



## Improving land management in Brazil: A perspective from producers



Agnieszka E. Latawiec<sup>a,b,c,d,\*</sup>, Bernardo B.N. Strassburg<sup>a,b,e</sup>, Daniel Silva<sup>b</sup>,  
Helena Nery Alves-Pinto<sup>a,b,e</sup>, Rafael Feltran-Barbieri<sup>b,f</sup>, Ana Castro<sup>a,b</sup>, Alvaro Iribarrem<sup>a,b</sup>,  
Márcio Cordeiro Rangel<sup>b</sup>, Kemel Amin B. Kalif<sup>b</sup>, Toby Gardner<sup>b,g</sup>, Francisco Beduschi<sup>h</sup>

<sup>a</sup> Rio Conservation and Sustainability Science Centre, Department of Geography and the Environment, Pontifícia Universidade Católica, 22453900 Rio de Janeiro, Brazil

<sup>b</sup> International Institute for Sustainability, Estrada Dona Castorina 124, 22460-320 Rio de Janeiro, Brazil

<sup>c</sup> Institute of Agricultural Engineering and Informatics, Faculty of Production and Power Engineering, University of Agriculture in Kraków, Balicka 116B, 30-149 Kraków, Poland

<sup>d</sup> School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, United Kingdom

<sup>e</sup> Programa de Pós Graduação em Ecologia, Universidade Federal do Rio de Janeiro, 21941-590 Rio de Janeiro, Brazil

<sup>f</sup> World Resources Institute-Brazil, Claudio Soares 72, 05422-30 São Paulo, Brazil

<sup>g</sup> Stockholm Environment Institute, Linnégatan 87D, 115 23 Stockholm, Sweden

<sup>h</sup> Instituto Centro de Vida, Rua Américo Salgado, 1890, Santa Helena, 78045-055 Cuiabá, Mato Grosso, Brazil

### ARTICLE INFO

#### Article history:

Received 19 September 2016

Received in revised form 28 January 2017

Accepted 31 January 2017

Available online xxx

#### Keywords:

Amazon

Cattle ranching

Farmers' decision making

Deforestation

### ABSTRACT

The low productivity of many tropical pasturelands is a major driver of deforestation and other negative environmental and socio-economic impacts. In Brazil, the second biggest meat producer in the world, 85% of cattle farms remain within extensive pasture systems, and cattle farming is by far the most important proximate driver of deforestation. It is possible to expand Brazilian agriculture with zero deforestation through improvements to rangeland productivity yet understanding of the challenges and motivations of the actual cattle farmers in the face of such a transition remains sparse. To better understand the importance of the underlying factors that lead to or inhibit improvements to land management, we used focus groups and semi-structured interviews (N=250) with farmers from the state of Mato Grosso in the Brazilian Amazon. We found that the majority of the respondents (60%) claimed that the principal benefit of adopting good agricultural practices was increased productivity, followed by increased income (43%) and better farm administrative management (34%). The adoption of improved pasture management techniques was positively correlated with stocking rates ( $p < 0.005$ ,  $r = 0.48$ ). Farms that adopted improved pasture management, most often through rotational grazing had, on average, lower levels of forest cover ( $p < 0.05$ ,  $r = 0.22$ ). We found that scarcity of labour was the major issue affecting the adoption of improved techniques (36%), followed by financial constraints (18%). We also identified a shortfall in access to technical extension services to be a significant problem because 40% of the technical assistance is currently provided by vendors of fertilizers and other chemicals. To our knowledge, this is the first study to systematically assess the barriers to and the conditions surrounding the adoption of good agricultural practices in Brazilian pasturelands from the perspective of the farmers from the Amazon involved in the implementation of these practices. It is critical that decision-makers involved in the design of technical assistance schemes, education and credit programmes consider these factors if sustainable land management is to be realised at scale. In particular, the lack of skilled and available labour contrasts with the widespread assumption that new credit lines for sustainable agriculture will automatically result in better land management. A failure to consider factors discussed in this paper may contribute to the continued clearance of native vegetation and the environmental degradation of existing pasturelands, in addition to the persistence of widespread poverty among cattle-farmers. These results can assist the large scale implementation of sustainable land use policies in Brazil and elsewhere.

© 2017 Elsevier B.V. All rights reserved.

\* Corresponding author at: Rio Conservation and Sustainability Science Centre, Department of Geography and the Environment, Pontifícia Universidade Católica, 22453900 Rio de Janeiro, Brazil.

E-mail addresses: [a.latawiec@iis-rio.org](mailto:a.latawiec@iis-rio.org), [alatawiec@gmail.com](mailto:alatawiec@gmail.com) (A.E. Latawiec).

## 1. Introduction

Decisions agricultural producers make on how to use their land have far reaching environmental, social and economic ramifications. Global land use and land-use change impact atmospheric and hydrological cycles, cause soil, water and air pollution, are the main drivers of biodiversity loss and may improve or worsen food security of the world's poorest (Lambin and Geist, 2006; Lambin and Meyfroidt, 2011). For instance, the global hydrological cycle has been transformed to provide freshwater for irrigation, and agriculture impacts water quality and coastal and freshwater ecosystems through high sediment loads and nutrient inputs from fertilizers and atmospheric pollutants (Tilman et al., 2001). Agricultural mismanagement and overgrazing may lead to soil chemical and physical degradation (Foley et al., 2005). Land-use change causes declines in biodiversity through degradation of soil and water, and the modification, fragmentation and loss of native habitats. Between 1980–2000, more than half of the new agricultural land throughout the tropics came at the expense of intact forests (Gibbs et al., 2010) and habitat loss has been identified as the principal cause of species extinction worldwide (Baillie et al., 2004). Finally, land use and land-use change is the main source of anthropogenic greenhouse gas emissions (IPCC, 2007).

Degraded and low productivity pasturelands are prevalent throughout the tropics and are associated with a wide range of negative environmental impacts at multiple levels, including land degradation, water and air pollution and greenhouse gas emissions (Soares-Filho et al., 2014). Land use in Brazil is predominantly dedicated to cattle ranching, which is the principal driver of deforestation in the Amazon and the Cerrado, the vast, biodiverse savannahs of central Brazil (Soares-Filho et al., 2013). The majority (85%) of Brazilian cattle farms are extensive, low-productivity systems (Dias-Filho, 2014) that are commonly degraded and provide very low economic returns for farmers (Walker et al., 2000).

Accordingly, to mitigate the negative impacts of unsustainable cattle ranching and to meet the growing domestic and export market demands resulting from diminishing land resources, there is an urgent need for this situation to change (FAO, 2014). At the same time, Brazil has recently announced plans to restore some 12 million hectares of forest, one of the biggest pledged restoration targets of any country worldwide (INDC, 2015). Therefore, efforts to improve the efficiency of cattle ranching is not only paramount for better management of land resources and Brazil's agricultural sector, but it is also vital for reconciling increased agricultural production with the country's ambitious conservation and restoration targets (Latawiec et al., 2015). Furthermore, increasing cattle ranching efficiency may improve the direct economic benefits for hundreds of thousands of farmers who rely on the cattle sector for their livelihoods (Soares-Filho et al., 2014).

The yield gap in the efficiency of cattle ranching in Brazil is high, and current productivity is at approximately one-third of what may be considered a sustainable carrying capacity (Strassburg et al., 2014a). As such, improving the efficiency of low-productivity pasturelands is widely viewed as an important pathway for improving agricultural output and farmer income (Ramsey et al., 2005) and as a method to reduce the need to clear more new land for farming (Strassburg et al., 2014a). In a modelling exercise, Strassburg et al. (2014a) have demonstrated that improvements in the productivity of cattle ranching in Brazil can also, in theory, free up large areas of land for the production of other agricultural commodities, including those for which the export demand is also increasing, such as maize, soybeans, and sugarcane, and staple crops that play a key role in regional food security, such as manioc. Simultaneously, the government's goal of large-scale restoration could be achieved (Strassburg et al., 2014a).

Substantial attention has been paid to the social and environmental problems associated with extensive and under-productive cattle ranching by government programmes and a range of non-government-led trial initiatives to improve both the productivity and sustainability of cattle farming systems in many areas. In 2005, the Brazilian Agricultural Research Corporation (EMBRAPA – *Empresa Brasileira de Pesquisa Agropecuária*, in Portuguese) launched a package of good agricultural practices for cattle ranching (hereafter GAP) to “ensure the production of safe food and quality attributes that meet the interests of major markets” (EMBRAPA, 2007). There are 12 sets of GAP that may be broadly divided into practices focused on (i) animals (animal wellbeing, identification, sanitary control, reproductive management, pre-slaughter management and supplemental feeding), (ii) the environment (environmental management, which includes compliance with environmental legislation), (iii) pasture management, which includes recuperation or pasture renovation, and (iv) administration (management of rural property, social functions of the property, human resources management and farm facilities maintenance). Given the focus of the GAP to increase farm productivity through improved pasture management, animal wellbeing and improved breeding, and its support of the adoption of environmental and labour laws, these practices can contribute significantly to a transition away from low-productivity pasture systems (EMBRAPA, 2007). In addition, in 2010, the Brazilian government, perceiving the potential of low-productivity pastures to diminish carbon emissions, launched the ‘Low-Carbon Agriculture Plan’ (*Agricultura de Baixo Carbono* in Portuguese, hereafter ABC), with a primary goal to restore 15 million hectares of degraded pastures and to incentivize the adoption of improved agricultural practices. However, most pasturelands remain under-productive, with less than one animal unit per hectare (AU = 0.7 of cattle head) (Nogueira et al., 2013; Dias-Filho, 2014).

Given the persistence of extensive and unsustainable cattle farming across Brazil and elsewhere in the tropics, there is an urgent need to better understand the factors affecting farmers' decisions regarding land use, and cattle farming in particular. Despite widespread recognition of, and intense policy interest in, the problems associated with extensive cattle farming, the barriers facing the adoption of improved cattle management practices have been relatively poorly explored in Brazil. Previous studies have focused on issues related to cultural resistance and attitudes (Wagner and Rocha, 2007), education (Vicente, 2002), financial aspects (Wagner and Rocha, 2007), technical extension services (Buainain and Souza filho, 1998), labour availability (Souza-Filho et al., 2011), property size (Souza-Filho et al., 2011) and biophysical conditions (Vicente, 2002). However, few of these studies are empirically based and none have systematically assessed the perspectives of cattle farmers regarding the relative importance of different barriers facing the adoption of improved management practices. Understanding farmers' perceptions is essential if the desired behavioural changes are to be achieved at scale and over the long term (Edwards-Jones, 2006; FAO, 2014; Halbrendt et al., 2014; Lastra-Bravo et al., 2015).

This study seeks to overcome this knowledge gap by systematically assessing the opportunities for and barriers to adoption of improved cattle management practices in Brazil. We first report the benefits of the adoption of better land management practices as perceived by cattle ranchers. Second, we identify the principal bottlenecks to this adoption and propose recommendations regarding how to overcome some of these obstructions. Third, we analyse whether the adoption of good agricultural practices is associated with increases in cattle productivity, and we explore the possible relationship between changes in farm productivity and forest cover. We focus on the state of Mato Grosso in Brazil, a major agricultural-forest frontier region where

decisions regarding farming practices are tightly linked to deforestation dynamics. Finally, we discuss lessons learned from the Brazilian example for decision-makers involved in promoting sustainable land management elsewhere.

## 2. Methods

### 2.1. Study area

The research was performed in the Amazon part of the state of Mato Grosso (Fig. 1). Mato Grosso is one of the fastest growing agricultural regions in the world (Graesser et al., 2015) and is among the most important states for cattle ranching and agriculture in Brazil, holding the largest herd in the country, with more than 29 million heads (ACRIMAT, 2012) and the stocking rates of 1.21 heads/ha (IMEA, 2012). Moreover, it is among the states with the highest deforestation rates (INPE, 2015). By 2009, more than 20 municipalities of Mato Grosso were included on the Ministry of Environment's 'Black List' of municipalities with high rates of deforestation (Nepstad et al., 2014).

Alta Floresta, a municipality where a more focused study was performed, is located in northern Mato Grosso (Fig. 1) in the arc of the deforestation region. Comprising approximately 2317 properties spread over 535,321 ha, it hosts a cattle herd of nearly one million heads (IBGE, 2006). Because of its high deforestation rate, it was included on the Black List in 2007. Several programmes have been developed to promote better environmental practices amongst producers in the municipality by providing information, technical assistance and funding; increasing production; and reducing deforestation (Alves-Pinto et al., 2015). As a result, the municipality was recently removed from the Black List and is currently one of only a few municipalities that have more than 80% of its private properties registered in the Rural Environmental Registry (*Cadastro Ambiental Rural* in Portuguese, hereafter CAR). Being listed on this registry has been a requirement since 2012 to be compliant with Brazilian environmental law and to have access to rural credit.

### 2.2. Research approach

A pilot questionnaire (N=5) was developed on the basis of consultations with local farmers to maximise the relevance of the study to local conditions and issues related to the adoption of improved management practices. We also conducted a series of meetings with local stakeholders, including members of local non-governmental organisations (NGOs), researchers, farmers and technical assistants, to design a robust research approach that gathered data in a credible and comprehensive manner. The research approach consisted of focus groups (N=25), data validation events (N=23), semi-structured phone interviews (N=250), follow-up structured phone interviews (N=82) and stakeholder semi-structured interviews (N=17). Upon consultations with the farmers and other stakeholders such as local NGOs implementing programmes on better land management, we adopted Embrapa's GAP protocol of improved cattle management practices as our proxy for adoption of better land management. It was agreed by all these stakeholders that the adoption by the farmers Embrapa's GAP reflects best the producer's shift towards sustainable land management in the Amazon. There are 12 GAP: management of rural property, social function of rural property, management of human resources, environmental management, rural facilities, pre-slaughter management, animal welfare, pasture management, supplemental feeding, animal identification, sanitary control, and reproductive management. After consultations with technical extension assistants, for the purposes of this study, we merged the practices related to pre-slaughter management and animal welfare because they were suggested to be closely linked.

### 2.3. Focus groups

Focus groups are considered to be an appropriate method to collect data under circumstances of data scarcity (Bloor et al., 2001). In this study, focus groups were useful for (i) understanding farmers' perspectives regarding barriers to the adoption of the GAP, (ii) exchanging knowledge amongst farmers regarding the

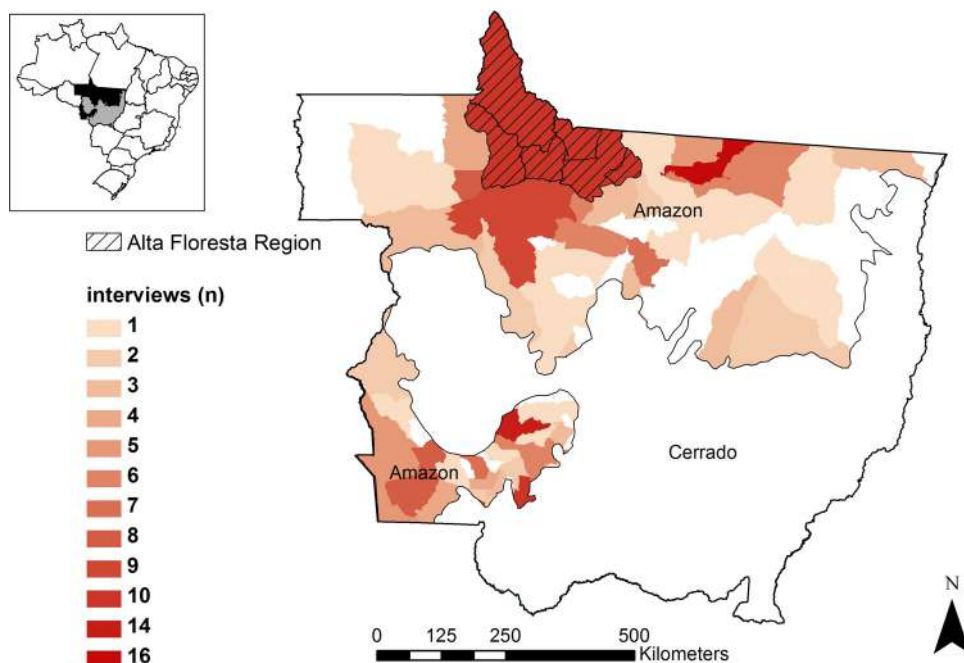


Fig. 1. Study area and the number of interviews performed in each region of Mato Grosso (only Amazon biome). Hatched is the region of Alta Floresta.

adoption of the GAP and (iii) developing a broader survey that was subsequently administered to 250 farmers. A detailed description of the focus groups' dynamics is included in the Supplementary material.

The focus groups were conducted with farmers from the municipality of Alta Floresta in December 2013. The 25 participants were divided into five focus groups. Each focus group had two moderators (one from a local NGO and one trained moderator). The answers to the question, "What are the difficulties associated with adopting GAP for cattle ranching?" were indexed and ascribed to categories (e.g. labour, finance, awareness, technology, credit access, technical assistance) using an induction analysis (deviant analysis; Bloor et al., 2001). As each farmer was asked to mark the most important barriers, we then were able to rank the answers by using the following equation:

$$P_c = \frac{n_c}{3 \cdot \sum_{i=1}^5 m_i} \quad (1)$$

$P_c$  = percentage of choice  $c$ ,  $N_c$  = number of answers in choice  $c$ ,  $m_i$  = number of members in group  $i$ .

The complete list of answers and rankings are included in the Supplementary material.

During the focus group, an anonymous questionnaire was administered. The responses to the questionnaire provided contextual information that some respondents would not otherwise share but that might have been important factors in decision-making, such as salary, education level, and stocking rates. Although we were unable to link information from the participant of the focus group to specific responses, the responses to the questionnaire provided valuable information regarding the backgrounds of the farmers who participated in the research and, for some questions, enabled triangulation of the responses. Of the 20 questionnaires retrieved, only 17 were complete and used for further analysis (Supplementary material).

A second meeting with the producers from Alta Floresta was organized in July 2014 to present the results from the focus groups and the questionnaire. This event included 23 producers and provided an opportunity, through moderated discussion, to validate the results and clarify ambiguities that arose during the analysis of the focus groups results. Details regarding the feedback event are available in the Supplementary material.

#### 2.4. Large sample questionnaire

Data from the focus groups, the anonymous questionnaire and the feedback event were used to enhance the questionnaire that was administered to 250 farmers throughout 2015. We opted for telephone interviews because of the logistical challenges inherent in securing personal interviews and the lack of Internet access amongst the target population, which precluded e-mailing the questionnaire. To increase the credibility of the obtained data, the phone interviews were conducted by an organization that has an established relationship with the farmers and has experience with phone interview surveys. The criteria for sampling included the following: farms must be located in the Amazon biome, they must have separate data on farm and pasture areas, and the final research sample must have a range of stocking rates. The farm area of the interviewed cattle ranchers followed the distribution of the farm area according to the IBGE (2006) and is presented in Table 1 (along with pasture area). The stocking rates are presented in Table 2. Figures representing farm size distribution in this study in addition to the IBGE and other background information (e.g., education level) are presented in the Supplementary material. The majority of the interviewees ( $N=60$ ) were from the Alta Floresta micro-region. The rest of the respondents were distributed

**Table 1**

Number of questionnaires retrieved in each class of property size.

Area class (in hectares)	Property total area (N)	Pasture total area (N)
<100	10	10
100–250	16	25
250–500	24	29
500–1000	35	36
1000–1500	18	28
1500–2000	21	12
2000–5000	47	24
5000–10,000	16	16
>10,000	27	7
Lack of answer	36	63

**Table 2**

Distribution of retrieved questionnaires depending on the stocking rate.

Stocking rates (AU/ha)	N
<1.0	18
1.0–1.5	45
1.5–2.0	56
2.0–2.5	10
2.5–3.0	22
>3.0	23
Lack of answer	76

throughout the municipalities (Fig. 1). We opted for this distribution to verify whether the results from the focus groups with the farmers from Alta Floresta could be extrapolated to the entire region and to determine whether any differences existed between the Alta Floresta micro-region and the rest of Mato Grosso. In recent years, there has been a range of initiatives aimed at sustainable land management to remove Alta Floresta from the Black List; therefore, we hypothesised that the stocking rates and the adoption of better land management would be higher there than in other regions of Mato Grosso.

One prerequisite of this research was that the majority of the interviewed farmers had to be familiar with GAP. This was determined after our previous research into opportunities and constraints with respect to the adoption of GAP in another Brazilian state (São Paulo), where low familiarity with these practices precluded a comprehensive analysis of the obtained data (see Supplementary material for details of this research and Strassburg et al., 2014b).

The semi-structured questionnaire used in this study was divided into four broad areas:

- Background information, such as location, size of farm and pasture area, stock size, degraded area of the farm, education, and age;
- Good agricultural practices, i.e., knowledge of different GAP, level of adoption of GAP and willingness to adopt different practices, and integrated systems;
- Barriers to adopting GAP;
- Forest conservation and management, i.e., area of the farm under forest cover, intention and willingness to reforest, and benefits of the forest.

The full list of questions is included in the Supplementary material.

Descriptive statistical analyses were performed using IBM SPSS Statistics 20. Other statistical analyses were performed using the R software package (R Core Team, Vienna, Austria, 2013), including a log-linear analysis to test the correlation between socioeconomic



variables (such as stocking rate, education, and age) and the adoption of different practices. Log-linear analyses do not assess causal relationships but instead assume that the observations are independent and random and that they can indicate correlations among several categorical variables, as defined by

$$X^2 = 2 \sum O_{ij} \ln \frac{O_{ij}}{E_{ij}} \quad (2)$$

$O_{ij}$  = observed frequency ( $i$  = observation;  $j$  = variable),  $E_{ij}$  = expected frequency,  $X^2$  = deviance for the model.

We also performed a probit analysis (regression with binary dependent variable) to investigate which factors influence the probability that the farmer will adopt GAP, where adopt is  $y = 1$  and not adopt is 0, and whether there is a relation between the adoption of GAP and compliance with the requirement of the new Forest Code (Law 12.651/12), the law that requires farmers in the study region to maintain 50% of their farm as natural vegetation. The formal definition of probability in the probit model is

$$P_i = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{U_i} \exp\left\{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right\} dx \quad (3)$$

$P_i$  = probability of event  $i$ ,  $U_i$  = value of utility function associated with event  $i$ ,  $\mu$  = mean of the associated normal distribution,  $\sigma$  = variance of the associated normal distribution.

Furthermore, we used a general linear model (GLM) with a normal distribution to evaluate the influence of the variable stocking rate, scale of production (cattle herd), GAP adoption, and access to credit on the percentage of forest retained inside the farm.

### 2.5. Stakeholder interviews

To complement the producers' perspective on the adoption of good agricultural practices, we performed semi-structured interviews with a range of non-farmer stakeholders who were associated with the cattle production chain (representatives from the local farmer association, local government, and an organization that provides technical assistance,  $N=17$ ; see details in the Supplementary material). We also aimed to verify whether any differences existed between expert opinions and producers' personal perspectives.

## 3. Results and discussion

### 3.1. Adoption of good agricultural practices and perceived benefits

Sanitary control was found to be the most commonly adopted GAP (82%, Fig. 2). This was not an unexpected result, because compliance with animal health requirements, such as vaccinations for the control and eradication of diseases, including foot and mouth and brucellosis (for females between four and nine months of age), is enforced by the Brazilian authorities (MAPA, 2009). Sanitary control is also directly associated with export to international markets that can impose strict embargos (MAPA, 2009). High adoption rates are also supported by the fact that good sanitary control contributes to better animal development and performance, and reduced mortality rates (Knight-Jones and Rushton, 2013). The second practice, adopted by 70% of the respondents, is related to rural farm infrastructure, such as irrigation, energy and storage. The third practice, which is aimed at environmental management and includes listing in the CAR or complying with the Forest Code, was adopted by 65% of the farmers. Animal identification and reproductive management were the least-adopted practices (46%), perhaps because these practices are expensive and may be adopted for only certain management systems (Cócaro and Jesus, 2008).

One of the techniques that may increase cattle ranching productivity is the use of integrated systems on the same farm (Herrero et al., 2010). Despite 94% of the respondents being aware of integrated systems, the majority had not adopted them (67%). Of those respondents who had adopted integrated systems, the majority (88%) had adopted integrated crop-livestock systems, whereas the remaining 12% had adopted the silvopastoral – livestock-forestry or crop-livestock-forestry – system; these results were consistent with the results of Gil et al. (2015), who have found similar results for 41 municipalities from Mato Grosso. Only 10% of the respondents were interested in crop-livestock-forestry, and 26% were interested in crop-livestock or livestock-forestry. We also found that 41% of the respondents were not interested in any sort of integration. Gil et al. (2015) have found that the farmers who were not willing to introduce silvopastoral systems on their farms noted financial reasons and difficulties selling forest products. Our study found that the attitudes of farmers regarding adoption of a crop-livestock-forestry system was the dominant cause for their refusal, as illustrated by comments from respondents such as: “There is already enough forest around” and “I am not interested”.

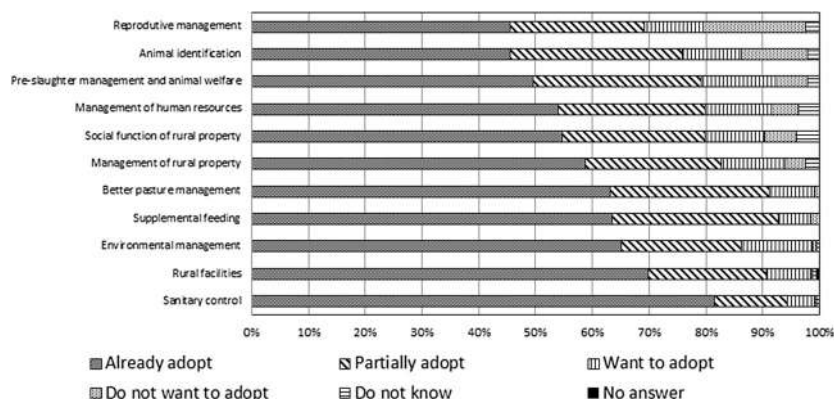


Fig. 2. The adoption of Embrapa's good agricultural practices in Brazilian cattle ranching.

**Table 3**

Correlation between stocking rates, agricultural practices and other variables. Values below 0.005 represent statistically significant correlation.

	Stocking rate (AU/ha)	Adopts GAP in general	Adopts improved pasture management
Perceives benefits of intensification	0.55	0.55	0.10
Planning (in years)	0.59	0.20	0.56
Education	0.76	0.46	0.71
Farming is the primary source of income	0.26	0.63	0.49
Herd size	0.59	0.00	0.10
Adopts GAP in general	0.13	–	–
Adopts improved pasture management	0.01	–	–

Crucially, the adoption of improved pasture management practices, such as rotational grazing, was significantly related to the stocking rate value (Table 3), and farmers adopting improved pasture management were 22% more likely to have higher stocking rates (see Supplementary material). Furthermore, herd size was significantly and positively associated with the adoption of GAP, whereas other key socioeconomic variables such as education and income source were not (Table 3). Considering the scale of the producers, smaller-scale farms showed significant impact of improved pasture management on the stocking rates (Table 4). This result may be because smaller producers need to be more efficient because they cannot compensate for low levels of productivity with the scale of production. It does not mean that improving the management of pastures improves stocking rates only at smaller scales but it does corroborate that marginal effects of improved productivity are more pronounced for smaller-scale producers (those usually with lower stocking rates; Berdegué and Fuentealba, 2011).

Improved pasture management is most often achieved in Mato Grosso through the use of rotational grazing. By fencing pasture areas and dividing them into plots, this method optimizes the establishment of forage species and plant growth and prevents degradation, thus increasing the availability of pasture for cattle (Eaton et al., 2011; Andrade et al., 2012; Latawiec et al., 2014). For example, Eaton et al. (2011) found a two to six-fold increase in forage production in the Brazilian Pantanal when rotational grazing was adopted.

The probability of adopting improved pasture management decreased by 17%, if the rural property was the main source of income. It may seem counterintuitive as it would be expected that if the cattle ranching is the main source of income, farmers would improve pasture management to maximise revenues. However, cattle ranchers are often unwilling to change their traditional practice, especially if it can increase financial risks. Furthermore, one of the critical drivers of low productivity in cattle ranching in Brazil is the feedback of low productivity and low revenues that implies low investments in the farm. On the other hand, farmers who have other economic activities may regard cattle ranching as a business that needs investment and continuous improvement; and consequently they may benefit from their business experience in those other areas. In addition, farmers who engage in off-farm activities may be more resilient to shocks and are less risk-averse because they have more diverse income portfolios (Lin, 2011).

We also found that if the property was registered in the CAR, the likelihood of adopting improved pasture management increased by 31%. This result can be explained by the need for credit access

because the new Forest Code mandate that Brazil's banks require farms to be registered to receive rural credit, even if they do not assess compliance with forest conservation (legal reserves). Or simply that those producers that implement GAP also implement CAR. Indeed, we found that 68% of the producers registered, 63% reported to comply with the requirements of the Forest Code, although according to our calculations less than half (42%) preserved the legal minimum level of forest cover. It may also be partially explained by the fact that following a legal settlement, Brazil's leading meatpacking companies now require that their suppliers are registered in the CAR systems. Furthermore, 84% of the respondents reported that ownership of the land is important: "the farmer is conservative and does not want to invest in land that is not his" reported one respondent.

The perceived benefits of the adoption of GAP include increased productivity (60%), increased income (43%) and improved farm administrative management (34%) (Fig. 3). The majority of the respondents (93%) agreed that it is worthwhile adopting GAP to increase pasture productivity because the 'benefits outweigh the costs'. Of these respondents, 90% indicated increases in yields, and thus income, as the motivating incentive.

We did not find any confirmation of our hypothesis that the producers in Alta Floresta adopted more good agricultural practices than producers elsewhere in Mato Grosso. In fact, the opposite was found: the probability of adopting GAP pasture in the micro-region of Alta Floresta was 43% lower than in the rest of the state. However, the initiatives to promote the adoption of GAP in Alta Floresta such as the Novo Campo Program are relatively recent. In addition, the stocking rates in Alta Floresta were higher than in the rest of Mato Grosso (2.57 against 1.21 heads of livestock per hectare). This result can be explained by relatively recent deforestation compared with other areas of Mato Grosso, thus rendering the pastures more fertile, or more favourable climatic conditions in Alta Floresta that facilitate the maintenance of higher stocking rates.

### 3.2. Barriers to the adoption of good agricultural practices

The most significant barrier to the adoption of GAP was a lack of qualified labour (65%; multiple choice question, Fig. 4), far ahead of all financial and technical constraints. When asked to point out the most important bottleneck the lack of labour was corroborated by the respondents (Supplementary material). This is a striking result with wide-ranging technical and socioeconomic implications. In Mato Grosso each additional worker increases the size of the herd by 3.89 heads, given a fixed area of pasture (Supplementary

**Table 4**

Correlation between the adoption of GAP, improved pasture management and stocking rates depending on the production scale (measured as herd size). Values that are smaller than 0.005 are statistically significant.

	<500 heads	501–1500 heads	1501–3000 heads	>3000 heads
Adopts GAP in general	0.30	1.00	0.42	0.87
Adopts improved pasture management	0.01	0.91	0.22	0.52

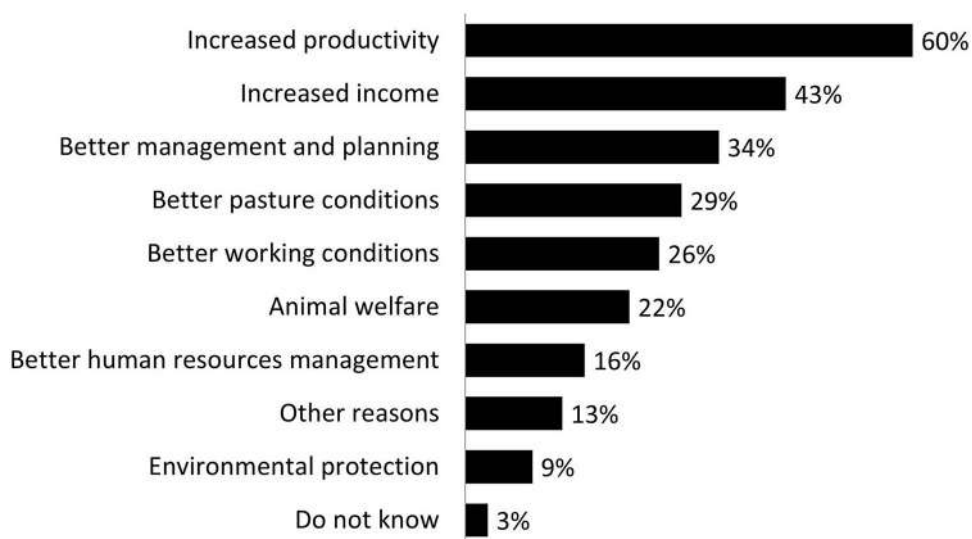


Fig. 3. Perceived benefits of the adoption of Embrapa's good agricultural practices.

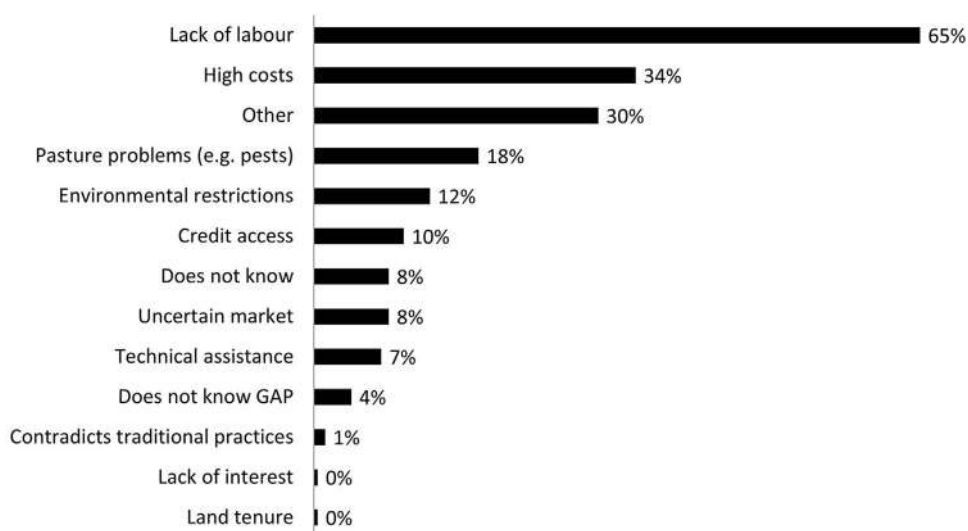


Fig. 4. Limitations perceived by the cattle ranchers to adopt Embrapa's good agricultural practices (multiple choice question).

material). Although similar results regarding labour scarcity have also been found in an earlier work in the 1990s in the state of Pará (Perz and Skole, 2003), our survey demonstrates that labour scarcity is a persistent problem in frontier regions. Perz and Skole (2003) has found that the farmers who were most likely to use pasture rotation are those close to the market and with ready access to qualified labour. Labour scarcity and low remuneration for rural jobs have also been highlighted as key barriers to other economic activities, such as restoration, thus indicating that this is a general problem. In some regions of Brazil, labour shortages for the agricultural sector have been linked to rural-urban migration (Strassburg et al., 2014b). Moreover, during our focus groups, insufficient funds, the lack of a qualified team and problems with credit access were identified as the principal barriers to the adoption of GAP (Supplementary material).

High implementation costs were the second-most-important barrier to adopting GAP according to 34% of the farmers surveyed (Fig. 4). We also found, through both focus groups and interviews, that even though credit is theoretically available, it may not be

accessible, owing to inhibitive levels of bureaucracy and a lack of capacity of the local agency to process applications. Of the respondents to the larger survey, 60% indicated that bureaucracy, understood as delays and problems with providing adequate documentation (31%) were the principal barriers associated with credit access (Fig. 5), echoing our preliminary findings from the focus groups. Similar results have been reported by Gil et al. (2015), who have found that farmers who had applied for the ABC credit lines (17% of the survey participants) indicated bureaucracy as the main obstacle. Therefore, the financial support for initiatives aimed at better land management must extend beyond making funds nominally available and must include financial mechanisms to efficiently channel these funds such that the impact on the ground can be higher. Indeed, Brazil's ABC Plan has had funds available since 2010, but uptake was severely limited in the first years (13% of the funds actually being disbursed), increasing to approximately 43% on average since then, still a relatively low pick up (Angelo, 2012; Lopes and Lowery, 2015). Although the situation has improved, it remains unclear whether the funding is reaching

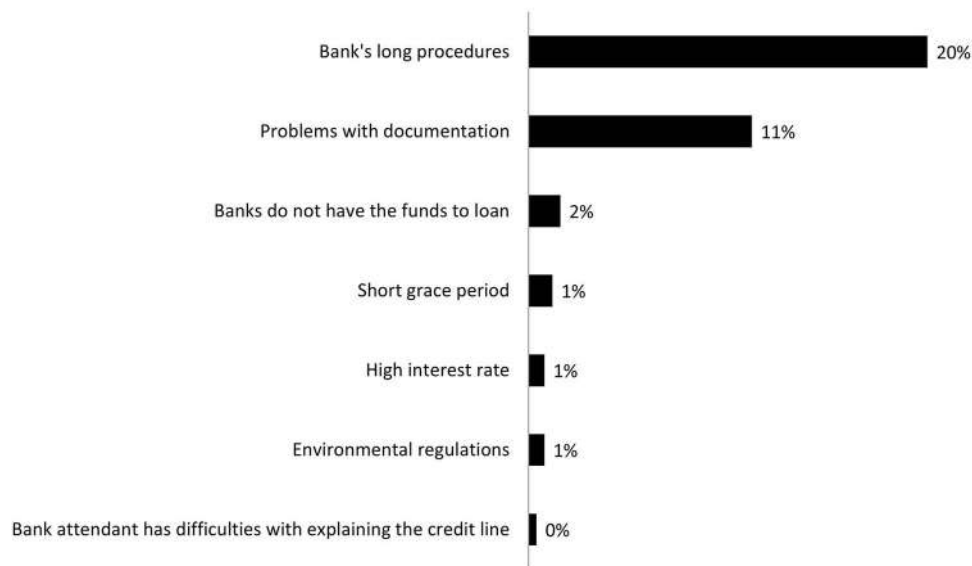


Fig. 5. Problems associated with rural credit access.

the areas where it is most needed. There is also a lack of incentives for bank managers to disburse ABC credit. Because major international funding programmes for agriculture development, land-based mitigation and restoration have encountered similar problems, they, too, would greatly benefit from efficient fund allocation mechanisms.

The majority of the farmers (63%) used technical assistance to adopt GAP, and 81% of the respondents claimed to be satisfied with the assistance that they have received. It was only through the follow-up study that we identified that a significant proportion (40%) of the technical assistance was being provided by vendors of fertilizers and other agrochemicals, which raises questions about potential conflicts of interest and the sustainability of this technical assistance.

The perception of key barriers to the adoption of GAP differed between producers and other stakeholders. Although high costs, labour scarcity and technical assistance were also noted by the interviewed stakeholders as difficulties in the region, 13 of 17 stakeholders noted a lack of interest on the part of the farmers and insufficient dissemination of information regarding GAP as the principal barriers facing the adoption of good agricultural practices at scale. On the other hand, the results of our interviews with the producers showed that 73% of them understood what GAP are, and although the majority of the respondents had not yet implemented GAP, they were interested (Table 3 and Supplementary material). Similarly, Halbrendt et al. (2014) have found that there are discrepancies between expert opinions and the local community regarding the adoption of technologies for conservation agriculture, thus reinforcing the need for more comprehensive surveys than those based only on expert opinions. Although the responses of the stakeholders and producers regarding the barriers to adoption of GAP differed, they both indicated the need for increased capacity building (qualified worker and knowledge dissemination). Indeed, the producers who answered that they were not interested in adopting GAP ( $N=19$ ) claimed a lack of information about GAP and high costs associated with implementing GAP as their principal reasons ( $N=5$  and  $N=7$ , respectively). Notably, the difference between the producers and other stakeholders may be explained by our sampling since the majority of the interviewed farmers was familiar with GAP. Details regarding the

results of the stakeholder interviews can be found in the Supplementary material.

Capacity building is the leading solution to facilitate the adoption of GAP by producers, and was cited by 47% of farmers. This comprises the provision of qualified labour and improving the dissemination of information about GAP. The second-most-common answer (41%) was related to financial aspects of farm management, including reducing the costs associated with GAP implementation, increasing market favourability to more environmentally friendly products, and increasing credit access (minimizing bureaucracy) and other financial incentives from the government.

The Novo Campo Program, developed in the municipality of Alta Floresta, implements demonstration units on farms where good agricultural practices, such as pasture rotation, are implemented (ICV, 2015). These are often used as showcases for farmers from the same or different regions who visit the area because exposure to information and implementation are important for

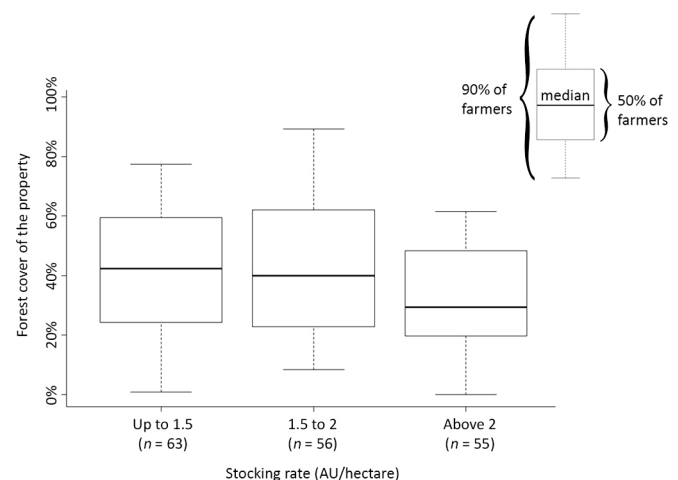
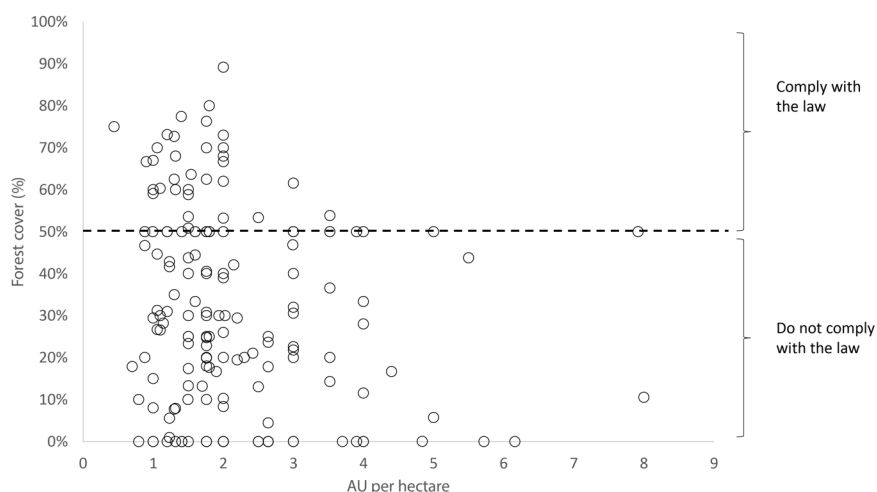


Fig. 6. Relationship between cattle stocking rates (AU/ha) and area of the farm covered by forest (%). Numbers are based on the data from the large sample questionnaire.





**Fig. 7.** Relationship between stocking rates (AU/ha) and forest cover at the farm (%). Dashed line indicates the area of the farm that needs to be covered by the forest to comply with the environmental law (50% of the farm needs to be covered by the forest).

adoption of agricultural innovations (Guerin and Guerin, 1994; Chi and Yamada, 2002; Pannell et al., 2006).

### 3.3. Adoption of improved agricultural practices and forest conservation

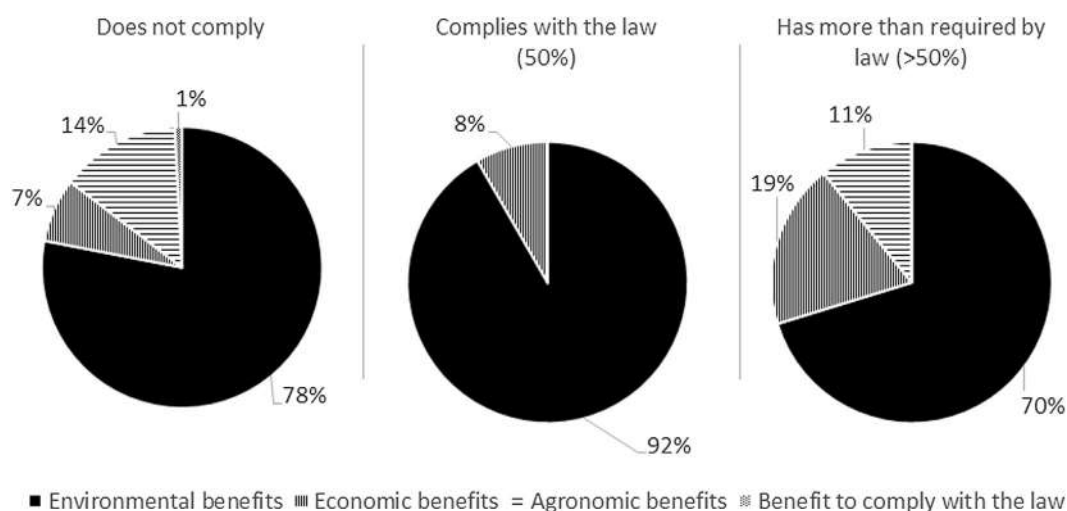
A key result of our survey was that farms with higher stocking rates (adopting GAP pasture) generally had a lower level of forest cover (chi-squared less than 5% and regression coefficient of  $-0.22$ ; Fig. 6). This can be explained in several ways. One possibility is that the farmers who had previously cleared their land, adopted GAP afterwards as a shift towards a better land management. Also there may be a non-causal correlation with farmers both clearing the land and increasing stocking rates because they have more capital. This observation may also be explained by a type of rebound effect in which increased profits from higher-productivity cattle ranching can drive the increased expansion of cattle pasture into the remaining areas of the forest (Lambin and Meyfroidt, 2011). Stocking rates above three to four animal units per hectare in Brazil can generally be considered unsustainable from the perspective of pasture management (Strassburg et al., 2014a).

We also found that farmers with more than four AU per hectare tended not to comply with the requirements of the Forest Code in

terms of areas of the farm being set-aside for conservation. In the Amazon biome, this corresponds to 80% of the property, but in Mato Grosso, 50% of the farm needs to be forested (Fig. 7). We found that there was a 32% probability of farmer compliance with the set-aside requirements of the Forest Code. However, if a farm adopted improved pasture management practices, there was a 22% greater probability of the farmer not complying with the Forest Code (using a 10% significance level given small sample size; see the Supplementary material). None of the other factors (scale of production, stocking rate or credit access) were associated with the conservation of forests on the farms analysed in this study (chi-squared greater than 5%).

Our results underscore the need for improved technical assistance in addition to the need to align sustainability incentives across different policies and incentive schemes, for example, to avoid the perverse outcome of rebound effects following increases in productivity. Currently, to obtain credit, farmers must declare that they have CAR and that they are in compliance with the Forest Code, although this information is rarely verified. Our results seem to support the need for verification and linking streamlined access to credit or technical support to CAR compliance.

Interestingly, we found that a substantial number of these frontier farmers (70%) believed that forests provided them with



**Fig. 8.** The perception of forest benefits. With increasing % of area covered by forest at the farm, the perception of economic benefits of the forest increases.

benefits (mainly water). However, the majority did not believe that forests provided any financial benefits (70%), whereas the other 30% agreed that forests provided financial gain. The reason given by the majority of farmers (90%) for reforestation was to comply with the Forest Code, whereas 11% cited economic benefits, e.g., market access and credit access, and 3% (9 of 250 respondents) indicated that environmental protection was the primary reason for engaging in reforestation (multiple choice question). Different results were found by Trevisan et al. (2016) that show that few farmers in the Atlantic Forest region were willing to comply with the Code. We found that compliance with the law increased when the farmers realised the economic value of forests, i.e., credit access, ecosystem services and no clear-cutting exploration (Fig. 8).

#### 4. Conclusions

If the ambitious food security, conservation and restoration targets such as the Sustainable Development Goals, the Paris Agreement on Climate Change and the New York Declaration on Forests are to be met simultaneously, wholesale improvements are needed in how land is managed. There are huge and untapped opportunities to improve agricultural practices, especially cattle farming, across much of the tropics, and even marginal improvements in productivity have been shown to both increase farmers' incomes and reduce negative impacts on the environment. Such improvements have yet to be widely adopted in many agriculturally under performing regions and countries.

Our study highlights a range of factors that influence the adoption of good agricultural practices in cattle ranching systems in the Brazilian Amazon. We found that the adoption of some of these practices, such as improved pasture management, increases cattle ranching stocking rates. Yet such improvements do not necessarily come hand-in-hand with improved protections of remaining areas of native vegetation, with land owners that have adopted improved pasture management being more likely to have less forest. Reconciling agricultural improvements and environmental protection thus requires increased effort to overcome problems of credit access, technical extension and labour scarcity, while improving efforts to monitor and enforce compliance with environmental regulations, which can in turn be used as a condition for easier access to credit. Efforts to foster the adoption of more sustainable land management practices at scale, including both agricultural and conservation areas, require early engagement with a representative and broad range of stakeholders, in particular farmers.

Sustainable practices for improving yields, whilst promoted for several years in the scientific literature and through demonstration units in many developing countries, have not been widely adopted. A poor understanding of what the farmers themselves perceive as the major barriers to good practice has been a key factor in contributing to this situation. This paper highlights the need to give more systematic consideration to both socioeconomic conditions and farmer's perspectives in the development of both agricultural policies and conservation incentive schemes.

#### Acknowledgements

Betty and Gordon Moore Foundation and Norwegian Agency for Development Cooperation – Norad are gratefully acknowledged for their financial support. We thank very much the cattle-ranching producers and other stakeholders that found their time and willingness to take part in the pilot study, focus groups and interviews. Sindicato Rural de Alta Floresta is gratefully acknowledged for invaluable help to host and organise focus groups. We gratefully acknowledge Holly Gibbs, Rita Pereira, Ramon Arigoni

Ortiz, Rachael Garrett and Erasmus zu Ermgassen for their useful comments on the research related to focus groups. We thank the moderator, Prof. Samuel Giordano, and others that helped to run the focus groups: Larissa Stoner, Mauricio Penteado, Laurent Micol, Eduardo Florence and Vando Telles. We thank Scot Consultancy for their professionalism, commitment and smooth collaboration while executing large sample interviews and the follow up study. Thanks to Pedro Sales for great help with Portuguese translation and formatting. Prof. Andrew Balmford and Dr. Ben Phalan are gratefully acknowledged for their useful comments that greatly improved the analysis and interpretation of the results.

#### 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.agee.2017.01.043>.

#### References

- ACRIMAT, 2012. Diretrizes para o Desenvolvimento da Pecuária de Corte no Estado do Mato Grosso. Associação dos Criadores de Gado do Mato Grosso, Cuiabá, MT.
- Alves-Pinto, H.N., Newton, P., Pinto, L.F.G., 2015. Reducing deforestation and enhancing sustainability in commodity supply chains: interactions between governance interventions and cattle certification in Brazil. *Trop. Conserv. Sci.* 8 (4), 1053–1079.
- Andrade, C.M.S., Garcia, R., Valentim, J.F., Pereira, O.G., 2012. Productivity, utilization efficiency and sward targets for mixed pastures of marandugrass, forage peanut and tropical kudzu. *R. Bras. Zootec.* 41, 512–520.
- Angelo, C., 2012. Brazil's fund for low-carbon agriculture lies fallow. *Nature* doi: <http://dx.doi.org/10.1038/nature.2012.11111>.
- Baillie, J.E.M., Hilton-Taylor, C., Stuart, S.N., 2004. Red List of Threatened Species A Global Species Assessment. IUCN, Gland, Switzerland and Cambridge, UK, pp. XXIV.
- Berdegúe, J.A., Fuentealba, R., 2011. Latin america: the state of smallholders in agriculture-1. International Fund for Agricultural Development, Via Paolo Di Dono, 44, Rome 00142, Italy.
- Bloor, M., Frankland, J., Thomas, M., Robson, K., 2001. Focus Groups in Social Research: Introducing Qualitative Methods. Sage Publications, London.
- Buainain, A.M., Souza filho, H.M., 1998. PROCERA: impactos produtivos e capacidade de pagamento. FAO: INCRA. Relatório do Convênio FAO/INCRA., Brasília, DF.
- Cócaro, H., Jesus, J.C.S., 2008. Casos sobre a rastreabilidade bovina em empresas rurais informatizadas: impactos gerenciais. Anais do XLVI Congresso da Sociedade Brasileira de Economia. Administração e Sociologia Rural. Rio Branco, AC.
- Chi, T.T.N., Yamada, R., 2002. Factors affecting farmers' adoption of technologies in farming system: a case study in Omon district, Can Tho province, Mekong Delta. *Omonrice* 10, 94–100.
- Dias-Filho, M.B., 2014. Diagnósticos das pastagens no Brasil Belém: Embrapa Amazônia Oriental. Série Documentos. 402. (Available from: <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/986147/diagnostico-das-pastagens-no-brasil>).
- EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), 2007. Boas práticas agropecuárias – bovinos de corte. Campo Grande, MS: Embrapa Gado de Corte. Available from: [http://www.agricultura.gov.br/arq\\_editor/7.pdf](http://www.agricultura.gov.br/arq_editor/7.pdf).
- Eaton, D., Santos, S.A., Santos, M., Lima, J., Keuroghlian, A., 2011. Rotational Grazing of Native Pasturelands in the Pantanal: an effective conservation tool. *Trop. Conserv. Sci.* 4, 39–52.
- Edwards-Jones, G., 2006. Modelling farmer decision-making: concepts, progress and challenges. *Anim. Sci.* 82, 783–790.
- FAO, 2014. Understanding Smallholder Farmer Attitudes to Commercialization—The Case of Maize in Kenya Rome. . Online <http://www.fao.org/3/a-i3717e.pdf>.
- Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, S.F., Coe, M.T., Daily, G.C., Gibbs, H., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C., Monfreda, C., Patz, J.A., Prentice, C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. *Science* 309, 570.
- Gibbs, H.K., Ruesch, A.S., Achard, M.K., Clayton, M.K., Holmgren, P., Ramankutty, N., Foley, A., 2010. Tropical forests were the primary sources of new agricultural land in the 1980 and 1990. *Proc. Nat. Acad. Sci.* 107 (38), 16732–16737.
- Gil, J., Siebold, M., Berger, T., 2015. Adoption and development of integrated crop-livestock-forestry systems in Mato Grosso Brazil. *Agric. Ecosyst. Environ.* 199, 394–406.
- Graesser, J., Aide, T.M., Grau, H.R., Ramankutty, N., 2015. Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environ. Res. Lett.* 10, 034017.
- Guerin, L.J., Guerin, T.F., 1994. Constraints to the adoption of innovations in agricultural research and environmental management: a review BC Aust. J. Exp. Agric. 34, 549–571.
- Halbrendt, J., Gray, S.A., Crow, S., Radovich, T., Kimura, A.H., Tamang, B.B., 2014. Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. *Global Environ. Change* 28, 50–62.

- Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., van de Steeg, J., Lynam, J., Parthasarathy Rao, P., Macmillan, S., Gerard, B., McDermott, J., Seré, C., Rosegrant, M., 2010. Smart investments in sustainable food production: revisiting mixed crop livestock systems. *Science* 327, 822–825.
- Censo Agropecuário 2006: Brasil 2006. Rio de Janeiro-RJ: IBGE. Online. [http://biblioteca.ibge.gov.br/visualizacao/periodicos/51/agro\\_2006.pdf](http://biblioteca.ibge.gov.br/visualizacao/periodicos/51/agro_2006.pdf)
- ICV, 2015. Novo Campo Program a Strategy for Sustainable Cattle Ranching in the Amazon. Instituto Centro de Vida, pp. 2015.
- IMEA, Instituto Mato-Grossense de Economia Agropecuária, 2012. AgroMT2022 OutlookIMEA, Cuiabá. Available at <http://pt.slideshare.net/BeefPoint/imea-agromt-outlook-2022>.
- INDC, 2015. Federative Republic of Brazil Intended Nationally Determined Contribution. Owards Achieving the Objective of the United Nations Framework Convention on Climate Change. (Online) <http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20INDC%20english%20FINAL.pdf>.
- INPE, 2015. Projeto PRODES—Monitoramento Da Floresta Amazônica Brasileira Por Satélite. Online <http://www.obt.inpe.br/prodes/index.php>.
- IPCC, 2007. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Online [https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4\\_wg3\\_full\\_report.pdf](https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf).
- Knight-Jones, T.J.D., Rushton, J., 2013. The economic impacts of foot and mouth disease –What are they, how big are they and where do they occur? *Prev. Vet. Med.* 112 (3–4), 161–173.
- Lambin, E.F., Geist, H., 2006. Land-use and land-cover change. Local Processes and Global Impacts. Springer, Berlin; New York, pp. c2006.
- Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl. Acad. Sci. U. S. A.* 108, 3465–3472.
- Lastra-Bravo, X.B., Hubbard, C., Garrod, G., Tolón-Becerra, A., 2015. What drives farmers' participation in EU agri-environmental schemes? Results from a qualitative meta-analysis. *Environ. Sci. Policy* 54, 1–9.
- Latawiec, A.E., Strassburg, B.N.S., Valentim, J., Ramos, F., Nery Pinto, H., 2014. Intensification of cattle ranching production systems: socioeconomic and environmental synergies and risks in Brazil. *Int. J. Anim. Biosci.* 8 (8), 1255–1263.
- Latawiec, A.E., Strassburg, B.B.N., Brancalion, P.H.S., Rodrigues, R.R., Gardner, T., 2015. Creating space for large-scale restoration in tropical agricultural landscapes. *Fron. Ecol. Environ.* 13 (4), 211–218.
- Lin, B.B., 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. *Bioscience* 61, 183–193.
- Lopes, D., Lowery, S., 2015. Rural credit in Brazil: challenges and opportunities for promoting sustainable agriculture. a forest trends policy brief. *For. Trends*. [http://www.forest-trends.org/documents/files/doc\\_5016.pdf](http://www.forest-trends.org/documents/files/doc_5016.pdf).
- MAPA, 2009. Manual de Legislação: programas nacionais de saúde animal do Brasil. Secretaria de Defesa Agropecuária. Departamento de Saúde Animal. –Brasília: MAPA/SDA/DAS. Online [http://www.agricultura.gov.br/arq\\_editor/file/](http://www.agricultura.gov.br/arq_editor/file/Aniamal/Manual%20de%20Legisla%C3%A7%C3%A3o%20-%20Sa%C3%BAde%20Animal%20-%20low.pdf)
- Aniamal/Manual%20de%20Legisla%C3%A7%C3%A3o%20-%20Sa%C3%BAde%20Animal%20-%20low.pdf .
- Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Motta, R.S., Armijo, E., Castello, L., Brando, P., Hansen, M.C., McGrath-Horn, M., Carvalho, O., Hess, L., 2014. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science* 344, 1118–1123.
- Nogueira, S.F., Silva, G.B.S., Andrade, R.G., Vicente, L.E., 2013. Geotecnologias para o monitoramento dos níveis de degradação das pastagens no Brasil. *MundoGEO* 15 (72), 60–64.
- Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. *Aust. J. Exp. Agric.* 46 (11), 1407–1424.
- Perz, S.G., Skole, D.L., 2003. Secondary forest expansion in the Brazilian Amazon and the refinement of forest transition theory. *Soc. Nat. Resour.* 16 (4), 277–294.
- Ramsey, R., Doye, D., Ward, C., McGrann, J., Falconer, L., Bevers, S., 2005. Factors affecting beef cow-herd costs, production, and profits. *J. Agric. Appl. Econ.* 37 (1), 91–99.
- Soares-Filho, B., Rodrigues, H., Follador, M., 2013. A hybrid analytical-heuristic method for calibrating land-use change models. *Environ. Modell. Softw.* 43, 80–87.
- Soares-Filho, B.S., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H., Alencar, A., 2014. Cracking Brazil's forest code. *Science* 344, 363–364.
- Souza-Filho, H.M., Buainain, A.M., Silveira, J.M.F.J., Vinholis, M.M.B., 2011. Condicionantes da adoção de inovações tecnológicas na agricultura. *CC&T* 28 (1), 223–255.
- Strassburg, B.B.N., Latawiec, A.E., Barioni, L., Assad, E., Porfírio, V., Valentim, J., 2014a. When enough should be enough: improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. *Global Environ. Change* 28, 84–97.
- Strassburg, B.B.N., Latawiec, A.E., Pentead, M., Stoner, L.A., Barros, F.S., Rangel, M.C., Sansevero, J.B.B., Irribarem, A., Feltran-Barbieri, R., Alves-Pinto, H., Resende, F., Lemgruber, L., Simas, M., 2014b. Análise integrada do uso da terra e de incorporação dos serviços ecossistêmicos na formulação de políticas regionais. Report Prepared for the Secretary of Environment Sao Paulo. International Institute for Sustainability, Bacia do Rio Paraitinga São Paulo.
- Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D., 2001. Forecasting agriculturally driven global environmental change. *Science* 292, 281–284.
- Trevisan, A.C.D., Schmitt-Filho, A.L., Farley, J., Fantini, A.C., Longo, C., 2016. Farmer perceptions, policy and reforestation in Santa Catarina. Brazil. *Ecol. Econ.* 130, 53–63.
- Vicente, J.R., 2002. Pesquisa, adoção de tecnologia e eficiência na produção agrícola. *Apta/SAESP*, São Paulo, pp. 153 (Série Discussão. 2).
- Wagner, D., Rocha, C., 2007. Inovações na Agricultura Familiar: fatores que influenciam no processo de adoção de tecnologias. VII Reunião da Sociedade Brasileira de Sistema de Produção. Anais Eletrônicos da VII Reunião da Sociedade Brasileira de Sistema de Produção .
- Walker, R., Moran, E., Anselin, L., 2000. Deforestation and cattle ranching in the Brazilian Amazon: external capital and household processes. *World Dev.* 28 (4), 683–699.