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The value of pollinator-friendly practices: Synergies between natural and anthropogenic assets

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Abstract

Sustainable livelihoods and human well-being depend on multiple anthropogenic and natural assets (stock of materials or information that exists in a point in time). However, the simultaneous and multiple impacts of land-use decisions on these assets are often ignored. In this study, we focus on pollinator-friendly practices (PFP: practices that intend to increase the abundance and diversity of natural pollinators) to quantify the multi-dimensional value of land-use decisions and to address potential synergies and trade-offs among assets. We combined socio-economic and ecological methods to quantify natural (pollinator richness) and anthropogenic (human, physical, social, and financial) assets in 30 coffee plantations with a gradient in the number of PFP in eastern Brazil. We found that an increase in the number of PFP resulted in both enhanced flower-visitor richness (natural asset) and coffee yield (financial asset). Farmers who dedicated more time to field work than to administrative work applied more PFP on their farms. Our results highlight that land-use decisions oriented toward enhancing natural assets can also provide the highest levels of financial assets. This provides a general framework for efforts toward ecological intensification that can be employed in other regions.

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Zusammenfassung

Eine nachhaltige Lebensgrundlage und menschliches Wohlergehen hängen von verschiedenen anthropogenen und natürlichen Aktivposten (Vorräte von Materialien oder Informationen, die zu einem bestimmten Zeitpunkt vorhanden sind) ab. Indessen werden die gleichzeitigen und zahlreichen Einflüsse von Landnutzungsentscheidungen auf diese Aktivposten häufig nicht berücksichtigt. In dieser Studie konzentrieren wir uns auf pollinatorenfreundliche Praktiken (PFP: Maßnahmen, die darauf zielen, die Abundanz und Diversität natürlicher Bestäuber zu steigern), um den mehrdimensionalen Wert von Landnutzungsentscheidungen zu quantifizieren und mögliche Synergien und Zielkonflikte zwischen den Aktivposten anzusprechen. Wir kombinierten sozioökonomische und ökologische Methoden, um natürliche (Bestäuberreichtum) und anthropogene (humane, physikalische, soziale und finanzielle) Aktivposten in 30 Kaffeeplantagen (östliches Brasilien) mit unterschiedlicher Zahl von PFPs zu quantifizieren. Wir fanden, dass eine Zunahme der PFPs sowohl einen erhöhten Artenreichtum der Blütenbesucher (natürlicher Aktivposten) als auch einen erhöhten Kaffeeertrag (finanzieller Aktivposten) ergab. Bauern, die mehr Zeit für die Feldarbeit als für administrative Aufgaben aufwendeten, wandten mehr PFP auf ihren Betrieben an. Unsere Ergebnisse unterstreichen, dass Landnutzungsentscheidungen, die auf eine Stärkung der natürlichen Aktivposten zielen, auch die höchsten finanziellen Erträge ergeben können. Dies ergibt ein generelles Bezugssystem für Anstrengungen hin zu einer ökologischen Intensivierung, das auch in anderen Regionen angewendet werden kann.

Keywords: Conservation; Pollinators; Crop yield; Socio-economic analysis; Pollinator-friendly practices

Introduction

In the beginning of the 1960s, the "Green Revolution" intensified agriculture by increasing the use of external inputs (fertilizer, pesticides) and promoting monocultures (Evenson & Gollin, 2003). This "conventional" agriculture intensification is resulting in environmental degradation (Tilman et al., 2001), which is leading to loss of biodiversity and decay of ecosystem services (Biesmeijer et al., 2006; Potts et al., 2010). Despite being comparatively less studied, a number of studies have reported important impacts of conventional agriculture intensification on human and social assets (Pretty & Smith, 2004; Pretty, 2008; Würtenberger, Koellner, & Binder, 2006). These impacts on natural and anthropogenic assets are often not accounted for when evaluating agricultural efficiency in agricultural production, which threatens sustainable livelihoods and human well-being.

The transformation of the current "conventional" production system into one more sustainable requires strong and convincing arguments to persuade multiple audiences unwilling to change (e.g. farmers, politicians and industry). One way to achieve this goal is through the valuation of ecosystem services (Constanza et al., 1997; Hanley, Breeze, Ellis, & Goulson, 2014). However, most valuations have focused on the monetary benefits (Constanza et al., 1997; Hein, 2009; Roubik, 2002; Salles, 2011), neglecting many other values that cannot be expressed only in monetary terms (e.g. human health: as pain or suffering, social wellbeing: loss of leisure) (Christie, Fazey, Cooper, Hyde, & Kenter, 2012; Farber et al., 2006; IPBES, 2013; Landefeld & Seskin, 1982). Specifically, agricultural systems directly affect many of the assets (natural, social, human, physical and financial) on which they depend (Pretty, 2008), and thus these values need to be assessed in the models that evaluate their productivity.

Insect pollination is an important ecosystem service in agricultural systems (Klein et al., 2007). Decreases in pollinator populations can result in economic loss through pollination deficits (Gallai, Salles, Settele, & Vaissière, 2009; Roubik, 2002). Additionally, pollination deficits can decrease the stability and resilience of producers' livelihoods, since farming systems with more diverse assets (human, natural, social, financial and physical) tend to have a higher capacity to opt for alternative strategies under stress (DFID, 1999; Nelson et al., 2010). Methodological pluralism is thus an important approach in undertaking ecological and socio-economic analyses, in order to account for the different dimensions of the values to be analyzed (Howarth & Farber, 2002; Laurila-Pant, Lehikoinen, Uusitalo, & Venesjärvi, 2015). This approach can also quantify tradeoffs or synergies between conservation, production and producers' profits (Fischer et al., 2008; Foley et al., 2005; Laurila-Pant et al., 2015; Pretty et al., 2006; Pretty, 2003).

The potential for "win–win" scenarios increases with the availability of more effective methods to assess ecosystem services (Power, 2010). A recently developed approach by Garibaldi, Carvalheiro, et al. (2016), Garibaldi, Dondo, et al. (2016) encompasses the methodological pluralism by identifying different assets that can impact the use of "pollinator-friendly landscapes or practices", i.e. practices that intend to increase the abundance and diversity of natural pollinators through the enhancement of diverse floral resources, farmland heterogeneity, reduced- or non-use of synthetic insecticides, among others (Garibaldi et al., 2014). This approach may have two clear benefits: (i) political (providing evidence-based information that reinforces the case for biodiversity conservation and sustainable land-use planning) and (ii) instrumental (efforts may spur institutional designs and market mechanisms that effectively promote environmental protection) (Salzman, Thompson, & Daily, 2001). Taking into account not only the five aforementioned assets (natural, social, human, physical and financial) but also legislation aspects (legal framework), could increase the importance and applicability of the results to decision makers as well as land use (DFID, 1999; OECD, 2000). This should be important for pollination services, as a direct legal framework for their provision and a compensation scheme is currently lacking, despite scientific evidence (Olschewski, Klein, & Tscharntke, 2010).

To investigate the relationship among multiple assets, legal framework and pollinator-friendly practices, we tested the following hypothesis, using the approach described above: (1) pollinator-friendly practices enhance pollinator diversity and density in agricultural systems; and (2) pollinator-friendly practices can generate beneficial synergies in agricultural system when multiple assets are considered.

Case study

Study area

The study was conducted in coffee farms at Mucugê and Ibicoara (Bahia State, Brazil) (41°22′11″W, 12°59′47″S and 41°16′58″W, 13°24′41″S). The main crop in the study region is coffee, although potatoes, tomatoes, strawberries, garlic, and apples are also cultivated. Most of these crops are managed using intensive agricultural practices in the study region (i.e., high use of pesticides and fertilizers). The farmland area borders the National Park of Chapada Diamantina, the largest conservation area in Brazil outside of the Amazon region (Fig. 1). The region is dominated by several types of Brazilian savannah (Cerrado), with areas of high-altitude grasslands. The average annual temperature is 21 °C, ranging from 26 °C to 16 °C. The rainy season is from November to March, and the average annual precipitation is 757 mm.

Survey data

A draft survey questionnaire was designed and tested initially with 12 coffee farmers as a pilot experience that allowed us to improve the selection of our variables in order to increase the accuracy of their answers. Final questionnaires were related to questions below for each asset (see Appendix B). In order to capture the multidimensional nature of ecological and socio-economic values, we measured five livelihood assets in agricultural landscapes (Nelson et al., 2010; Pretty, 2008): Human Asset, Natural Asset, Financial Asset, Physical Asset and Social Asset. In the following sections we further define each of these variables considering "asset" as a stock of materials or information that exists at a point in time (Constanza et al., 1997).

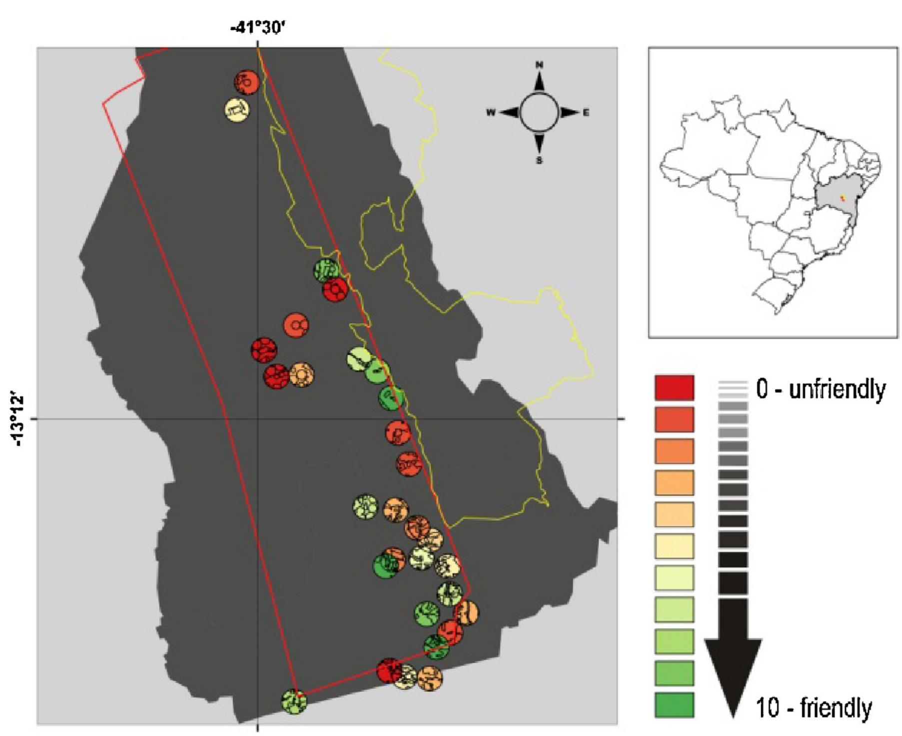

Fig. 1. Map of the study area evidencing the proximity of the agricultural pole (red polygon) to the national park of Chapada Diamantina in Bahia, Brazil (yellow polygon). Colored circles indicate the number of pollinator-friendly practices from red (no pollinator-friendly practices) to green (10 pollinator-friendly practices). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1. Number and type of pollinator-friendly practices on coffee farms in Chapada Diamantina, Bahia, Brazil. In each farm, the number of pollinator-friendly practices was calculated by adding the numbers of all the practices.

Practice	Friendly	Unfriendly
Beehives	1 = *Apis mellifera* 2 = native	0 = no
Pesticide use	1 = only when necessary (low) 2 = no	0 = always
Weed control	1 = partial manual weeding	0 = total weeding
Organic certificated farming	1 = yes	0 = no
Hedge presence	1 = present	0 = none
Crop diversity	1 = presence of non coffee crops	0 = monoculture
Proportion of natural area*	1 = up to 2% 2 = 5 to 10% 3 = 12 to 20% 4 = >30%	0 = none

*The proportion of natural area in a landscape calculated through 200 m buffer area around farm (Greenleaf et al., 2007).

Human asset – The total capacity residing in individuals, based on their knowledge, skills, health and nutrition that contributes to the productivity of labor and capacity to manage land (Nelson et al., 2010). This capacity is often strongly influenced by family bonds (Morcillo & Beker, 2008).

- Formal education: number of years of formal education spent by the survey respondent (from 0 = illiterate to 15 = graduate).
- Type of work: survey respondent's job. The respondent could refer to working on administration-type work (related to farm management) or manual work (land labor).
- Family participation: number of family members, sorted by gender, that directly contribute to on-farm activities.
- Bee importance: awareness of the importance of bees for coffee pollination.

Natural asset – Related to environmental goods and services that contribute to land productivity, including wildlife, biodiversity and ecosystem services.

- Pollinator-friendly practices: practices are based on a review by Garibaldi et al. (2014) and adjusted to the specificities in the current study (refer to Table 1 for details).
- Species richness of flower visitors: in order to analyze if we detect successfully the best pollinator-friendly practices, we used data collected from another study but on the exactly same study sites (Hipólito et al., unpublished), on the cumulative numbers of pollinator species visiting flowers. In 2013, flower visitors were captured with nets within thirty coffee farms 2 km apart from each other on plots of the same size (50 × 25 m). Each sampling period lasted 20 min and we sampled twice on each farm, once in the morning and once in the afternoon). Sampling efforts were the same at all farms and during all periods.

Financial asset – Represents the stocks of financial resources accessible to farmers, such as access to cash, credit, income and yield.

- Yield: number of coffee bags in one hectare in each farm.
- Other income: income from activities other than crop production such as those related to credit (bank) and government benefits, such as pension. This variable was set to be either 1 if present or 0 if absent.

Physical asset – The store of human-made material resources to make labor more productive. These include infrastructure, transportation and irrigation, among others.

- Irrigation: presence (value = 1) or absence (value = 0) of irrigation in coffee farms.
- Total coffee plantation area (ha).
- Production system: it includes (i) use of fertilization: used periodically (value = 2); sometimes (e.g. when the farmer can afford it) (value = 1); or never (value = 0); and (ii) use of heavy machinery, e.g. for tillage (present = 1; absent = 0).
- Post-production system (improvements): if the farmer has any equipment to facilitate the sale of coffee, such as to dry, select or roast coffee.

Social asset – Social bonds among farmers that facilitate cooperative actions and social connections outside farmer groups that have potential to increase or exchange knowledge.

- Association member: if the farmer is part of an agricultural association.
- Agricultural Extension: it refers to the presence of agronomists or technicians outside the farm aimed at improving farmers' production, income, and (by implication) quality of life (present = 1; absent = 0).
- Product commercialization strategy: how the farmer commercializes the products (coffee fruits, or processed coffee): individually (value = 1); in partnership (value = 2); through a cooperative (value = 3); or if he/she commercializes it using more than one trade type (value = 4).

Legal framework – Related to Brazilian federal law (number 12.651/2012) that refers to natural vegetation protection and regulates and determines the presence of these areas.

- Government requirement of forest reserve: If natural areas are present (value = 1) or absent (value = 0), according to the law.

Thirty coffee farmers joined this study. Most interviews were carried out at the farmer's property or at the farmer's main activity place (outside the farm). The majority of the interviews were conducted with the farm owner or if not possible, with the person with highest knowledge of the farm management. Interviews were tape recorded and authorized to be published without personal information disclosed, through a signed Terms of Consent. As this study did not involve indigenous people nor disclose any personal information of its participants, approval by an ethics committee was not sought. No changes were made in questions at questionnaires except to order or guide answers, such as to explain questions or modify the language, when and as needed.

Statistical analysis

To test if the selected pollinator-friendly practices increased the diversity of pollinators, we performed a regression analysis using R v3.2.0 (R Core Team, 2015). We used species richness of flower visitors in coffee flowers as the dependent variable and number of pollinator-friendly practices as the independent variable.

Following a model selection approach, we ran Generalized Linear Models (GLM, Poisson error distribution) in order to analyze the influence of the socio-economic variables (predictor variables) on the number of pollinator-friendly practices (dependent variable). We first tested for multicollinearity between predictor variables using variance inflation factors (VIF) in the "car" package. We excluded the variable "agricultural extension" in the models due to its high VIF value (18.8) but we used it outside the statistical analysis, in order to describe features of the coffee farms in the region. Thus our models included predictor variables from human asset (years of formal education, type of work, family participation and bee importance), financial asset (yield and other income), physical asset (irrigation, total coffee area, production system and improvements), social asset (association member and product commercialization) and legal framework (presence of forest reserve) (see Appendix C: table). Based on the corrected Akaike's Information Criterion (AICc), we selected the best model, after evaluating the models resulting from all possible combinations of the predictor variables using the "dredge" function in the "MuMIN" package (Barton, 2015) in R. Additionally, the AICc values were used to obtain the Akaike weight of each model, which allowed to calculate the relative importance of the predictors.

Results

General features of the surveys

The age of coffee growers ranged from 31 to 81 years, 83% of which were male and 63% lived on the farm or had it as their main home. The farm owner was interviewed in 83% of the surveys. In 60% of the surveys, farmers stated that agricultural extension services were usually present in the region but these were mostly related to a private service (i.e. contracted by farmers) in 72% of the cases. Most farmers pointed out the following issues as the most limiting factors of coffee production (i) weather problems – drought (for those without an irrigation system), or water restriction (for those with an irrigation system), (ii) low prices of coffee, (iii) production losses, (iv) government bureaucracy (i.e. difficulty to get a permit for irrigation), (v) overall costs to maintain the crops (agricultural external inputs e.g. fertilizers), (vi) difficulties in dealing with coffee (as the blooming period in different months of year, making it hard to concentrate efforts in one season only), and (vii) to find and recruit workers to help in on-farm management.

Factors accounting for the number of pollinator-friendly practices

Our results revealed that farms with greater pollinator-friendly practices (mean = 1.97 ± 1.99; median = 1) (Fig. 1) exhibited higher flower visitor richness (mean = 5.35 ± 3.9; median = 4) ($R^2 = 0.31$; $p < 0.001$; $t = 4.53$) (Fig. 2). Model selection results, evidenced that the number of pollinator-friendly practices were best explained by: (1) total coffee area (physical); (2) yield (financial); and (3) type of work (human) (see Appendix C: table, Fig. 3). Relationships among these variables evidenced that: (1) larger coffee crop areas had lower number of pollinator-friendly practices (Fig. 4), (2) the number of pollinator-friendly practices used and yield (productivity) generate a positive relation and (3) in farms were owners working actively on the land exhibited a greater number of pollinator-friendly practices than those owned by farmers working in the management of the farm (Fig. 4).

Discussion

Although we considered only 30 farmers in this study, patterns for age, sex, dwelling and financial incomes were similar to higher surveys demonstrating the representativeness of our data. Those evidenced the age of coffee growers from 21 to 70 (Neves, 2010), majority male 86% (IBGE, 2006), who lived on farm 55% (Neves, 2010). A larger difference was found on the presence of technical assistance 87% (Neves, 2010) which could be related to change on management due political reasons and not necessarily due sampling.

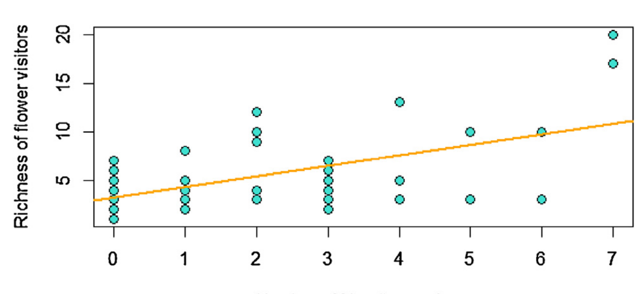

Fig. 2. Richness of flower visitors increase with the number of pollinator-friendly practices in coffee crops in Chapada Diamantina, Bahia, Brazil. Each point is a farm, while the line results from a linear regression model.

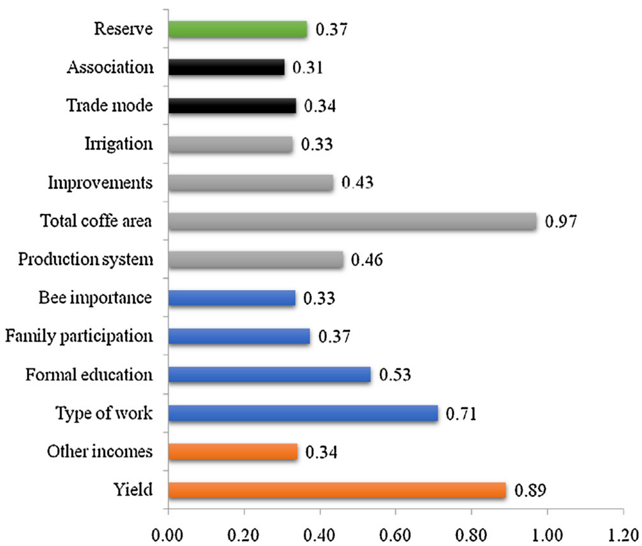

Fig. 3. Relative importance of predictor variables of pollinator-friendly practices ordered by assets (orange = financial; blue = human; gray = physical; black = social; and green = legal framework). The relative importance (values on graph) is the sum of the Akaike information criterion weights of the models with each predictor. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Valuation of pollinator-friendly practices in crops can be extremely important to call attention to actions that improve biodiversity and other assets related to agriculture (social, human, physical and financial). Results of this study reveal how the abundance of pollinator-friendly practices enhances flower-visitor species richness in coffee, and detected the most important physical, financial and human assets that increased these pollinator-friendly practices. As others studies (Clough et al., 2011; Kremen & Miles, 2012; Zhang, Ricketts, Kremen, Carney, & Swinton, 2007), we also found no trade-off between biodiversity (pollinator-friendly practices) and crop yield. Results here demonstrated that management practices should focus on multiple parameters instead of one (e.g. increasing floral abundance) (Wood, Holland, & Goulson, 2015) and must consider regional differences caused by environmental factors or even differences in crop management strategies (Seufert, Ramankutty, & Foley, 2012).

The trade-off between coffee yield and cultivated area (physical and financial assets) showed that there were no net changes in total coffee production (bags) per farm with increasing pollinator-friendly practices (i.e., with no optimum or maximum value, see Appendix A: figure). Therefore, there is an opportunity to increase coffee yield by improving the number of pollinator-friendly practices. Small farms can exhibit higher habitat diversity at landscape scale, reflecting a higher flower-visitor richness and yield (Belfrage, Björklund, & Salomonsson, 2005; Garibaldi, Carvalheiro, et al., 2016a; Garibaldi, Dondo, et al., 2016b). Even so, large coffee farms could increase the number of pollinator-friendly practices by other modifications within farm (Table 1) without a decrease in production.

We found that farms whose owner works actively on the land have more pollinator-friendly practices than those with owners working in the management of the farm. One explanation for this result is that farmers working actively on the land may acquire stronger knowledge of the reproductive biology of their crops, or even crop nutritional requirements (water, soil) and thus, implement more management practices that in result optimize the pollination (even if it is not their objective). Cumulative knowledge acquired by producers can increase production (Jaffé et al., 2015).

According to the Brazilian Forest Code, farmers are obliged to allocate at least 20% of their farms as protected areas. Interestingly, the Brazilian forest reserve law enforcement (where natural areas are preserved on the farm), did not necessarily result in a greater use of pollinator-friendly

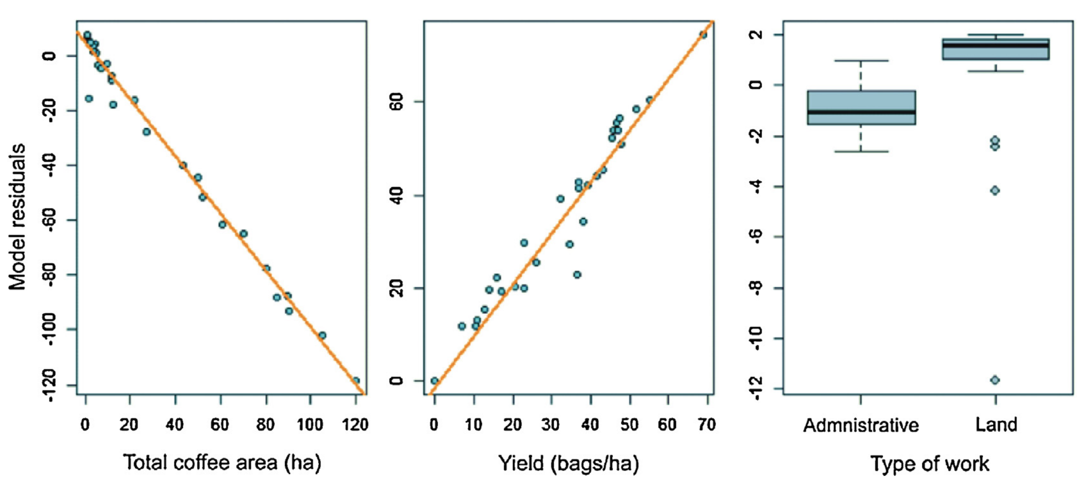

Fig. 4. Effects of the most important predictor variables on the number of pollinator-friendly practices in coffee farms in Chapada Diamantina, Bahia, Brazil. Graphs show residuals from the best model (points) without the predictor variable of interest and the adjusted model (lines) for each predictor variable.

practices. Indeed, this variable appeared only in one model within the top model set (see Appendix C: table). Additionally the presence of these areas should consider not only conservation of biodiversity and landscape, but also economic aspects (Federal Law, 2012). Here we evidenced that farmers who are implementing this law, are not aware of the importance that pollinator-friendly practices have for a sustainable crop production. A more integrated and sustainable approach to coffee farmers should consider not only pollinator-friendly practices but also the presence of natural areas close to crops, which will in turn result in higher flower-visitor frequency and richness (Blaauw & Isaacs, 2014; Steffan-Dewenter & Tscharntke, 1999).

The pollinator-friendly practices presented here have the potential to generate win–win scenarios and to help farmers and policy-makers to conserve or restore biodiversity and improve crop yield. To reach the goal of agricultural sustainability, farming practices should center on food production that optimally utilizes nature's goods and services without damaging these assets, e.g. sustainable intensification (Pretty et al., 2006). This would require accounting for farmers' needs and access to technology and information, especially for the resource-poor smallholders (Pretty, 2003; Steward et al., 2014). Strategies should focus on multiple and synergistic effects rather than single effect practices lacking sustainable effects (Gutzler et al., 2015).

Conclusions

Here we provided evidence that it is possible to generate win–win scenarios between biodiversity, crop production, and farmers' profitability. In particular, pollinator-friendly practices that can be especially beneficial include: introduction of beehives especially with native bees; reduction of pesticide use; partial manual weeding; introduction of hedges and flower strips; crop diversity; and the conservation or restoration of natural areas close to crop fields. These practices could be used as a general framework to achieve sustainable crop intensification. Using pollinator-friendly practices as a case study, our results further suggest that environmentally-friendly practices should be valued considering multiple assets.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.baae.2016.09.003.

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