the increase in the number of slash-and-burn and cultivation cycles, has also been presented as a negative impact (Ewel *et al*., 1981; Uhl and Jordan, 1984; Hölscher *et al*., 1997; Garcia-Oliva *et al*., 1999; Gafur *et al*., 2003; Davidson *et al*., 2007). Some authors have identified impacts on the physical properties of the soils that could intensify the resulting leeching process and mainly would result in a decrease in the quantity of organic matter (Tulaphitak *et al*., 1985a, 1985b; Hernani *et al*., 1987; Roder *et al*., 1994; Alegre and Cassel, 1996; Roder *et al*., 1997; McDonald *et al*., 2002; Pereira and Vieira, 2001; Frizano *et al*., 2003; Chidumayo and Kwibisa, 2003). The diversity of the seed bank was another negative aspect related to the use of fire in the conversion phase of shifting cultivation, which could result in a decrease in the biodiversity of these forest ecosystems (Mamede and Araújo, 2008).

Next, the impacts found in the literature review were grouped according to soil properties (physical, chemical, and biological) and according to the SCS component (conversion, cultivation, and fallow).

IMPACTS ON THE PHYSICAL PROPERTIES OF THE SOIL

The main physical properties of the soil that were impacted by shifting cultivation were the following: texture, structure (especially, aggregate stability), bulk density, porosity, color, soil moisture retention, and temperature.

a) Impact of conversion

The conversion phase is related to the opening of an area in which the cultivation will be performed. In this phase, a clearing is opened up, generally within a vegetable mosaic with plants at varied successional stages, to obtain a space for the crop. This opening is commonly cleared with manual tools, and after the trees are felled, fire is used to help clean the area and to increase the productivity of the crop (McGrath, 1987; Kleinman *et al*., 1995). According the studies researched here, the two main causes of the impacts on the physical properties of the soil in the conversion phase were the cutting down of the vegetation and the use of fire to open up the crop area.

Table 2 lists the main impacts on the physical properties in relation to the conversion phase, along with their effects in the soil. It is shown that, for this phase, the majority of the impacts on the physical properties of the soil were negative. With regard to the soil texture, there is a loss of material and a granulometric or grain size modification, the alteration of the fine fraction of the soil, with negative effects on surface runoff and erosion, and the compacting of the topsoil.

The soil structure is also affected, with impacts especially in macroaggregates (> 0,250 mm). These effects go beyond those related to the texture and affect water retention and the capacity to absorb nutrients in the soil. Moreover, these negative impacts in the structure are synergistic with other soil properties: density, macroporosity, humidity, and temperature.

Our review also suggested positive impacts during the conversion phase. Even though the use of fire decreases the amount of organic matter in the soil, the impact on soil structure, with a change in the macroaggregates (< 0,250 mm), may result in an increase of mineral carbon (Black Carbon) and carbonated matter. In addition, after the slash-and-burn of the vegetation, the soil moisture is maintained, which is important in controlling the fire severity, and therefore for the relative decrease of its negative impacts on the physical properties of the soil. This occurs because the latent heat of vaporization prevents soil temperature from exceeding 95 °C until water completely vaporizes, although heat in moist soil is transported faster and penetrates deeper (Campbell *et al*., 1994). After the complete evaporation of water the topsoil may reach temperatures higher than 200-300 °C (Franklin *et al*., 1997).

Soil Organ Carbon (SOC) is a component of the soil properties. SOC influences the physical soil property of structure. The studies reviewed here (Table 2) show that the main impact of the conversion of the forest into a cultivatable area, with regard to SOC, is caused by fire, which leads to the combustion of SOC. This causes a negative impact, mainly on the structure of the soil, which is presented as the main argument to conclude that this type of management is unsustainable.

Table 2. Impacts of the shifting cultivation system on the physical properties of the soil during the conversion phase.

Physical soil properties	Conversion phase			
	Impact	Cause	Effect	References
Texture	Loss of the soil surface layer	Opening of the clearing with exposure of the soil	- Negative: increase in surface runoff; erosion	9; 12; 13; 15; 19; 21; 30; 35; 40; 50; 51; 52; 67; 70; 71
	Alteration of the fine fraction of the soil	Use of fire	- Negative: compaction - Uncertain: changes in the granulometry lead to a decrease in fertility; improved capacity for the absorption of nutrients due to the increase of the Cation Exchange Capacity (CEC)	9; 12; 13; 15; 19; 21; 30; 35; 40; 50; 51;52; 67; 70; 71
Structure	Alteration of macroaggregates	Clearing of vegetation	- Negative: compaction; decrease in the absorption capacity; decrease of soil organic matter; increase in leeching; erosion; change in the water conductivity and the infiltration rate	2; 12; 13; 15; 19; 20; 21; 30; 40; 41; 50; 51; 62; 67; 70; 71
		Use of fire	- Positive: incorporation of carbon and carbonated matter in the humus	
Bulk density	Altered	Clearing of vegetation	- Negative: compaction; decrease of the absorption capacity; decrease of soil organic matter; increase of leeching; erosion; change in water conductivity and the rate of infiltration	3; 9; 13; 15; 16; 21; 30; 40; 50; 51; 58; 63; 67; 70; 71
Color	Altered	Use of fire	- Uncertain: with a density above 600 °C, yet with an unknown effect	13; 15; 30; 34
Moisture	Altered	Clearing of vegetation	- Positive: maintenance of the soil moisture with cleared plants	13; 15; 30; 40; 50; 51; 62; 65; 67; 70; 71
		Use of fire	- Negative: decrease of the humidity of the surface layer, reducing the biological activity and compromising the structure	13; 15; 30; 40; 50; 51; 62; 65; 67; 70; 71
Temperature	Altered	Clearing of vegetation	- Negative: increase in decomposition with a decrease in organic matter	13; 15; 30; 40; 50; 51; 67; 70; 71
		Use of fire	- Negative: changed texture, structure, and biota	13; 15; 30; 40; 50; 51; 67; 70; 71

b) Impacts of cultivation and fallow

Table 3 lists the main impacts, and their respective references, on the physical properties of the soil, with regard to the cultivation and fallow phases. These phases have a common characteristic of plant growth, which allows for soil cover and avoids an accentuated exposure to drying and erosive factors.

However, depending on the number of crop cycles before the beginning of the fallow phase, the impact on the physical properties may be accentuated.

Table 3. Impacts of the shifting cultivation system on the physical properties of the soil in the cultivation and fallow phases.

Physical soil properties	Cultivation and fallow phases			
	Impact	Cause	Effect	References
Texture	Loss of material in the surface layer of the soil	Exposure of the soil in the cultivation cycles and in the beginning of the fallow period	- Negative: increase in surface runoff; erosion	9; 13; 21; 30; 35; 40; 50; 51; 52; 64; 67; 71
	Alteration of the fine fraction of the soil	Exposure of the soil in the cultivation cycles and in the beginning of the fallow period	- Negative: compaction	9; 13; 21; 30; 35; 40; 50; 51; 52; 64; 67; 71
		Growth of the cultivars	- Positive: improved capacity for absorption of the nutrients by the increase in the Cation Exchange Capacity (CEC); recuperation of the fine layer of the soil	9; 13; 21; 30; 35; 40; 50; 51; 52; 64; 67; 71
Structure	Alteration of the macroaggregates	Exposure of the soil in the cultivation cycles and in the beginning of the fallow period	- Negative: compaction; decrease in the absorption capacity; decrease in the soil organic matter; increase in leeching; erosion; alteration in water conductivity and the rate of infiltration	2; 13; 20; 21; 30; 40; 41; 50; 51; 62; 64; 67; 71
		Growth of the cultivars	- Positive: recuperation of the structure of the soil with the progressive increase of the amount of organic matter	2; 13; 20; 21; 30; 40; 41; 50; 51; 62; 64; 67; 71
Bulk density	Altered	Growth of the cultivars	- Positive: gradual recuperation of the initial density prior to the conversion phase	2; 13; 20; 21; 30; 40; 41; 50; 51; 62; 64; 67; 71
Moisture	Altered	Exposure of the soil in the cultivation cycles and in the beginning of the fallow period	- Negative: decrease in soil moisture	13; 30; 40; 50; 51; 62; 64; 65; 67; 71
		Growth of the cultivars	- Positive: plant coverage impedes the exposure of the soil, increasing humidity	13; 30; 40; 50; 51; 62; 64; 65; 67; 71
Temperature	Altered	Exposure of the soil in the cultivation cycles and in the beginning of the fallow period	- Negative: increase in decomposition with the decrease of organic matter	13; 30; 40; 50; 51; 64; 67; 71
		Growth of the cultivars	- Positive: improvement of the texture, structure, and microbial community	13; 30; 40; 50; 51; 64; 67; 71

This impact causes an alteration of the texture and structure of the soil, as a result of the repeated exposure of the soil (Table 3). The deepening of the negative effects is related to the increase of surface runoff and erosion and the decrease of water conductivity and the rate of infiltration, which impedes the subsequent recovery of the soil in the fallow phase and results in its progressive degradation (Table 3).

With regard to the conversion phase, the cultivation and fallow phases decrease the negative impacts on the physical properties of the soil (Table 3). The fallow phase, according to the literature reviewed here, is responsible for the return to the initial soil conditions from before the use of shifting cultivation. The average fallow that allows for the return to initial soil conditions, as found by this review, is ten years

IMPACTS ON THE CHEMICAL PROPERTIES OF THE SOIL

The main chemical properties of the soil that were impacted by shifting cultivation were the following: pH, dynamics of the macro and micronutrients in the soil, cation exchange capacity (CEC), soil organic matter (SOM), and the soil organic carbon (SOC). The organic matter intermediates the nutrient cycling by interfering in its dynamic and influencing the pH and cation exchange capacity (Pedroso-Junior *et al.*, 2008, 2009; Bruun *et al.*, 2009). These impacts are positive in the conversion phase, but in the cultivation phase negatively impact the soil fertility.

a) Impacts of conversion

The chemical properties of the soil are altered after the conversion component of the shifting cultivation system. However, in contrast to the impact on physical properties, the effects on soil chemical properties are mainly positive. Table 4 lists the main impacts of the conversion phase on the soil chemical properties and its main effects in the soil.

These positive effects were expected because the SCS is based on the availability of stored nutrients in the burned biomass, so that the productivity of the cultivation phase does not depend on external resources (Pedroso-Junior *et al.*, 2008, 2009; Bruun *et al.*, 2009). Thus, a considerable portion of the macronutrients stored in the burned biomass (vegetation) becomes available for the cultivation phase, as was shown in the bibliographic survey.

The positive impacts are mainly related to the increase of soil pH due to the increase of basic cations (Mg, Ca, and K). The vast majority of the surveyed studies demonstrated the benefit of this impact that is caused by the absorption of ash by the soil (Table 4). Even with the initial decrease in the organic matter and the volatility of the N, C, and S, the fertility of the soil was markedly increased. Thus, the conversion stage of the SCS is justified because the next phase, cultivation, has soil fertility conditions that are compatible with agricultural activity.

Yet, the impact on the dynamics of macronutrients such as P or K is uncertain. Our review found disagreement over the availability of these elements after the use of fire. However, the studies also demonstrated that, for the subsequent SCS phases, these elements did not compromise the productivity of the crop and the recovery of the initial soil conditions during the fallow phase (Table 4).

The negative impact on the chemical properties of the soil associated with the conversion stage is related to the organic matter and to the SOC due to their vulnerability to fire as a result of the relatively low volatilization temperatures of these elements (Table 4). Depending on the characteristics of the burning, such as the intensity and the frequency of the disturbance, these properties may significantly compromise the resilience capacity and the fertility of the soil (Table 4).

b) Impacts of cultivation

The cultivation component of the SCS has an impact on the soil due to the flow of matter and energy outside the system. Even so, cultivation may result in positive impacts on the soil, provided that the resilience capacity is not exceeded by an increase in the number of cultivation cycles (Pedroso-Junior *et al.*, 2008, 2009; Bruun *et al.*, 2009). Table 5 lists the main SCS impacts on the chemical properties related to the cultivation phase and their effects on the soil. These processes are described below.

Table 4. Impact of the shifting cultivation system on the chemical properties of the soil during the conversion phase.

Chemical soil properties	Conversion phase			
	Impact	Cause	Effect	References
pH	Altered	Clearing of vegetation	- Negative: acidification of the soil due to the increase in the rate of decomposition	3; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 53; 55; 57; 58; 69
		Use of fire with the production of ash	- Positive: alkalinization of the soil, from the ash, with saturation by bases (Mg, Ca, Na, K). This effect improves the other soil properties such as the CEC, the availability of nutrients, and a decrease in the saturation by aluminum	3; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 53; 55; 57; 58; 69
Dynamic of the macronutrients	Volatilization of N, C	Clearing of vegetation	- Negative: in this phase, the area is a source of C emissions into the atmosphere, due to the increase in the rate of decomposition; less availability of N, set with an increase in microbial activity; decrease in soil fertility	2; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 55; 57
		Use of fire	- Negative: volatilization of these elements, which is greater with a greater intensity of fire; decrease in soil fertility	2; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 55; 57
	Saturation of bases (Ca, Mg)	Use of fire	- Positive: availability of the bases beyond the requirement of the crop; effect of the ashes	2; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 55; 57
	Altered availability of P	Use of fire	- Uncertain: studies vary regarding the sufficient and insufficient availability for the cultivation phase	3; 6; 10; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 38; 43; 47; 49; 55; 57; 63
	Altered availability of K	Use of fire	- Uncertain: studies vary regarding the sufficient and insufficient availability for the cultivation phase	3; 6; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 55; 57
Cation Exchange Capacity (CEC)	Altered	Use of fire	- Positive: increase in CEC, increase in electric conductivity; greater availability of bases; increase in soil fertility	2; 12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 50; 55; 57
Organic matter	Altered amount	Clearing of vegetation	- Positive: increase in texture, structure, and microbial community; greater availability of macronutrients with an increase in the amounts	12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 51; 55; 57; 62
		Use of fire	- Negative: decrease in the amount, with significant volatilization of N and C	12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 47; 49; 51; 55; 57; 62
Soil Organic Carbon (SOC)	Altered stock	Clearing of vegetation	- Negative: increased rate of decomposition, with a flow of carbon into the atmosphere	12; 13; 20; 21; 23; 24; 30; 32; 33; 34; 36; 37; 43; 44; 45; 47; 49; 51; 55; 57; 62; 66; 69

At the beginning of the cultivation phase, which coincides with sowing, the soil is exposed. The studies compiled here show that, during this stage, the impacts are negative for the chemical variables of the soil. The negative effects on the pH, the dynamics of the nutrients, the organic matter, and the SOC are related to transitory unavailability. With the growth and development of the crop, these conditions are changed, ensuring agricultural productivity and maintaining the fertility of the soil. However, it is the number of cultivation cycles that determines the degree of the negative impacts. The effect may be the loss of the soil resilience, leading to the unsustainability of the shifting cultivation system, as shown in many of the reviewed studies (Table 5).

Table 5. Impacts of the shifting cultivation system on the chemical properties of the soil during the cultivation phase.

(Continue)

Chemical soil properties	Cultivation phase			
	Impact	Cause	Effect	References
pH	Altered	Exposure of the soil during the beginning of the phase	- Negative: superficial runoff and leeching modifying the pH of the soil with a loss of bases	3; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 53; 55; 69
		Growth of cultivars	- Positive: upkeep of the pH in the soil changed by the ash, favoring the availability of nutrients. Throughout the cultivation period, the pH returns to its original, more acidic condition. This favors the availability of nutrients	3; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 53; 55; 69
		Number of cultivation cycles	- Negative: the greater number of cycles decreases the amount of bases, acidifying the soil and compromising fertility	3; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 53; 55; 69
Dynamic of macro- and micronutrients	Alteration of the amount of nutrients	Exposure of the soil in the beginning of the phase	- Negative: decrease in the amount of macronutrients through surface runoff, leeching, and erosion	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55
		Growth of cultivars	Positive: coverage of soil by vegetation decreases the loss of nutrients; progressive increase of organic matter with an increase in the availability of the nutrients	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55
			- Negative: a greater number of cultivation cycles, decreasing the concentration of nutrients to levels which impede cultivation	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55
		Number of cultivation cycles	- Negative: the greater number of cycles decreases the concentration of nutrients, compromising the fertility of the soil	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55

Table 5. (Conclusion)

Chemical soil properties	Cultivation phase			
	Impact	Cause	Effect	References
Cation Exchange Capacity (CEC)	Altered	Exposure of the soil in the beginning of the phase	- Negative: decrease of the CEC due to surface runoff, leeching, and erosion	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 50; 55; 64
		Growth of the cultivars	- Positive: increase in the CEC, increase in electric conductivity; greater availability of bases; an increase in soil fertility	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 50; 55; 64
		Number of cultivation cycles	- Negative: the greater number of cycles decreases the concentration of the bases, compromising the soil fertility	2; 12; 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 50; 55; 64
Organic matter	Altered amount	Exposure of the soil in the beginning of the phase	- Negative: a decrease in the amount of organic matter with a temporary compromise of the availability of the nutrients and soil fertility	12: 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55; 64; 68; 69; 72
		Growth of cropping	- Positive: an increase in the amount, increasing overall fertility conditions. With the increase in the number of cycles this parameter is not greatly affected, as management maintains humus in the crop	12: 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55; 64; 68; 69; 72
		Number of cultivation cycles	- Negative: the greater number of cycles decreases the amount of organic matter, compromising the fertility of the soil	12: 13; 20; 21; 23; 24; 30; 33; 34; 43; 47; 55; 64; 68; 69; 72
Soil Organic Carbon (SOC)	Altered stock	Exposure of the soil in the beginning of the phase	- Negative: increased rate of decomposition, with a flow of carbon into the atmosphere	12; 13; 20; 21; 23; 24; 30; 33; 34; 42; 43; 44; 45; 47; 55; 66; 69

c) Impacts of fallow

The fallow component of the SCS represents the reestablishment of the initial conditions of the forest ecosystem prior to crop management. This ecosystem recuperation is caused by the natural ecological processes related to ecological succession. The more relevant matter in this phase is the period of time for which the ground is left to rest. Table 6 contains the main impacts identified in this review in relation to the chemical properties related to the fallow phase and their effects on the soil. These processes are described below.

The negative impacts are limited to the beginning of the fallow phase. With the progress of ecological succession, the variables that compose the chemical properties of the soil change (e.g., become less acidic). These changes lead to positive effects that reestablish the initial fertility of the soil. Thus, the fallow period would only result in negative impacts on the soil system, compromising its resilience, with an inadequate rest period. A period of ten years is considered to be the minimum to avoid soil degradation. Recovery also depends on the ratio of cropping period to fallow, that describes the relative ability of an agroecosystem to maintain soil conditions over the long term. A review by Kleinman *et al*. (1995) shows ratios ranging from 1:3 (Nye and Greenland, 1960) to 1:9 (Zinke *et al*., 1978). Moreover, data compiled in this review demonstrate that the longest periods of close to 25 years not only allow the recovery of soil fertility but also the recovery of SOC accumulated under natural conditions, which had been emitted into the atmosphere during the agricultural activity (Table 6).

Table 6. Impacts of the shifting cultivation system on the chemical properties of the soil during the fallow phase.

(Continue)

Chemical soil properties	Fallow phase			
	Impact	Cause	Effect	References
pH	Altered	Exposure of the soil during the beginning of the phase	- Negative: surface runoff and leeching modify the pH of the soil with a loss of bases	17; 53; 54; 65; 69
		Ecological succession	- Positive: gradual change of the pH during the evolution of the successional stages towards the initial condition before the entire cycle	17; 53; 54; 65; 69
		Fallow period	- Negative: period less than the recuperation of the initial soil conditions, prior to the agricultural cycle. A period of less than ten years - Positive: period more than the recuperation of the initial soil conditions, prior to the agricultural cycle. A period of more than ten years	17; 53; 54; 65; 69
Dynamic of macronutrients	Alteration of the amount of nutrients	Exposure of the soil during the beginning of the phase	- Negative: decrease of the amount of macronutrients due to surface runoff, leeching, and erosion	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 42; 46; 47; 54; 55; 68
		Ecological succession	- Positive: soil covered by vegetation decreases the loss of nutrients; progressive increase of the organic matter with an increase in the availability of the nutrients	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 42; 46; 47; 54; 55; 68
		Fallow period	- Negative: shorter period impedes the recuperation of the fertility conditions of the soil prior to the use of agriculture - Positive: longer period allows for recovery of the fertility conditions of the soil prior to the use of agriculture	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 42; 46; 47; 54; 55; 68

Table 6. (Continue)

Chemical soil properties	Fallow phase			
	Impact	Cause	Effect	References
Cation Exchange Capacity (CEC)	Altered	Exposure of the soil during the beginning of the phase	- Negative: decrease of the CEC due to surface runoff, leeching, and erosion	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 42; 46; 47; 50; 54; 55; 64; 65
		Ecological succession	- Positive: increase in the CEC, increase in electric conductivity; greater availability of bases; increase in soil fertility	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 42; 46; 47; 50; 54; 55; 64; 65
		Fallow period	- Positive: longer period allows for an increase in the CEC; an increase in electric conductivity; greater availability of bases; an increase in soil fertility; - Negative: shorter period impedes the reestablishment of the concentration of bases, compromising the soil fertility	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 42; 46; 47; 50; 54; 55; 64; 65
Organic matter	Altered amount	Exposure of the soil during the beginning of the phase	- Negative: decrease in the amount of organic matter with temporary compromising of the availability of the nutrients and fertility of the soil	3; 7;12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 40; 42; 46; 47; 54; 55; 64; 65; 68; 69; 72
		Ecological succession	- Positive: with the succession of the stages, a greater accumulation of organic matter, increasing the overall fertility conditions Variable considered fundamental as an indicator of soil fertility	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 40; 42; 46; 47; 54; 55; 64; 65; 68; 69; 72
		Fallow period	- Negative: less time impedes the formation of humus, compromising soil fertility - Positive: longer time allows for the formation of humus, improving the physical, chemical, and biological properties of the soil	3; 7; 12; 13; 17; 20; 21; 24; 26 ;27; 28; 30; 31; 33; 34; 40; 42; 46; 47; 54; 55; 64 ;65; 68; 69; 72

Table 6. (Conclusion)

Chemical soil properties	Fallow phase			
	Impact	Cause	Effect	References
Soil Organic Carbon (SOC)	Altered stock	Exposure of the soil during the beginning of the phase	- Negative: increased rate of decomposition, with a flow of carbon into the atmosphere	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 40; 42; 44; 45; 46; 47; 54; 55; 65; 66; 69
		Ecological succession	- Positive: increase in the stock of C in the biomass above the soil with the evolution of the stages; increases the composting organic matter and, consequently, the entrance of carbon into the SOC stock	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33 ;34; 40; 42; 44; 45; 46; 47; 54; 55; 65; 66; 69
		Fallow period	- Negative: the stock of SOC is positively altered with the decrease in the growth rate of the biomass above the soil, as in the late successional stages. Shorter fallow time does not allow for the entrance of new C into the SOC. The system begins to emit C into the atmosphere	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 40; 42; 44; 45; 46; 47; 54; 55; 65; 66; 69
			- Positive: the stock of SOC is positively altered with the decrease in the growth rate of the biomass above the soil, as in the late successional stages. A longer fallow time allows for the entrance of new C into the SOC. The system begins to capture C from the atmosphere	3; 7; 12; 13; 17; 20; 21; 24; 26; 27; 28; 30; 31; 33; 34; 40; 42; 44; 45; 46; 47; 54; 55; 65; 66; 69

IMPACTS ON THE BIOLOGICAL PROPERTIES OF THE SOIL

The main biological properties of the soil found to be impacted by SCS are the following: the microfauna (mainly the bacterial community), the macrofauna, and the seed bank. Table 7 outlines the main impacts of shifting cultivation over the biological properties for the three phases and their effects in the soil. These processes are described below.

a) Impacts of conversion and cultivation

Only 17.5% of the studies we reviewed investigated the biological properties of the soil (Table 7). Even so, these properties were found to be fundamental to conserving the resilience capacity of soils under the SCS.

The biological properties of the soil are negatively impacted by the action of fire and by repetitions of the cultivation cycles. The reduction of the amount of organic matter, caused by the use of fire, influences the structure, composition, and diversity of the biota (micro-, meso-, and macrofauna) of the soil (Table 7).

The exposure of the soil increases its temperature by promoting an increase in desiccation which diminished the activity of micro-, meso- and macrofauna. However, this elevation in the temperature increases the rate of decomposition, consequently raising fauna's biomass.

Nevertheless, after the use of fire fauna biomass and diversity decrease, compromising soil fertility via a reduction on the mineralization of nutrients. In summary, the number of cultivation cycles impacts soil fauna biomass negatively, leading to a decrease in the nutrient recycling activity rate (Table 7).

Table 7. Impacts of the shifting cultivation system on the biological properties of the soil in the conversion, cultivation, and fallow phases.

(Continue)

Biological soil properties	Conversion, cultivation, and fallow phases			
	Impact	Cause	Effect	References
Microfauna	Alteration of biomass and diversity	Exposure of the soil	- Negative: increase in temperature and drying of the soil decrease the activity of microfauna	2; 3; 21; 49; 52; 60; 62; 68
			- Positive: increase in the temperature of the soil, increase in the rate of decomposition, with an increase of the biomass of the microfauna	2; 3; 21; 49; 52; 60; 62; 68
		Use of fire	- Negative: decrease of the biomass and diversity of the microfauna, compromising soil fertility, with a reduction of the mineralization of the nutrients	2; 3; 21; 49; 52; 60; 62; 68
		Number of cultivation cycles	- Negative: reduction of the fertility conditions of the soil affects the biomass and diversity of the microfauna. The recycling function decreases the activity rate	2; 3; 21; 49; 52; 60; 62; 68
		Fallow period	- Positive: the ecological succession increases the amount of organic matter in the soil, increasing the rate of microfauna activities, increasing its biomass and diversity	2; 3; 21; 49; 52; 60; 62; 68
Macrofauna	Alteration of biomass and diversity	Exposure of the soil	- Negative: increase in the temperature and drying of the soil decrease macrofauna activity	16; 25; 29; 30
			- Positive: increase in the temperature of the soil; increase in the rate of decomposition, with an increase in the biomass of macrofauna	16; 25; 29; 30
		Use of fire	- Negative: decrease in the biomass and diversity of the macrofauna, compromising soil fertility, with a reduction of the mineralization of the nutrients	16; 25; 29; 30
		Number of cultivation cycles	- Negative: reduction of the fertility conditions of the soil affects the biomass and diversity of the macrofauna. The recycling function reduces the activity rate	16; 25; 29; 30
		Fallow period	- Positive: the ecological succession increases the amount of soil organic matter, increasing the rate of macrofauna activity, increasing its biomass and diversity	16; 25; 29; 30

Table 7. (Conclusion)

Biological soil properties	Conversion, cultivation, and fallow phases			
	Impact	Cause	Effect	References
Seed bank	Alteration of density and diversity	Exposure of the soil	- Positive: the possibility of the entrance of seedlings and the germination of seeds with phototropism	4; 23
		Use of fire	- Negative: reduction of seed density and diversity, mainly of the herbaceous group	4; 23
		Number of cultivation cycles	- Negative: reduction of seed density and diversity, mainly of the herbaceous group	4; 23
		Fallow period	- Positive: possibility of germination of the seed bank and the entrance of seedlings, favoring the evolution of the ecological succession. With this, the reestablishment of the initial soil conditions is favored	4; 23

The seed bank is also strongly impacted by fire, which was highlighted as an important aspect in some studies, due to the effect that it has over ecological succession (Table 7). The loss of the diversity and density of seeds facilitates the emergence of invasive species and compromises the resilience capacity of the soil.

b) Impacts of fallow

The impacts of fallow on soil biological properties were considered positive for the studies reviewed. The ecological succession increases the amount of organic matter in the soil, increasing the rate of fauna activity, and its biomass and diversity (Table 7).

The fallow phase makes possible the germination of the seed bank and the entrance of seedlings, favoring the evolution of the ecological succession. With this, the reestablishment of the initial soil conditions is favored (Table 7).

INDICATORS FOR THE EVALUATION OF SOIL CONDITIONS UNDER SHIFTING CULTIVATION SYSTEMS

The studies that have been reviewed in this article (Table 1) show that, under SCS, the soil properties of tropical forests vary from the moment an area is opened up for planting (conversion) to the end of a cultivation and fallow cycle. The direction, magnitude, and duration of these changes may be used to monitor the impacts of this agricultural system on the soil.

The monitoring of the dynamics of soils properties under different land uses has been performed with the assistance of model projections and quantitative indicators (Larson and Pierce, 1991; Andrews and Carroll, 2001; Yemefack *et al*., 2006a, 2006b). The model proposed by Yemefack *et al*. (2006b) used the concept of a minimum data set (MDS) to evaluate the quality of the soil under SCS. In this model, the soil property variables most affected by shifting cultivation practices, and which composed the MDS, were the following: pH measured in water, exchangeable Ca, available P, density, and SOC.

Another way to evaluate the quality, status, and productivity potential of the soils under agricultural systems is through the use of the soil quality index (SQI). Andrews and Carroll (2001) constructed an index that integrated the physical, chemical, and biological attributes of the soil to evaluate its functional capacity. In this index, the authors applied concepts of soil ecology to evaluate the sustainability of soil management by combining a variety of information for multi-objective analysis.

The selection of the attributes that are appropriate to be included in a soil quality index (SQI) should take into consideration the functions of the soil as well as the objectives of agricultural use (Andrews and Carroll, 2001). A SQI to evaluate the sustainability of SCS, for example, should consider the characteristics of this type of management as well as the functions performed by the soil. Yet, there are limitations for the application of these indices. First, the indices are always site-specific and, therefore, difficult to extrapolate to other locations. Second, the development of a SQI requires specialists to select soil attributes relevant to its composition[1].

Considering the proposals of Yemefack *et al*. (2006b) and Andrews and Carroll (2001), we sought to verify whether the variables suggested by these authors for the evaluation of the impact of the SCS over tropical soils agree with those found in the reviewed literature. Based on common variables and including others suggested in the literature, we sought to propose qualitative indicators for evaluating the impact of SCS on the soil. These qualitative indicators were selected with the objective of allowing for monitoring the degradation or conservation of soils in SCS. In addition, an attempt has been made to contribute to the construction of future indicators based on quantitative analysis, which seeks to improve the management conditions of the system to make them more sustainable.

The physical properties impacted by shifting cultivation systems that were common to the majority of the studies reviewed were the following: texture (variables: surface layer and fine layer of the soil), structure (macroaggregates), and density. The most widely cited causes of these impacts were the use of fire and the exposure of the soil.

The chemical properties most commonly impacted by SCS were the following: pH, dynamics of the macronutrients (variables: total N, total S, available P and K, and the concentration of bases), cation exchange capacity, organic matter, and SOC. The most frequent causes of these impacts were the use of fire, the exposure of the soil, the number of cultivation cycles, and the fallow period.

The biological properties most commonly impacted by SCS were the following: the microfauna (variables: biomass and diversity), the macrofauna (variables: biomass and diversity), and the seed bank (density and diversity). The most frequently cited causes of these impacts were the use of fire, the exposure of the soil, and the fallow time.

The variables relevant to the soil properties common to the formation of the various SQI and MDS identified from another review article on the construction of soil quality models and indicators subjected to agricultural management are shown in Table 8, which was adapted from Andrews and Carroll (2001).

The suggested indicators were divided into physical, chemical, and biological and are shown in Table 9. For each class of indicators, the impact of each one of the three components of the SCS (conversion, cultivation, and fallow) are presented, along with the effect on the degradation (D) or conservation (C) of soil quality.

Thus, the soil quality may display a conservation tendency when, for example, the indicator has returned to the initial conditions or to conditions similar to those from the beginning of agricultural production (C). When the variable displays a result different from its result prior to agricultural production (altered condition), this would indicate a tendency of degradation of the soil quality (D).

As an example, we can cite organic matter as a chemical indicator, including the amount of organic matter modified by agricultural production, with specific concentrations for each phase. During conversion, the amount of organic matter is reduced, but it is recovered in the next phases.

[1] To circumvent the first problem and allow for the extrapolation and the use of these indices in different management and soil conditions, a statistical method could be used in the construction of an SQI or an MDS. The quantitative multi-criteria statistical method created by Yemefack *et al*. (2006b), for example, makes it possible to define variables relevant to the properties of the soil which will form the quality index, allowing it to be used in different environmental and management conditions.

Table 8. Relevant variables of soil properties, common to the formation of various Minimum Data Set (MDS) and Soil Quality Index (SQI) presented in the literature, adapted from Andrews and Carroll (2001).

Variable	Soil property	References
Moisture	Physical	Doran and Parkin (1996); Lowery *et al.* (1996)
Bulk density	Physical	Larson and Pierce (1991); Doran and Parkin (1996); Arshad *et al.* (1996); Karlen *et al.* (1996)
Macroaggregates	Structure/Physical	Harris *et al.* (1996); Arshad *et al.* (1996); Karlen *et al*. (1996)
pH	Chemical	Larson and Pierce (1991); Doran and Parkin (1996); Elliot *et al.* (1994); Sikora and Stott (1996); Andrews and Carroll (2001); Paniagua *et al.* (1999); Yemefack *et al*. (2006a, 2006b)
Total N Available P and K Exchangeable Ca	Dynamics of macronutrients/ Chemical	Larson and Pierce (1991); Doran and Parkin (1996); Elliot *et al*. (1994); Sikora and Stott (1996); Andrews and Carroll (2001); Paniagua *et al*. (1999); Yemefack *et al*. (2006a, 2006b)
CTC	Chemical	Larson and Pierce (1991); Doran and Parkin (1996); Elliot *et al*. (1994); Sikora and Stott (1996); Andrews and Carroll (2001); Paniagua *et al*. (1999); Yemefack *et al*. (2006a, 2006b)
Organic matter	Chemical	Larson and Pierce (1991); Doran and Parkin (1996); Elliot *et al*. (1994); Sikora and Stott (1996); Andrews and Carroll (2001); Paniagua *et al*. (1999); Yemefack *et al*. (2006a, 2006b)
Soil Organic Carbon (SOC)	Chemical	Larson and Pierce (1991); Doran and Parkin (1996); Elliot *et al*. (1994); Sikora and Stott (1996); Andrews and Carroll (2001); Paniagua *et al*. (1999); Yemefack *et al*. (2006a, 2006b)
Microbiota biomass	Biological	Andrews and Carroll (2001); Paniagua *et al*. (1999)

Table 9. Physical, chemical, and biological indicators and their impact on the soil, with the related tendencies of soil degradation and conservation. Legends: C = tendency of conservation; D = tendency of degradation.

(Continue)

Physical indicators				
Variable	Impacts			Final tendency
	Conversion	Cultivation	Fallow	
Surface layer of the soil	Loss of matter	Loss of matter	Recovery	(-) loss = C (+) loss = D
Fine layer of the soil	Granulometric change	Granulometric change	Granulometric recovery	Initial condition = C Altered condition = D
Moisture	Loss	Recovery	Stabilization	Initial condition = C Altered condition = D
Bulk density	Increase	Increase	Recovery	Initial condition = C Altered condition = D
Macroaggregates	Destruction	Recovery	Stabilization	Initial condition = C Altered condition = D

Table 9. (Conclusion)

Chemical indicators				
Variable	Impacts			Final tendency
	Conversion	Cultivation	Fallow	
pH	Increase	Relative decrease	Return to initial condition	Initial condition = C Altered condition = D
Total N	Greater concentration	Stable concentration	Return to initial concentration	Initial concentration = C Altered concentration = D
Available P	Greater concentration	Decreased concentration	Return to initial concentration	Initial concentration = C Altered concentration = D
Available K	Greater concentration	Decreased concentration	Return to initial concentration	Initial concentration = C Altered concentration = D
Exchangeable Ca	Greater concentration	Decreased concentration	Return to initial concentration	Initial concentration = C Altered concentration = D
Cation Exchange Capacity (CEC)	Greater	Decrease	Return to initial CEC	Initial condition = C Altered condition = D
Organic matter	Lower amount	Relative increase	Recovery	Initial amount = C Altered amount = D
Soil Organic Carbon (SOC)	Lower amount	Relative increase	Recovery	Capture of CO_2 = C Emission of CO_2 = D
Biological indicators				
Variable	Impact			Final tendency
	Conversion	Cultivation	Fallow	
Microfauna biomass	Decrease	Increase	Recovery	Initial condition = C Altered condition = D
Microfauna diversity	Decrease	Increase	Recovery	Initial condition = C Altered condition = D
Macrofauna biomass	Decrease	Increase	Recovery	Initial condition = C Altered condition = D
Macrofauna diversity	Decrease	Increase	Recovery	Initial condition = C Altered condition = D
Density of seed bank	Decrease	Increase	Recovery	Initial condition = C Altered condition = D
Diversity of seed bank	Decrease	Increase	Recovery	Initial condition = C Altered condition = D

Yet, if at the end of the fallow phase, the amount of organic matter is greatly changed in relation to the period before conversion, this result indicates that the quality of this soil displays a degradation tendency. If the results were similar to the initial conditions, the soil quality would display a conservation tendency (Tables 4, 5, 6, and 9).

CONCLUSIONS: ARE SHIFTING CULTIVATION SYSTEMS SUSTAINABLE?

The most relevant result of this review is the relative homogeneity of the impact that SCS have on tropical soils. In other words, the impacts of SCS do not vary considerably in relation to the different locations, biomes, and types of soil researched in the reviewed studies.

The vast majority of the reviewed studies, 90% (Table 1), conclude that SCS does not compromise soil quality. Therefore, with respect to soils, the SCS would be a sustainable agricultural system, adapted to the ecological conditions of the tropical forests where this system is practiced, provided that a sufficiently long fallow period facilitates recovery.

The negative impacts on the soil are restricted to the conversion and cultivation phases. Depending on the management conditions and on the intensity of the disturbances in the forest ecosystem (mainly the number of cultivation cycles before the fallow period), these impacts may increase the level of soil degradation. Thus, the soils could lose their resilience capacity that is mainly ensured by an adequate fallow period.

The main causes of the negative impacts on the soils subjected to shifting agriculture were also common to the majority of the reviewed studies. The use of fire and the exposure of the soil during the agricultural production phases are the most commonly reported causes of the negative impacts. The effects of the negative impacts were also similar in that they affected variables related to the three types of soil properties (physical, chemical, and biological).

The positive effects on the soils were mainly related to the fallow component of the system and were common to the majority of the reviewed studies. These positive effects occurred because the fallow phase mimics the ecological processes of the forest ecosystems. It does so because it uses the natural mechanisms of the ecological succession of the forests to reestablish the initial conditions of the soil before the productive activity.

Therefore, we conclude that the reviewed studies did not consider SCS to be unsustainable *per se* in relation to the soil system dynamics. The causes that may lead to the unsustainability of the SCS are related to the social, economic, political, and cultural changes that affect the communities that subsist on this agricultural practice (Mertz, 2002; Van Vliet *et al*., 2012). These changes may cause an increase in the number of cultivation cycles and/or decrease the fallow time and cause the resilience capacity of the soils to be surpassed.

Finally, we believe that the construction of indicators allows for the development of models that may facilitate the monitoring of soil quality in the different phases of the SCS. Future research should also focus on the creation of indicators based on practical criteria, allowing shifting cultivators to use them.

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