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Slash-and-burn agriculture in southern Brazil: characteristics, food production and prospects

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ABSTRACT

There is a shortage of studies about slash-and-burn in well-established agricultural systems and its importance for improving food production and enhancing biodiversity and agricultural diversity in the tropics and sub-tropics. A long and important tradition of slash-and-burn in black bean (*Phaseolus vulgaris* L.) production persists in the Prudentópolis municipality in southern Brazil. This agricultural system is practised over hilly terrain with shallow soil. In addition, mountainous areas prevent agricultural modernization, ensuring the persistence of this farming technique. Using an official dataset of bean production and semi-structured interviews with farmers and agricultural experts, the paper investigates slash-and-burn characteristics in a consolidated agricultural region and assesses the prospects for its persistence. The slash-and-burn system, intended mainly for bean crops, corresponds to 30% of the total bean yield in Prudentópolis. Slash-and-burn agriculture has a vital role to play for local food production and a sustainable eco-system. Therefore, a demographic and land-use transition might be experienced in this region and in similar regions in the tropics, with social and environmental implications for food production, land use dynamics and rural migration and development.

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Subsistence agriculture; food security; rural changes; population ageing; rural development

1. Introduction

Agricultural modernization has not occurred equally worldwide, with the slash-and-burn agricultural system persisting in the tropical world (Adams et al., 2012; Fujisaka et al., 1996; Mukul & Herbohn, 2016). Slash-and-burn, alternatively known as shifting cultivation or swidden, is an agricultural system where farms and their existing vegetation are cut down and burned off, and subsequently, the land is used for the cultivation of agricultural crops. Generally, the fallow period is much longer than the cropping phase (Hauchhum & Tripathi, 2020; Lintemani et al., 2019;

Nair, 1993; Silva-Forsberg & Fearnside, 1997; Wapongnungsang & Tripathi, 2018). This strategy takes advantage of the post-fire ash-enriched nutrient bed and the fact

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that weeds are reduced by the slash-and-burn system (Giardina et al., 2000; Juo & Manu, 1996; Nye & Greenland, 1964). Some studies also highlight the possible unsustainability of this agricultural practice (Gafur et al., 2003; Juo & Manu, 1996). Therefore, land use intensification and more profitable cash cropping are proposed in order to replace slash-and-burn with a more rational agricultural system (Alepa & Rajashekhar, 2016; Brady, 1996; Grogan et al., 2012). However, land use intensification, specially, for cash cropping, can lead to soil degradation (Cho & Zoebisch, 2003).

Agricultural production from the slash-and-burn system is assumed to be considered as subsistence farming for a smallholder family (Silva-Forsberg & Fearnside, 1997; Mertz et al., 2009). About 795 million people are undernourished globally and enhancing the productivity and incomes of smallholder family farmers is key to progress (McGuire, 2015). However, in 1957, the Food and Agriculture Organization of the United Nations (FAO) stated, 'shifting cultivation in the humid tropical countries is the greatest obstacle to the immediate increase of agricultural production as well as soil and forest conservation' (Nye & Greenland, 1964; Grogan et al., 2012). Nevertheless, half a century later, slash-and-burn agriculture is being practised widely (Devendra & Thomas, 2002; Mukul & Herbohn, 2016; van Vliet et al., 2012). In short, slash-and-burn is a key system coupled to rural development in the tropics and subtropics.

Thomaz et al. (2014) showed the positive effects of fire and soil quality on two small properties in the Terra Cortada community. In addition, the slash-and-burn dynamics in the region have been studied with respect to fallow length and soil proprieties, fire effects on soil physicochemical properties, and post-fire soil erosion (Thomaz, 2009; 2013). These studies have provided a background for characterizing the system at the plot level. However, it is critical now to think beyond the plot level characteristics and the soil system dynamics affected by fire. It is necessary to understand the persistence of the slash-and-burn agricultural system and its role on food production in areas with well-consolidated farming systems, i.e. the prospect of this system coexisting with modern agricultural practices. Most current studies focus on investigating shifting cultivation dynamics with respect to the modern agricultural frontier (Aragão & Shimabukuro, 2010; van Vliet et al., 2012; Salisbury & Schmink, 2007). However, only a few studies have pointed out the current consequences of slash-and-burn systems on local livelihoods and rural development (N. Van Vliet et al., 2013), with its role in food production largely ignored.

The slash-and-burn technique contributes to biodiversity conservation (Padoch & Pinedo-Vasquez, 2010) and preservation of diversity of cultivated varieties (Peroni & Hanazaki, 2002). Moreover, well-balanced (e.g. fallow period) swidden cultivation can maintain hill slope hydrology, functionally decreasing soil erosion and conserving superficial water quality (Ziegler et al., 2009).

In certain conditions, it is a type of conservationist agricultural system, which is also productive and sustainable (Ziegler et al., 2011). Furthermore, it is possible that in some localities of southern Brazil the system produces more than a small household needs to survive, meaning that in some cases there can be a surplus.

However, food production in the slash-and-burn agricultural system needs greater recognition. The Prudentópolis municipality was selected because it is an important area of black bean production (IPARDES, 2010), with most of the smallholders producing black beans (*Phaseolus vulgaris* L.) and a large part of the bean yield coming from local slash-and-burn agriculture.

In this study, slash-and-burn is practised within the private property limit, restricted only to the secondary forest in the early regeneration stage because of the short fallow period of ~5 years. Therefore, mature forest and agriculture frontier expansion are not involved in the present study. In addition, in this process, farmers organize their property in plots (~1–2 ha) with different stages of forest regeneration. Thus, annually a plot is slashed and burned, and cropped with black bean and maize. The rotation cycle is completed in approximately five years (Thomaz, 2009). The aim of this study is to characterize the slash-and-burn in a consolidated agricultural region, and to assess the key prospects for its persistence and the land use implications of its demise.

2. Study area

The Prudentópolis municipality is in Paraná state in the southern part of Brazil (25°12′47″ S, 50°58′40″ W, Figure 1). The municipality has an area of 2242.46 km^2, and the average terrain altitude is 840 m.a.s.l. The total population of Prudentópolis is 49,150, 46% of which is urban and the remaining 54% is rural (IPARDES, 2010).

Prudentópolis is located at the transition between the second and the third Paranaense plateaus, which is limited to the west by the Serra da Esperança Escarpment (Cuesta). Terrains near the escarpment (Figure 4) have slopes between 11° and over 25°, covered predominantly with shallow soils (e.g. Leptosols and Cambisols) (FAO, 2006). The front of the escarpment is also divided by fluvial erosion owing to a rich drainage network that develops deep V-valleys and isolates mounts, and tabular relief from the rest of the escarpment, because of parallel retreat. This mountainous area is composed of upland mesas, mounds, and lined hills formed by diabase dikes and sills (Mineropar, 2006).

The diabase intrusions are locally higher (100–300 m) than the hills, and are composed of sedimentary rocks (e.g. red siltstones and mudstones with intercalated fine textured sandstones, mudstones, and shales). This land formation arises from differential erosion. While erosion causes the lowering of the surrounding sedimentary rocks, the diabase remains exposed because of its greater resistance to erosion. In the diabase landforms, the slopes are steep (~25°) and the soils are shallow (Leptosols) and moderately deep (Cambisols)—deeper on gentle slopes (Nitisols). Overall, the slash-and-burn agricultural system is practiced over this hilly terrain (Figure 4).

The area has a mesothermal humid sub-tropical climate with a cool summer and no dry season (Type Cfb oceanic climate, with summer wetter than winter, abundant rains, well distributed throughout the year, and relatively cool and moist summer). The average temperature in the coldest month is below 18°C and the average temperature in the warmest month is below 22°C. The annual average precipitation ranges from 1600 to 1800mm (Caviglione et al., 2000). The soils are shallow (Leptosols) on steep slopes (11° to >25° inclination) and moderately deep (Cambisols) on moderate slopes (~14° inclination).

Agriculture is the most important economic activity in the Prudentópolis municipality, and more than half of the population lives in the countryside, resulting in diverse rural landscapes. The varied agricultural landscapes include commercial agriculture (i.e. mechanized), reforested areas, forests, and so called Faxinal systems associated with slash-and-burn agriculture.

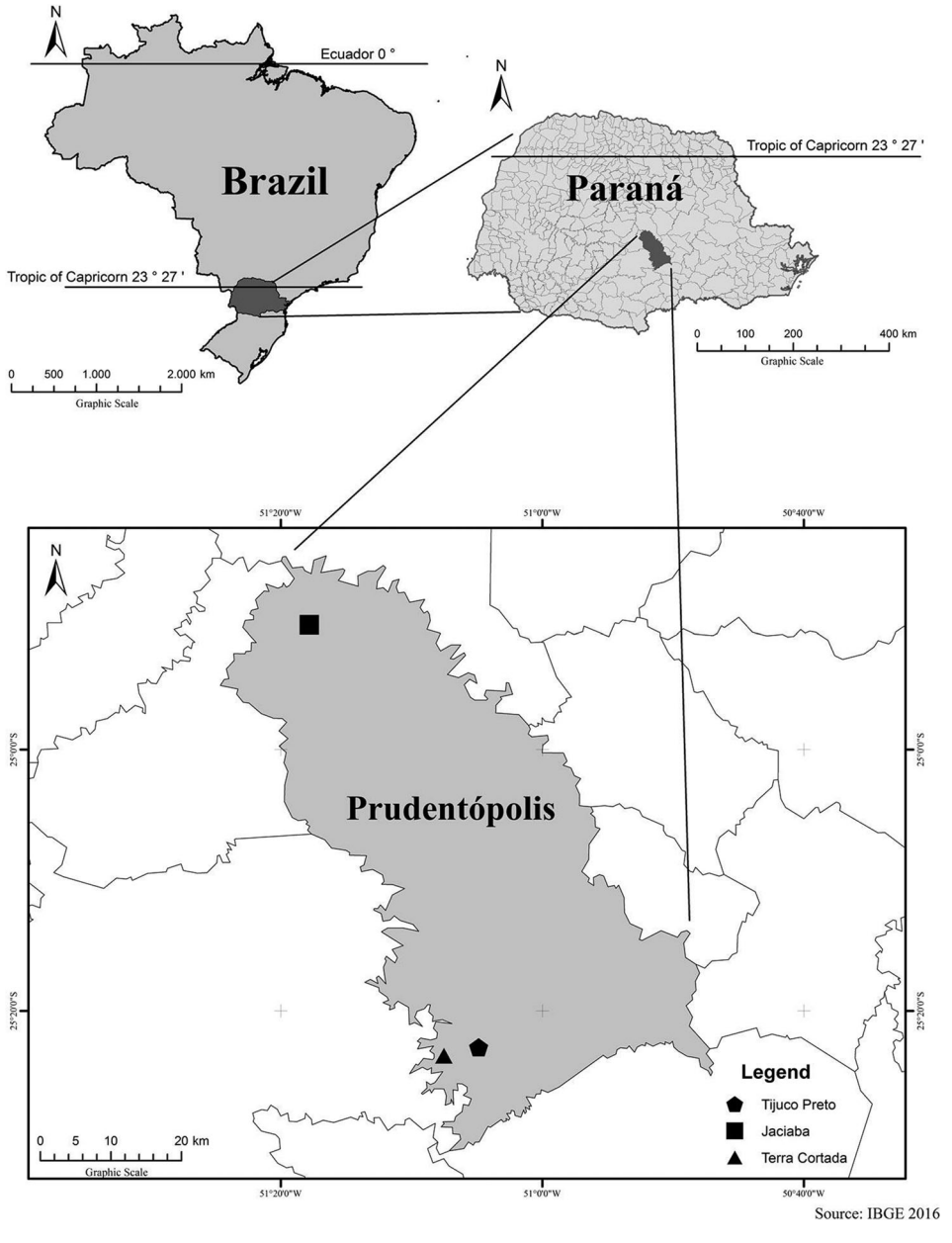

Figure 1. Study area showing the location of rural communities.

The Faxinal system is based on the integration of three components: a) communal livestock production, b) subsistence agricultural production (e.g. maize, beans, rice, and potatoes), and c) low-impact forest extraction (Chang, 1988). Therefore, the Prudentópolis municipality is truly a land mosaic owing to land use diversity and landscape fragmentation.

3. Methods

A three-level survey was performed and the findings from the different phases were triangulated. At the first level, we analysed an official government dataset series from IBGE (Brazilian Institute of Geography and Statistics) of bean total production (tons or kg) and productivity (production per area, e.g. kg ha^{-1}) from 1947 to 2010 for Paraná State and from 1980 to 2010 for Prudentópolis municipality. In addition, we analysed other documents related to the Prudentópolis municipality economy, such as demographic and rural economic census. This analysis was used as a background to choose Prudentópolis as the case study and perform subsequent surveys.

At the second level, we performed semi-structured interviews with farmers involved in the slash-and-burn system in three different agricultural communities. In total seventy-two farmers (59 men and 13 women) from three different rural localities were interviewed. In Tijuco Preto, 24 farmers were interviewed, in Terra Cortada, 28 farmers were interviewed and in Jaciaba 20 farmers were interviewed. Tijuco Preto and Terra Cortada communities are approximately 5 km away from each other, while Jaciaba is approximately 65 km away from the other two communities (Figure 1). These three rural communities displayed different socio-economic and cultural characteristics. Tijuco Preto is a community belonging to a Faxinal system (regional term) with communal livestock production, subsistence agricultural production, and low-impact forest extraction (Chang, 1988). Terra Cortada exhibited similar socio-economic and cultural characteristics when compared to Tijuco Preto; however, the rural activities are not practiced in the Faxinal system. Jaciaba community differed substantially from the other localities. Jaciaba is out of the Faxinal system context and farmers produced black bean in two ways: conventional mechanized tillage system and slash-and-burn. Therefore, farms used conventional tillage on gentle slope where it is possible and slash-and-burn on steep slope. In Jaciaba, the property is explored more intensively in comparison to other communities. These observations were based on fieldwork as well as several previous studies (Thomaz et al., 2014; Thomaz, 2013).

The questionnaire that was used focused on several aspects such as: a) farm identification (e.g. name, age, education level and number of people living in the property); b) property description (e.g. total area, area designated to black bean and corn, duration of living in the property, duration of slash-and-burn practice, types of crops, fallow period, crop production/productivity, type of black bean use, consumption or commercialization?) c) slash-and-burn perspective (e.g. the persistence of the slash-and-burn system, the main advantages and disadvantages of slash-and-burn, age range of people working with slash-and-burn, quality of life over the years of practice). For the farms, answering the questionnaire took approximately 30 min and usually one member per family was interviewed. The farmhouses were located along the main and secondary roads. Thus, the interviews were performed following the roads into the communities and by surveying respondents randomly.

Finally, at the third level, we performed 10 semi-structured interviews with experts, planners, policy makers, and stakeholders from the Prudentópolis municipality. Most of these professionals, if not all, were responsible in several ways to visit all the communities of the municipality to carry out socioeconomic survey, provide technical assistance and to buy or serve as an intermediate for buying the excess yield from the farmers. Therefore,

they not only possess regional knowledge but also an external perspective of the slash-and-burn system.

Some questions were similar for farms and experts. For the experts, the questionnaire lasted around 15 min, with questions about: property area, bean production, approximate duration that the slash-and-burn agricultural system has been used in the region, percentage of bean production originating from the slash-and-burn system, persistence possibilities of the system, fallow length, and main factors influencing the slash-and-burn system development.

3.1. Characterization of bean production

A dataset from the Brazilian Institute of Geography and Statistics (IBGE, 2010) with 64 years of bean productivity in the Paraná State was assessed to understand the crop development. In addition, a smaller dataset with 31 years (1980–2010) of bean productivity in Prudentópolis was assessed to understand the crop development and productivity in comparison to Paraná State.

The official data about bean productivity analyses served as evidence to argue the role of the slash-and-burn agricultural system on bean production in the Prudentópolis municipality compared to modern agricultural systems in the region.

3.2. Data analyses

The data were organized and exhibited with mean followed by one standard deviation. In some cases, the data were displayed only as median. Simple Pearson regression analysis was used to test the bean productivity increase along the data set period ($p < 0.05$). Analysis of variance (ANOVA) with non-parametric statistics such as Mann–Whitney, were performed for two independent paired sample comparison and Kruskal–Wallis for k population comparison. Differences between individual averages for k population were tested using the post-hoc Dunn test at $p < 0.05$.

4. Results and discussion

4.1. Evolution of bean productivity in the Paraná State and Prudentópolis municipality

The bean productivity in the Paraná State changed significantly over the last 60 years (Figure 2). We identified three phases, which, to a certain extent, are related to agricultural development and modernization in the Paraná State and the general study area. The first phase, from 1947 to 1974, displays a period when coffee plantations, timber and natural resources extraction were dominant (Ahrens, 2006). The bean production was associated with coffee plantations and small subsistence properties. Therefore, the agricultural system was characterized by the application of low technology to crop production without mechanization, fertilizers, agrochemicals and certified seeds (Ahrens, 2006). During this phase, bean productivity was low, at 813 ± 91 kg ha^{-1}, and a decrease of 3.8 kg ha^{-1} yr^{-1} in crop productivity occurred ($p = 0.02$).

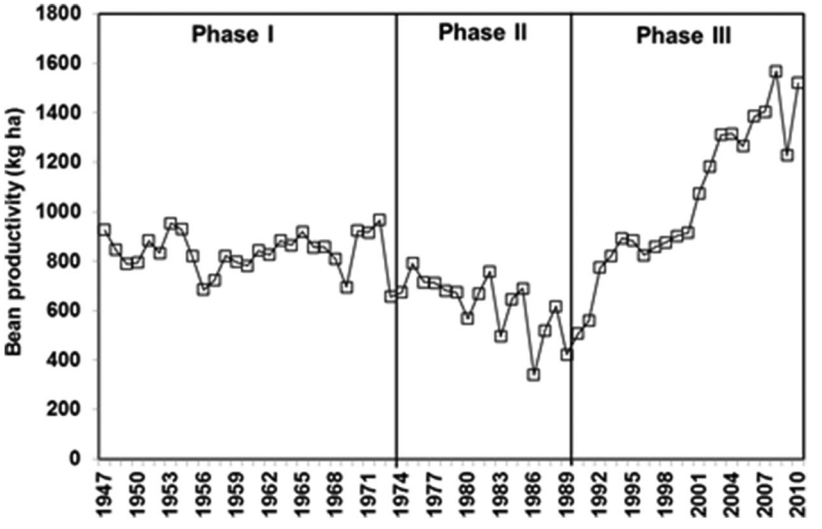

Figure 2. Evolution of bean productivity in Paraná State and its relationship with agricultural modernization and slash-and-burn persistence in Prudentópolis. Source: IBGE.

The second phase, from 1980 to 1989, was characterized by an agricultural transition in Paraná State. The bean productivity in Paraná State was only 625 ± 120 kg ha^{-1} and it decreased around 15 kg ha^{-1} yr^{-1} ($p = 0.006$). In Prudentópolis, the bean yield was 497 ± 139 kg ha^{-1}, with the productivity being 26% lower compared to the Paraná state average.

Overall, the productivity decreased approximately by 30% compared to the first phase. During this period, a reorganization of the agricultural system in the Paraná State occurred (Oliveira, 2001). The coffee plantations diminished, and the production of wheat and soybean increased rapidly. Modernization of agriculture for production of commercially important crops (e.g. wheat, soy, and corn) pushed the bean crop farms to marginal lands, such as areas with hilly terrain, shallow soil, and poor soil fertility (Ahrens, 2006).

During the third phase, from 1989 to 2010, agricultural modernization reached the bean producers (Ahrens, 2006) (Figure 2). The bean productivity in the Paraná state in the 1980s was around 500 kg ha^{-1} and it increased to over 1500 kg ha^{-1}in 2010 (Figure 3a). In the same period in Prudentópolis, the bean productivity increased to an average yield of 821 kg ha^{-1}. However, the bean yield gained per hectare during this period in Prudentópolis was about 64% lower than that for Paraná State (Figure 3a).

Figure 3b displays the seven highest bean-producing municipalities in Paraná State. In most of these municipalities, the bean yield is over 1500 kg ha^{-1} and for three of them, the bean yield is over 2000kg ha^{-1}. Overall, bean yield in Prudentópolis (898 kg ha^{-1}) is 2.2 times lower compared to the yield average of the other six municipalities (2008kg ha^{-1}) (Figure 3b).

These results indicate that Prudentópolis has the lowest bean productivity, compared to the other municipalities of the same state (Figure 3b), representing evidence of the significance of the slash-and-burn agricultural system on bean yield, given that it is a low-technology agricultural system with low productivity which does not use certified seeds, fertilizers, liming and pesticides. Overall, the bean yield in the subsistence agriculture

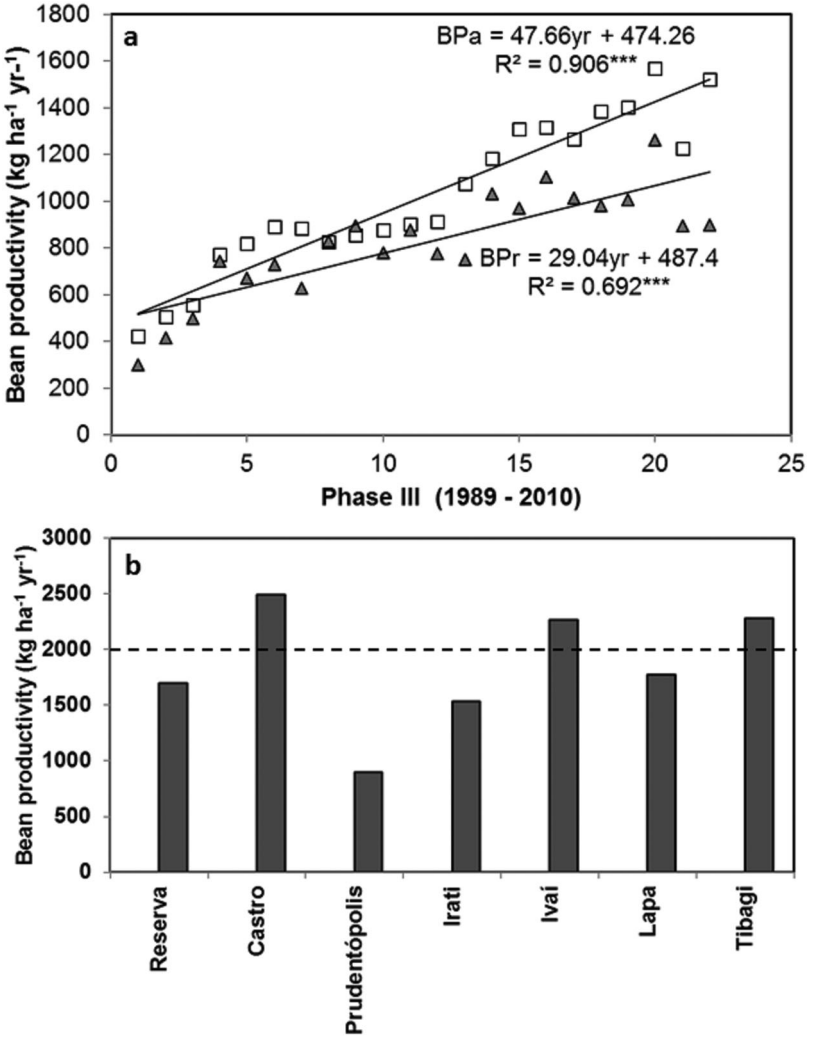

Figure 3. Bean productivity from 1989 to 2010: a) differences in the increase in bean productivity between Paraná State and Prudentópolis, b) comparison of bean productivity in Prudentópolis and other municipalities. Source: IBGE.

parts of the region ranges from 400 to 720 kg ha^{-1} (Lollato et al., 2001). This yield is similar to that registered in Quilombola shifting cultivation communities of the Atlantic rainforest (600 kg ha^{-1}) (Adams et al., 2012).

In addition, all the municipalities (Figure 3b), including Prudentópolis, have the same technology available for bean production, and they occupy similar ecoregions; however, the bean productivity was observed to be much lower in the study area. Unfortunately, the bean yield obtained by producers by using the conventional mechanized tillage systems as well as the slash-and-burn method is presented in a combined form in the government official data. Thus, it is not possible to determine the exact proportion of yield obtained using exclusively slash-and-burn in the whole municipality. Therefore, combining the Paraná State official data, local Prudentópolis official data, and evidence from the

present study, it is reasonable to deduce that the lower productivity of black bean in Prudentópolis is related to slash-and-burn, given that bean yield is lower than in conventional and no-tillage systems. This condition is similar to other low-technology systems; for example, rice yields were 2–3 times lower on swidden than when using conventional systems (Padoch & Pinedo-Vasquez, 2010).

Farmers' in Paraná state produce 25% of the total bean production in Brazil, whereas Prudentópolis contributes 1.1% of the total yield (33,582 t) (IBGE, 2010). In 2010, Prudentópolis harvested an area of 37,400 ha with a yield of 898 kg ha^{-1} (IBGE, 2010). In Prudentópolis, official estimations indicate that slash-and-burn agricultural systems occupy annually an area of 11,200 ha, intended mainly for bean crops, excluding fallow areas. Considering a yield average of 800 kg ha^{-1}, the slash-and-burn system produces approximately 8976 t of bean. Therefore, the slash-and-burn system produces at least 30% of the total bean yield in Prudentópolis (EMATER, 2012).

Bean consumption in Brazil is around 15 kg *per capita* per year (Salvador, 2014). With this approach, the slash-and-burn agricultural system in Prudentópolis can feed approximately 600,000 inhabitants annually. Given that the Prudentópolis municipality has 48,792 inhabitants (IBGE, 2010), the slash-and-burn system can easily feed the entire population (i.e. bean supply is 12 times what the Prudentópolis population needs).

4.2. Slash-and-burn agricultural system characteristics and farmers' perception in Prudentópolis

The environmental context such as mountainous areas with shallow soils and the socio-spatial organization of the agricultural system in the Prudentópolis municipality provide conditions for the persistence of livelihoods associated with the slash-and-burn system (Figure 4). Overall, these conditions were and still are determining the current performance of the regional agriculture. In addition, mountainous areas prevent agricultural modernization (i.e. mechanization and the land use intensification typical of conventional agriculture) (Ahrens, 2006).

The farmers in Tijuco Preto, Terra Cortada, and Jaciaba indicated that the use of slash-and-burn agriculture began in their communities in the early twentieth century (Table 1). However, an earlier onset for the system is estimated, since several farmers stated that their families practised this system even before. In the Tijuco Preto community, the farmers believed that the decline of the slash-and-burn system began at the beginning of this century. Additionally, although the average age of the farmers was higher in Tijuco Preto than in the other two communities, and the farmers were growing old, their perception of livelihood improvement was superior compared to those from Terra Cortada and Jaciaba. Fifty percent of the farmers from Tijuco Preto were retired and received a monthly minimum salary (foresight salary) from the Federal Government. It is possible that the annual income from this salary is greater than the income originating from the yield sold to the local market. All the communities were old settlements in the Prudentópolis municipality; however, Tijuco Preto and Terra Cortada seemed to face a faster demographic transition with ageing farmers, decreasing number of family members, and abandonment of slash-and-burn agricultural practices, with abandonment taking place earlier in Tijuco Preto than in the other localities ($p<0.05$) (Table 1).

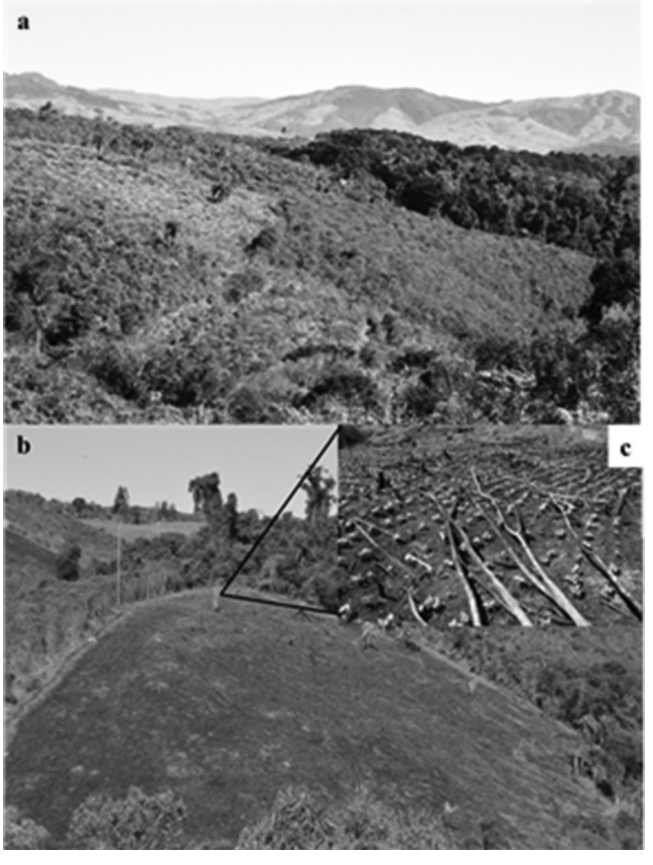

Figure 4. Land use pattern on the slash-and-burn landscape: a) hilly topography displaying a land mosaic with different successional vegetation phases; b) convex steep slope sowed with black beans; c) trunks and twigs not consumed by the fire over the ground.

Table 1. Slash-and-burn characteristics and farmer's perception.

Parameters	Tijuco Preto	Terra Cortada	Jaciaba
Slash-and-burn onset	1933	1938	1925
Farmers age (years)[1]	60	52	43
Number of member per family	2	3	3
Years at present site	47	36	30
Land area (ha)	13	3.6	24
Fallow length (years)	5	3.5	5
Fire is used to clean the land (%)[2]	92	82	80
Perception of yield decline (%)	83	79	100
Perception of livelihood improvement (%)	71	39	30
Perception of young people is not working on the slash-and-burn system (%)	71	86	100

Note: [1]based on the median of the total respondent; [2]based on the percentage of the total respondent.

Farmers from Terra Cortada had the least property areas (Table 1) ($p<0.05$). This may have led farmers to intensify the land use with a clear reduction in the fallow length ($p = 0.005$). The land intensification is not a recent process, since slash-and-burn is an old land use tradition in the community. Possibly, with less land for rotation, the area destined for

black bean was lower than that in the other communities and so was the yield. The reduction of fallow length can also increase soil degradation (i.e. soil fertility, organic carbon depletion, and soil erosion) (Borggaard et al., 2003; Thomaz, 2009).

Overall, the farmers harvested between 480 and 960 kg ha^{-1} of bean. This amount was consistent with black bean productivity using slash-and-burn subsistence agriculture (Adams et al., 2012; Lollato et al., 2001). Moreover, a noticeable decline of yield was pointed out by most of the farmers in all the communities. However, the farmers did not suggest a reason for this decline in crop production. Occasionally, though, climate had been cited by the farmers as a cause for yield reduction (Figure 5). The most common climate-induced damage on the black bean is the excess of rainfall during the harvest phase in summer (December-January).

Other less common factors related to climate were low temperature during flowering phase and dry spells in any phase of bean development, especially grain formation, which contributed towards yield decrease to a certain extent. Climate change has been a challenge for agricultural systems adaptation and food production worldwide (Cerri et al., 2007; de la Riva et al., 2013; Trenberth et al., 2013). Unfortunately, for this region, there is no study prior to the decrease in bean yield due to climatic factors.

Only 25% of the farmers believed that fire improves the soil fertility, while most of them (85%) used fire only as a simple tool to clear the land. However, burning the vegetation produces a rich ash-bed that fertilizes the soil and it is a process widely recognized in the slash-and-burn system (Nye & Greenland, 1964; Reuler & Janssen, 1993; Ribeiro Filho et al., 2015). In addition, soil heating can release extra nutrients for crop growth (Giardina et al., 2000).

Finally, more than 70% of the farmers in Tijuco Preto and 100% in Jaciaba believed that young people were not interested in carrying on with slash-and-burn anymore. According to the older community members, young people are prone to migration since they consider agricultural labour heavy and tiring (Table 1). Only 14% of the interviewed farmers were between 19 and 25 years old. Our results are similar to other studies regarding swidden cultivation systems in the Brazilian Atlantic Forest (Peroni & Hanazaki, 2002). Despite several constraints for the development of the slash-and-burn system in the region, as will be explained further, the ageing of the section of population involved in practising this system is an important variable for the system's demise. Besides, the loss of farming interest in the younger generation will further threaten the farming succession (Lieskovský et al., 2015).

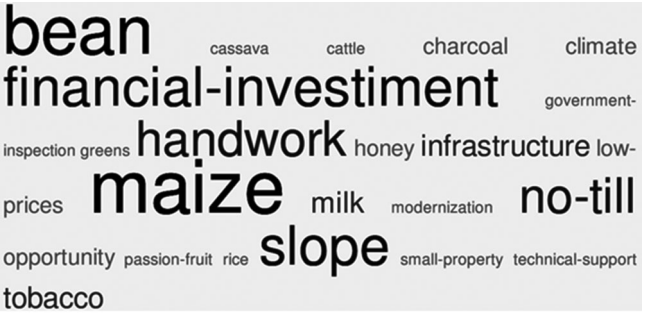

Figure 5. Word cloud displaying the characteristics and constraints of the slash-and-burn system.

The slash-and-burn technique displayed in Prudentópolis area was different from those practised in the Atlantic Forest coastline and Amazon regions. In Prudentópolis, the slash-and-burn system was practised within a well-consolidated agricultural landscape. People involved in this system were predominantly European migrants of Ukrainian descent who arrived in the region during the end of the nineteenth century and the early twentieth century (1920). In addition, slash-and-burn was used mainly to cultivate black bean in consortium with maize. The maize was cropped to support small households' herds (e.g. chicken, pork, goat, horses, and cattle) and black bean was used for family subsistence; however, the surplus formed an important cash crop. Slash-and-burn in the region was integrated with the local-regional market, since the road network and consumers were well organized.

On the other hand, slash-and-burn practised on the *Quilombolas* – Afro-Brazilian communities (Adams et al., 2012) and *Caiçaras* (Peroni & Hanazaki, 2002) communities – were mainly for subsistence purposes and the human settlement on the region is older in comparison to the present studies (Ribeiro Filho, 2015). The main crops cultivated were various types of edible roots (e.g. cassava, yams, and sweet potato). Beans were not the main product and the diversity of crops in the system were higher, with 261 varieties from 53 crop species (Peroni & Hanazaki, 2002). Probably, slash-and-burn in the Atlantic Forest coastline region was not integrated with the local-regional market, unlike the slash-and-burn system presented here.

In short, slash-and-burn agriculture in the present study is more integrated with local-regional markets due to the existence of infrastructure and through being connected to the local modern agricultural system matrix. By contrast, the slash-and-burn practised in the Atlantic Forest coastline was mainly for livelihood subsistence and was much more isolated from the modern agricultural system.

4.3. Characteristics of slash-and-burn agricultural system and their role in bean production: experts' view

The experts agreed that slash-and-burn is an old system in the Prudentópolis municipality (Table 2). In addition, most of them (80%) considered that it has been diminishing gradually during this century and will probably be non-prevalent within one to two decades.

Table 2. Slash-and-burn characteristics and expert's perception.

Parameters	Experts responses
Slash-and-burn onset	>100 (more than hundred years ago)
Slash-and-burn ending[1]	~2028 (next 14 years)
Property area (ha)	14.5
Fallow length (years)	2.5
Fallow length is decreasing (%)[2]	60
Burned plot area (ha)	2
Ratio of the total bean yield originates from slash-and-burn system in Prudentópolis municipality (%)	50
The slash-and-burn system is not responsible for bean yield decreasing (%)	80
The slash-and-burn system is decreasing in the region (%)	80
The slash-and-burn system is responsible for deforestation (%)	50

Note: [1]based on the median of the total respondent; [2]based on the percentage of the total respondent.

According to the experts in Prudentópolis, the smallholder properties were approximately 14.5 ha and they burned annually a small plot of up to 2 hectares. According to our sources, (60%) the fallow length is decreasing in the region. Overall, the experts were aware of the slash-and-burn system dynamics in the region. Their understanding regarding the decreasing fallow length and burned plot area was consistent with the farmers' responses. In addition, both farmers' and experts' understanding were consistent with the conclusions of previous studies regarding the slash-and-burn characteristics and dynamics carried out in the region (Thomaz, 2013; Thomaz et al., 2014).

The most interesting response was that the slash-and-burn system accounts for 50% of the total bean produced in Prudentópolis municipality, indicating that a great amount of black bean originated from slash-and-burn. This supports the previous analysis relating to the evolution of bean productivity in Paraná State and in Prudentópolis municipality. Our analysis estimated that approximately 30% of bean yield was from slash-and-burn system. Because of the participation (i.e. extensive area with bean crop) of the slash-and-burn system for bean production, the Prudentópolis productivity per hectare was lower compared with other municipalities (Figure 3b).

One of the most controversial environmental impacts ascribed to shifting cultivation or less intense agriculture is deforestation (Alepa & Rajashekhar, 2016; Devendra & Thomas, 2002; Mertz et al., 2009; van Vliet et al., 2012). However, 50% of the experts claimed that the slash-and-burn system was not responsible for deforestation in the region. Here, the system was distinct from shifting cultivation practised in tropical forest-agriculture frontiers. In Prudentópolis, the agricultural system is well-established, and the farmers practiced land rotation (i.e. shifting cultivation) within their property limits. The slashed vegetation was mainly early secondary forest or shrubs (Thomaz, 2009; Thomaz et al., 2014) (Figure 4a).

In Prudentópolis, the slash-and-burn system reduced its contribution to food production, particularly, due to the ageing of the population involved in this type of farming as well as the out-migration of the younger population who show limited interest in farming. However, we did not ignore other important factors such as change in economy, market development, environmental degradation and conservation policies which have affected the persistence of slash-and-burn worldwide (Mertz et al., 2009; Schmook et al., 2013).

Overall, the Brazilian population is facing a strong demographic transition in terms of birth and mortality rates, and the ratio of elderly people (>65 years old) is increasing by 2–4% per year (Nasri, 2008). In addition, between 1990 and 2000, the urban population in Prudentópolis increased by 5.4%, and from 2000 to 2010 by a further 2.1%. In the same periods, the rural population decreased by 2.6% and 0.6% respectively (IPARDES, 2010). Demographics is a key factor affecting slash-and-burn persistence, especially population growth and migration (van Vliet et al., 2012; Schmook et al., 2013).

In the present study, we noticed two demographic aspects, namely, population ageing and migration that possibly affected the slash-and-burn persistence in the region. However, population ageing was more evident in Terra Cortada and Tijuco Preto, whereas in Jaciaba the population was younger than in the other communities. Consequently, the slash and burn system will probably disappear first in Terra Cortada and Tijuco Preto, whereas it will persist longer in Jaciaba. Also, Jaciaba exhibited a dynamic system, where most farmers practise black bean production at the same time on two different agricultural systems, i.e. conventional and slash-and-burn.

4.4. Prospects for the slash-and-burn system

Figure 5 summarizes several characteristics and prospects of the current slash-and-burn system, together with farmers' and experts' opinions. Overall, the main crops were the consortium of maize for small herd fodder and bean for family consumption and sale. However, the smallholder farmers had exhibited great diversity of crops on their properties, such as cassava, greens, rice and tobacco, and other products including milk, cattle, honey and charcoal (Figure 5). Such crop and product diversity can be important for better dietary conditions and quality of life of the smallholders (Sibhatu et al., 2015). Therefore, the black bean produced was not only for family consumption, but the surplus yield was made available for trade in local markets.

Smallholders stated that financial support (i.e. government credit) was the main constraint in improving their agricultural system. Moreover, other aspects that seemed to restrict the development of slash-and-burn were infrastructure (e.g. storehouse, machinery), low prices of cash crops, lack of opportunity to change or improve the agricultural system, and small property size. We observed that experts recognized the slash-and-burn characteristics, dynamics and its role in food production (Table 2). However, several smallholders pointed out the scarcity of technical support to modernize their system.

During the interviews, the experts identified slope terrain as a key constraint for slash-and-burn development and persistence (Figure 5), highlighting two main aspects (Figure 4). First, experts considered that the existence or the persistence of the system in the region was due to the slope terrain itself. In addition, because of the system occupying the hilly areas, it was not possible to guarantee an improvement or modernization of the agricultural system (e.g. soil conservation and machinery practice). There is not a more suitable system for hilly areas than slash-and-burn agriculture.

It is advantageous and profitable to use steep terrain for bean production where it is not possible to use mechanized agricultural such as tractors. The farmer performs the slash-and-burn, then the beans are sowed and after about three months, a reasonable yield is harvested. In addition, farms do not need to use agrochemical inputs in crop management. Conventional tillage is more productive but it is also more expensive (Lollato et al., 2001; Schmook et al., 2013). In addition, it is possible to ensure the family consumption and the sale of the surplus. The market pays well for a bag (60 kg) of beans. From 2010 to 2016, bean prices ranged from 17 US$ to 33 US$. In addition, in a recent bean supply crisis, the price reached 119 US$, considering the currency conversion of that time (DEPEC, 2017). Therefore, to be able to sell a few bags of beans could provide extra income.

Secondly, the slash-and-burn is a time-consuming activity and completely carried out by manual labour because of its characteristics (e.g. hilly topography, trunks and twigs over the ground) (Figure 4b and c). Farmers use elementary tools such as axes, sickles, machetes and chainsaws to slash the vegetation. Next, the bean and maize are sowed with a manual seeder. In addition, during crop development, weeds are controlled by hoe and at the end of the crop cycle the harvest and thresh are carried out manually. Therefore, slash-and-burn is entirely dependent on manual labour. However, the ageing population and the young people's migration are a threat to its persistence in the next decade.

The study area is facing a complex agro-forest-environmental change, where society (e.g. society modernization, rural population ageing, migration) and ecosystems (e.g. land use mosaic, land use intensity, slash-and-burn abandonment) are changing together. This could be a typical co-evolutionary process on communities with incomplete transitions displaying a mosaic of diverse productive practices, which is taking place elsewhere in Brazil (Jakovac et al., 2016; Moreno-Peñaranda & Kallis, 2010). In addition, agricultural landscapes are changing worldwide along different trajectories and in different local contexts (Woods, 2010). Consequently, the slash-and-burn system is embedded in the overall rural changes taking place in the Prudentópolis municipality.

Slash-and-burn is recognized as a long-term sustainable agricultural system in the tropics (Nye & Greenland, 1964). In addition, it is responsible for biodiversity conservation, for providing ecosystem services such as a carbon sink, and maintaining the cultural tradition of an agroforestry system (Adams et al., 2012; Bruun et al., 2009; Devendra & Thomas, 2002). Therefore, it is important for ecological services and for producing food on small scales (i.e. smallholder subsistence). In addition, this system of cultivating black beans can coexist with conventional agricultural systems (used for tobacco cultivation) and no-till systems (used for soybean cultivation). Besides, we observed that slash-and-burn is important for producing food off-site for the local communities.

Finally, we observed three possible implications of the demise of the slash-and-burn agricultural system in Prudentópolis municipality. First, Prudentópolis is responsible for 1.1% (33 582 t) of the national bean production (IBGE, 2010). Therefore, reducing the slash-and-burn black bean production would signify a reduction of 0.3–0.5% of the total municipality yield. Second, if the area currently occupied by slash-and-burn was abandoned, secondary forest would recover with benefits for nature conservation and ecosystem services (e.g. soil, water and biodiversity conservations). Third, slash-and-burn areas occupy steep terrain or mountainous areas, avoiding land use intensification by conventional agriculture. However, farmers could convert their land into pine and eucalyptus plantations for economic purposes. In addition, commercial forest is a more permanent land use and less dependable of handwork. This possible land use transition requires better monitoring in the coming years. As Heinimann et al. (2017) highlight, areas such as this in southern Brazil will face changes in the coming decades; demographic and land-use transitions would have social and environmental implications for food production, land use dynamics, and rural migration and development.

5. Conclusions

There is a long and important tradition of black bean production by slash-and-burn agriculture in the Prudentópolis municipality, a coupled human-environment system that coexists with conventional agricultural systems. The slash-and-burn system produces at least 30% of the total bean yield in the study area, and is thus a significant system for producing food outside the local scale, i.e. not only contributing to smallholders' subsistence. The environmental context of mountainous areas with shallow soils combined with the organization of the agricultural system in the Prudentópolis municipality provides conditions for the persistence of livelihoods associated with the slash-and-burn system. Socio-environmental conditions were, and still are, critical to the current performance and the organization of the regional agriculture. In addition, mountainous areas

prevent agricultural modernization. The slash-and-burn system has reduced contribution to food production because of the possible abandonment of the use of this system. The ageing population and out-migration of young people both represent threats to the persistence of slash-and-burn in the next decade, alongside other important drivers affecting the persistence of slash-and-burn locally. Experts recognize the importance of slash-and-burn for food production; however, they believe that the system is in decline, and that its prevalence in the hilly areas, where agricultural modernization is not feasible, also serves as a factor for its gradual demise. Changes are likely to take place not only in areas such as this part of southern Brazil but also in other sub-tropical or tropical areas, and they are most likely to experience social and environmental implications such as food production and local development problems if the slash-and-burn system is abandoned.

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