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Special Supplement: *Cerrado* **[Brazilian Savanna]**

Assessing the Impact of the ABC Cerrado Project[1]

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ABSTRACT

Projects that help rural producers to use sustainable production practices are essential for the preservation of biomes. The ABC Cerrado Project, for example, aimed to promote the sustainable land use, as well as to improve the forest management, in the Cerrado (Brazilian Savanna) biome, from 2014 to 2019. The Project's goals included assessing the impact resulting from training a group of farmers in sustainable technologies for agricultural production and offering them technical assistance for managing rural properties. In this study, the impact of this Project was evaluated. The perception of impact adopted here has three dimensions: technical efficiency; probability of the activity being a carbon sink; and reduction of carbon emissions. In general, there was an improvement in the environmental performance of farms assisted by the Project. This reflects the efforts of the farmers to adjust their production processes and incorporate the good agricultural practices disseminated by the technology transfer process proposed by the Project.

KEYWORDS: Sustainable land use, forest management, greenhouse gas emissions balance, soil carbon stocks.

RESUMO

Avaliação do Impacto do Projeto ABC Cerrado

Projetos que auxiliem o produtor rural a utilizar práticas sustentáveis de produção são fundamentais para a preservação dos biomas. O Projeto ABC Cerrado, por exemplo, visou promover o uso sustentável da terra e melhorar o manejo florestal no bioma Cerrado, entre 2014 e 2019. Dentre as metas do Projeto estava avaliar o impacto decorrente da capacitação de um grupo de agricultores em tecnologias sustentáveis para a produção agrícola e da oferta de assistência técnica para o manejo de propriedades rurais. Neste estudo, avaliou-se o impacto desse Projeto. A percepção de impacto aqui adotada possui três dimensões: eficiência técnica; probabilidade de a atividade ser um sumidouro de carbono; e redução de emissões de carbono. De maneira geral, houve melhora no desempenho ambiental das fazendas atendidas pelo Projeto. Isso reflete o esforço dos agricultores em adequar seus processos produtivos e incorporar as boas práticas agrícolas disseminadas pelo processo de transferência de tecnologia propostas pelo Projeto.

PALAVRAS-CHAVE: Uso sustentável da terra, manejo florestal, balanço de emissões de gases do efeito estufa, estoques de carbono do solo.

INTRODUCTION

Agribusiness, including inputs, agriculture/livestock, services and industry sectors, was responsible for almost 21 % of the Brazilian GDP in 2019 (Cepea 2021). The livestock sector was responsible for 30.4 % of the total revenue of the Brazilian agribusiness in the same year. Despite this good economic performance, livestock is an important source of greenhouse gas (GHG) emissions in the Brazilian agricultural sector, which, in 2016, accounted for 439,213 x 10^3 tons of CO_2 equivalent (Gg CO_2e) (Brasil 2020a). Given this context, the development and implementation of mitigation policies for low carbon agriculture become highly relevant.

During the 15th Conference of the Parties (COP15) held in Copenhagen, in 2009, the Brazilian government signed a voluntary commitment to the Convention on Climate Change to reduce

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36.1-38.9 % of the GHG emissions by 2020. During the COP21 meetings, held in Paris, in 2015, Brazil's commitment was to reduce the GHG emissions, by 2025, to levels 37 % below those recorded in 2005, and this reduction would reach 43 % in 2030. Brazil has also committed to increase the area of low-carbon agriculture in the country.

These commitments were ratified and regulated by a presidential decree in 2010 (Brasil 2010) by the Sectorial Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture (hereafter, ABC Plan). The ABC Plan is a public policy that proposes mitigation and adaptation through the adoption of selected sustainable production technologies to reduce GHG emissions in the agricultural sector (Brasil 2012).

In the context of the ABC Plan, there was a project proposed for Sustainable Production in Areas Already Converted for Agricultural Use (hereafter, ABC Cerrado Project). The intention of the ABC Cerrado Project was to promote the sustainable land use and improve the forest management in the Cerrado (Brazilian Savanna) biome, the second largest biome in the country. The Project aims to contribute to decreasing the pressure on the remaining forests, reducing GHG emissions and increasing the carbon sequestration.

The actions of the ABC Cerrado Project took place over five years (2014-2019), in eight states of the Cerrado biome, and were developed through a partnership between the Brazilian Ministry of Agriculture, Livestock and Supply, the Empresa Brasileira de Pesquisa Agropecuária (Embrapa) and the Serviço Nacional de Aprendizagem Rural (Senar), with financial support from the World Bank. The training and technical assistance were based on concepts of low-carbon agriculture consistent with Brazilian public policies and the ABC Plan. In this context, the question proposed in this study was whether training and technical assistance reached their objectives, i.e., if they improved the environmental performance of the farms assisted by the Project by incorporating good agricultural practices in their production systems.

In this study, are presented the results of a research developed between 2017 and 2019, in the states of Goiás, Maranhão, Mato Grosso do Sul and Tocantins, and carried out by Senar, in partnership with Embrapa. The purpose was to evaluate the environmental performance of medium-sized producers assisted by the ABC Cerrado Project, in terms of GHG emissions and carbon stocks in the soil, before and after receiving the training offered by the Project. The effect of covariates on the environmental performance of livestock activities to assess the impact of the technical training developed by the Project was also investigated. The impacts were assessed along three complementary dimensions: technical efficiency with which the emission reduction occurs; probability that the activity is a carbon sink; and presence of emission reduction. It was also investigated if the support offered by the Project produced the same results, in terms of environmental impacts, in these four Brazilian states.

MATERIAL AND METHODS

The goal of the ABC Cerrado Project was to promote the adoption of selected sustainable, low-carbon agricultural practices by small and medium-sized agricultural producers in the Cerrado. A pilot training and technical assistance program was established aiming to reduce the technological knowledge gap of these farmers (Senar 2019). Rural producers and support technicians from the Cerrado were trained in the technologies consistent with Brazilian public policies and the ABC Plan (e.g., recovery of degraded pastures, crop-livestock-forest integration, no-tillage system, planted forests), and they were also provided with technical and managerial assistance for the rural properties. The Project resources were provided by the World Bank, Embrapa developed and validated the content, Senar was responsible for the training, and the Brazilian Ministry of Agriculture, Livestock and Supply monitored the adoption of the technologies. The idea was to disseminate and encourage the adoption of sustainable practices to reduce GHG emissions. These investments were aimed at boosting productivity and income and preserving the environment (Brasil 2020b).

The Project activities began in 2014 and, during 2016-2018, rural producers were selected, and the training and technical and managerial assistance programs, as well as field days, were implemented. The ABC Cerrado Project ended in 2019, having trained 7,800 rural producers and benefited more than 18,000 people, recovered 93,800 hectares of pasture areas, and offered more than 214,000 hours of technical and managerial assistance (Senar 2019). This Project was conducted across the Brazilian states of Goiás, Mato Grosso do Sul, Tocantins, Maranhão, Bahia, Piauí, Minas Gerais and the Distrito Federal.

The Project team designed a trial with three experimental groups of farms: 'control'; 'training in sustainable practices'; and 'training in sustainable practices followed by local technical and managerial assistance'. The ABC Cerrado Project used a set of indicators to monitor results. The collection of information for impact assessment occurred after one year and six months of implementation of the Project with training and technical assistance, and the data were organized in a structured database, wich is maintained by the institutions responsible for this study.

A completely randomized design was repeated twice: in 2017 (before the training) and in 2019 (after the training, which was primarily focused on recovering degraded pastures). The idea was to evaluate the impacts resulting from the farmers training within the scope of the ABC Cerrado Project and calculating the GHG emissions and carbon sequestration of recovered degraded pastures.

A total of 447 farms, located in 87 municipalities in the Cerrado biome and belonging to the states of Goiás, Maranhão, Mato Grosso do Sul and Tocantins, were evaluate. The number of valid observations, i.e., those with data for each of the two periods from each state, were 53 for Goiás, 153 for Maranhão, 66 for Mato Grosso do Sul and 181 for Tocantins.

Table 1 shows the farms characteristics, regarding cattle herd and land use, by state and treatment. The presented values consider the sample here studied. These are total values for each variable in each farm type and state. In the 'control' treatment, farms maintained their total area between 2017 and 2019, while reducing the cattle herd and pasture areas, because forested areas increased slightly. The same trend was also observed in the other treatments. The concepts of forested and pasture areas are consistent with those described in the Brazilian agricultural census (IBGE 2021).

The impact assessment was applied to the three treatment groups of farms ('control', 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance'), using 2017 as the baseline and 2019 as the end of the capitalization period.

The analysis considered the effect of the degraded pasture recovery component on GHG emissions and soil carbon sequestration at 50 cm of depth. Enteric emissions and carbon stocks in the soil were calculated using the Agriculture and Land Use Greenhouse Gas Stock (ALU) software tool (CSU 2018) and the methodological procedure proposed by Freitas et al. (2019). Thus, the different types of land use were employed as input data: pasture area (ha), forest area (ha), crop area (ha), other land uses (ha) and cattle herd (heads). The indicators calculated by the ALU approach were enteric emissions from cattle, carbon stocks in the soil and changes in the biomass carbon stock for each type of land use. The emissions balance was calculated by the difference between the average annual enteric emissions, in tons of CO_2 equivalent per hectare per year ($tCO_2e\ ha^{-1}\ year^{-1}$), in

Table 1. Farms characteristics (total values for each variable in each farm type and state).

Farm type*	State	Cattle (heads)		Total area (ha)		Forest (ha)		Pasture (ha)		Crop (ha)		Other uses (ha)	
		2017	2019	2017	2019	2017	2019	2017	2019	2017	2019	2017	2019
Control	Goiás	2,509	2,165	2,485	4,195	609	1,726	1,874	2,336	2	2	23	131
	Maranhão	7,640	5,539	9,585	9,309	2,236	217	4,921	4,352	450	217	1,947	1,239
	Mato Grosso do Sul	2,438	4,041	5,043	4,636	1,221	1,394	2,207	2,631	167	29	1,448	582
	Tocantins	9,758	5,482	14,047	12,989	4,951	6,658	7,011	4,646	32	393	1,700	1,293
TSP	Goiás	6,914	4,678	5,618	5,430	1,450	1,527	4,861	3,888	77	31	87	4
	Maranhão	6,137	5,997	12,735	9,194	3,944	4,088	4,569	4,409	97	91	3,972	606
	Mato Grosso do Sul	7,716	5,496	7,546	8,062	1,610	1,880	5,461	6,131	194	24	281	27
	Tocantins	11,856	11,681	15,851	15,061	5,531	6,427	8,290	7,705	70	14	1,940	915
TSP + LTMA	Goiás	3,430	3,136	4,191	3,739	945	1,221	3,180	2,479	54	28	13	11
	Maranhão	7,388	5,624	10,425	9,673	2,888	3,026	5,651	5,798	111	134	1,891	715
	Mato Grosso do Sul	3,218	4,001	2,454	4,554	600	735	1,707	3,716	47	45	100	58
	Tocantins	21,420	17,760	28,869	24,962	10,827	11,304	14,611	12,162	811	11	2,620	1,485

* TSP: training in sustainable practices; LTMA: local technical and managerial assistance.

the capitalization period, and the annual difference in carbon stock in the soil (tCO_2e ha^{-1} year^{-1}). Farms were then classified into two categories: sinks of CO_2e (carbon sink), when the emissions balance was negative, and sources of CO_2e (carbon source), when the emissions balance was positive. This classification was used in the regression models, both as an indicator variable (in the covariance analysis) and as a response variable (in the logistic regression). The ALU software estimates the GHG emissions and removal related to agriculture and forestry, and does so based on the methods proposed in the IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al. 2006).

The basic assumptions of this analysis are related to pedoclimatic characteristics of the region under study. The climate is tropical humid, with an average annual temperature of 27 ºC (80.6 F). The Cerrado biome belongs to an ecological zone characterized by tropical humid deciduous forest and soil with low-activity clays. Given the variability of pedoclimatic conditions in the territory evaluated by the Project, the recommended standards for the description of beef cattle systems in Latin America were adopted (Eggleston et al. 2006).

Carbon pricing is indispensable for reducing emissions in an efficient way. The carbon price is generally normalized to the amount of GHG that would lead to the same amount of warming as a ton of CO_2 over a specific period and is specified as the price per ton of CO_2e (or CO_2 equivalent). The methodology for calculating carbon pricing assumes that 2017, the beginning of the treatment phase of the ABC Cerrado Project, is the baseline. In this way, the capitalization period is from 2017 to 2019.

The impact of the environmental performance of livestock raising activities in the context of the ABC Cerrado Project were assessed under three dimensions: technical efficiency with which the emission reduction occurs; probability that the activity is a carbon sink; and emission reduction. The purpose of this assessment was to evaluate the impact of the technical training activities developed by the Project. A joint analysis was performed, including four states: Goiás, Maranhão, Mato Grosso do Sul and Tocantins.

A data envelopment analysis (DEA) model (Coelli et al. 2005, Cooper et al. 2011) was used to assess the performance of the production process from a technical efficiency perspective. The inputs included in this analysis are pasture area, forested area and number of heads (cattle), and the outputs are carbon stock in the aboveground biomass and the inverse of enteric emissions (an undesirable output in the DEA jargon). The DEA model seeks the greatest possible radial increment of outputs for a given rural establishment, keeping control over input levels (this is the so-called output-oriented DEA model). The analysis was performed using the ranks of the input and output variables. The approach has a non-parametric nature that is robust to the presence of outliers (Conover 1999) and eliminates the presence of negative values.

Specifically, if Y represents the production matrix ($2 \times n$) of the farms considered in the analysis and X is the matrix ($3 \times n$) of inputs used by those farms, the performance measure (ϕ_o) of farm o is the solution of the linear programming problem (Equations 1-4):

$$\text{Max}_{\{\phi, \lambda\}}\, \phi_o \quad (1)$$

$$Y\lambda \geq \phi_o y_o \quad (2)$$

$$X\lambda \leq x_o \quad (3)$$

$$\lambda 1 = 1,\, \lambda \geq 0 \quad (4)$$

where (x_o, y_o) is the vector of inputs and outputs of farm o, with positive components, and λ is the vector of benchmarks of farm o. Following the prevalent practice, $\theta_o = \phi_o^{-1}$ is taken as a performance score, with values in the range (0, 1).

A fractional regression model (Equation 5) (Papke & Wooldridge 1996) was postulated:

$$E(\theta_i) = \Phi(\beta_0 + \beta_1 ABC_i + \beta_2 t_i + \beta_3 C_{1i} + \beta_4 C_{2i} + \beta_5 S_i + \beta_6 UF_{1i} + \beta_7 UF_{2i} + \beta_8 UF_{3i}) \quad (5)$$

where $E(\theta_i)$ represents the expected value of the efficiency measure θ_i, $\Phi(\cdot)$ is the standard normal distribution function, ABC is the rank of the area in the ABC Project, t is a time dummy variable, C_1 and C_2 represent indicator functions (dummies) of the presence of the 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance' treatments, respectively, and S is a dummy variable that represents the carbon capture (sink = 1). The estimation method for such models is quasi-maximum likelihood. The indicator variables UF_1, UF_2 and UF_3 represent the states of Goiás, Maranhão and Mato Grosso do Sul, respectively. The indicator variable representing Tocantins was dropped from the regression models to avoid singularities, otherwise the dummy states would sum to one, creating a multicollinearity condition. The analysis is not dependent on which dummy is dropped. Thus, the results for Tocantins are given by the constant term.

This model, computed in Stata (2019), assumes the expected response to be some probability function of the expression in Equation 5 to characterize the effects of contextual variables on the performance score. In the present study, a probit probability function was fitted. The contextual variables are time, treatments (types of training), area in the ABC Project and occurrence of carbon sequestration.

A logistic regression (Souza 1998) was also fitted to model the binary response, *S*, in this impact dimension. Thus, the expected value of the response is the probability of obtaining $S = 1$. The logistic regression model has the form shown in Equation 6:

$$E(S_i) = \Pr\{S_i = 1\} = (1 + \exp\{-(\delta_0 + \delta_1 ABC_i + \delta_2 t_i + \delta_3 C_{1i} + \delta_4 C_{2i} + \delta_5 \theta_i + \delta_6 UF_{1i} + \delta_7 UF_{2i} + \delta_8 UF_{3i})\})^{-1} \quad (6)$$

The dimensions of efficiency and probability of being a carbon sink, as previously described, do not model the GHG emissions reduction. In other words, this analysis does not detect if the presence of a contextual variable caused a reduction in the GHG emissions over the evaluated period. However, it is necessary to verify whether there was a reduction in the amount of emissions due to the presence of the contextual variables, even when $S = 0$. In this approach, the emissions offset (the difference between emissions and stocks) is ranked, and the linear regression model (Equation 7) is postulated:

$$E(offset_i) = \alpha_0 + \alpha_1 ABC_i + \alpha_2 t_i + \alpha_3 C_{1i} + \alpha_4 C_{2i} + \alpha_5 \theta_i + \alpha_6 UF_{1i} + \alpha_7 UF_{2i} + \alpha_8 UF_{3i} \quad (7)$$

where *offset* represents the normalized rank of the GHG emissions balance attribute (the lower the value of the normalized rank, the more favorable the emissions balance).

RESULTS AND DISCUSSION

In the period of 2017-2019, the 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance' farms improved the quality of cattle and pasture management. For example, there was a decrease of 9,757 animals and an increase of 6,804 ha of pastures in good condition, obtained mostly through the replacement of native pastures and recovering degraded ones. By the analysis of the aggregated input data in Table 2, it is apparent that the cattle herd and the total area of pasture decreased in each of the three categories of farms assisted by the ABC Cerrado Project ('control', 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance'), while the areas of the properties increased in the 'control' farms and decreased in the 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance' farms. These data show that there is a general trend of intensification of beef cattle in the Cerrado biome. Regarding the forest areas, they increased in the 'control' and 'training in sustainable practices + local technical and managerial assistance' treatments, but decreased in the 'training in sustainable practices' treatment. On the other hand, there is an increase in pasture in good condition for the farms in the 'training in sustainable practices + local technical and managerial assistance' treatment.

The indicators calculated (items B and C in Table 2) with the ALU software and the approach previously described show that, during the capitalization period, 'control' farms (without training) had a decrease in the soil carbon stocks from 55 to 48 $tCO_2e\ ha^{-1}$, and, after twenty years at this rate of decrease, they would emit 3.5 million tons of CO_2 equivalent (tCO_2e). In the scenarios with training, the 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance' farms captured -1,196,954 and -1,905,987 tCO_2e, respectively, by increasing the soil carbon stocks from 47 to 53 $tCO_2e\ ha^{-1}$ and 54 $tCO_2e\ ha^{-1}$, respectively. The 'training in sustainable practices + local technical and managerial assistance' farms performed better in capturing carbon.

Considering that the carbon balance of improving grassland in the ABC Cerrado Project was 1.6 $t\ CO_2e\ ha^{-1}\ year^{-1}$ for 'training in sustainable practices' farms and 2.3 $t\ CO_2e\ ha^{-1}\ year^{-1}$ for 'training in sustainable practices + local technical and managerial assistance' farms, these results are compatible, but higher than the average of

Table 2. Input data, greenhouse gas emissions, carbon stock and carbon balance.

Farm indicators	Control		TSP[8]		TSP + LTMA[9]	
	2017	2019	2017	2019	2017	2019
A. Input data						
Cattle herd (heads)	22,345	17,227	32,622	27,852	35,456	30,469
Total area (ha)[1]	29,764	31,032	44,857	37,082	44,279	40,712
Forest (ha)	9,018	13,279	12,535	7,509	15,260	16,286
Crop (ha)	652	641	266	6,573	275	11,499
Total pasture (ha)	14,888	13,868	25,776	21,448	24,123	21,952
Native pasture (ha)	7,139	8,255	16,852	9,556	16,570	10,563
Pasture in good conditions (ha)	7,748	5,611	8,924	11,892	7,554	11,390
Other uses (ha)	5,206	3,245	6,280	1,552	4,622	2,268
B. Enteric emissions data (EE) and carbon stocks in the soil (CSS)						
EE (tCO_2e)[2]	33,131	35,603	39,765	39,732	48,150	38,175
CSS (tCO_2e)	-1,649,283	-1,498,955	-2,089,444	-1,952,777	-2,092,917	-2,216,933
C. Balance sheet						
AACSS[3] ($tCO_2e\ ha^{-1}$)	-55.0	-48.0	-47.0	-53.0	-47.0	-54.0
ASDCS[4] ($tCO_2e\ ha^{-1}\ year^{-1}$)	0.0	3.6	0.0	-3.0	0.0	-3.6
AMEE[5] ($tCO_2e\ head^{-1}\ year^{-1}$)	1.5	2.1	1.2	1.4	1.4	1.3
BACEt[6] ($tCO_2e\ ha^{-1}\ year^{-1}$)	-	5.6	-	-1.6	-	-2.3
CEB20[7] (tCO2e)	-	3,488,579.0	-	-1,196,954.0	-	-1,905,987.0

[1] ha: hectare; [2] tCO_2e: ton of CO_2 equivalent; [3] average annual soil carbon stocks, in tons of CO_2 equivalent per hectare; [4] annual difference in carbon stocks in the soil, in tons of CO_2 equivalent per hectare per year; [5] annual mean enteric emissions, in tons of CO_2 equivalent per hectare per year; [6] balance of annual carbon emissions in the capitalization period, in tons of CO_2 equivalent per hectare per year; [7] carbon emissions balance after 20 years of project execution, in tons of CO_2 equivalent; [8] TSP: training in sustainable practices; [9] LTMA: local technical and managerial assistance.

0.47 $tCO_2e\ ha^{-1}\ year^{-1}$ suggested by Conant et. al. (2017), after an extensive review of the literature.

In terms of carbon pricing, the 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance' farms improved the quality of the management of cattle and pasture in the capitalization period, with a decrease of 9,757 animals and an increase of 6,804 ha of pastures in good conditions through the reestablishment of native pastures and recovering of degraded ones. As a result of adopting these recommendations from the ABC Cerrado Project, these farms sequestered 458,906 t CO_2e in an area of 112,699 ha. Considering that, in that period, $ 10 million were allocated to finance the Project's actions, the estimated carbon value was $ 22.0/tCO_2e for the beginning of the capitalization period and would be $ 33.6/tCO_2e after twenty years of Project execution (Table 3). The carbon value was also calculated using the values $ 40.0/tCO_2e and $ 80.0/t CO_2e as bases for low and high estimated values, respectively, as recommended by the High-Level Commission on Carbon Prices (HLCCP) (World Bank 2016).

All the effects considered in the joint performance (panel) model significantly affected performance (Table 4). The training levels are positive, but lower than that of the control, and

Table 3. Carbon pricing estimates ($/$tCO_2e$).

Year	ABC Cerrado	Lower HLCCP*	Higher HLCCP
2017	22.0	40.0	80.0
2018	22.5	40.9	81.8
2019	23.0	41.8	83.6
2020	23.5	42.8	85.5
2021	24.0	43.7	87.4
2022	24.6	44.7	89.4
2023	25.1	45.7	91.4
2024	25.7	46.7	93.5
2025	26.3	47.8	95.6
2026	26.9	48.9	97.7
2027	27.5	50.0	99.9
2028	28.1	51.1	102.2
2029	28.7	52.2	104.5
2030	29.4	53.4	106.8
2031	30.0	54.6	109.2
2032	30.7	55.8	111.7
2033	31.4	57.1	114.2
2034	32.1	58.4	116.8
2035	32.8	59.7	119.4
2036	33.6	61.0	122.1

* HLCCP: High-Level Commission on Carbon Prices (World Bank 2016).

Table 4. Fractional regression model fit for the joint analysis.

Parameter	Coefficient**	Standard deviation	z	p-value	95 % confidence interval	
β_0 (constant)	0.9185	0.1454	6.32	0.000	0.6335	1.2035
β_1 (*ABC*)*	-0.0005	0.0002	-1.95	0.052	-0.0009	0.0000
β_2 (t)	0.4494	0.0884	5.08	0.000	0.2761	0.6226
β_3 (C_1)	-0.4811	0.1064	-4.52	0.000	-0.6896	-0.2725
β_4 (C_2)	-0.4945	0.1127	-4.39	0.000	-0.7154	-0.2736
β_5 (S)	0.2935	0.0940	3.12	0.002	0.1091	0.4778
β_6 (UF_1)	1.0902	0.1480	7.37	0.000	0.8001	1.3803
β_7 (UF_2)	0.3959	0.0954	4.15	0.000	0.2089	0.5829
β_8 (UF_3)	1.2653	0.1431	8.84	0.000	0.9848	1.5458

* *ABC* is the rank of the area in the ABC Project; t is a dummy time; C_1 is a dummy of the 'training in sustainable practices' treatment; C_2 is a dummy of the 'training in sustainable practices + local technical and managerial assistance' treatment; S is a dummy of the carbon capture (sink = 1); UF_1, UF_2 and UF_3 represent the states of Goiás, Maranhão and Mato Grosso do Sul, respectively. ** Coefficient refers to the value of the parameter β of each variable in the model; z is the ratio 'coefficient/standard deviation'; and p-value is the significance level.

the area in the ABC Project had a negative effect, potentially induced by the results of Maranhão and Tocantins, which had a larger sample size. The effect of t is positive, and so is the effect of S (spill-over). Furthermore, there are differences among the states, with the best performance for Mato Grosso do Sul, followed by Goiás, Maranhão and Tocantins.

Given the scope of the livestock intensification process in Mato Grosso do Sul, the farms of this state presented the best performance of the balance of average carbon stocks in the soil in the three categories of farms ('control', 'training in sustainable practices' and 'training in sustainable practices + local technical and managerial assistance'). On the other hand, the worst performance was observed among farms in the Tocantins state, likely due to the expansion of crop areas and the decrease in native forest areas.

Table 5 presents the estimates resulting from the logistic approach using the maximum likelihood method and considering the four states, and shows that the treatments do not differ. The variable *ABC* significantly and positively affected the probability that $S = 1$, and so do the variables for performance (θ) and time (t). The states have different responses, with Maranhão being dominant, followed by Tocantins and Mato Grosso do Sul. Goiás and Tocantins do not differ significantly in their response.

Table 6 shows the regression fit for the joint analysis using ordinary least squares. The effect of the states is significant, although Goiás and Tocantins do not differ from each other. The performance gradient, determined by median values, is Mato Grosso do Sul < Goiás = Tocantins < Maranhão (see coefficients and significance). The 'training in sustainable practices + local technical and managerial assistance' treatment is better than the 'control' treatment in the sense of improving the emissions balance. The effects of time, performance and ABC area are significant and act to reduce emissions (more favorable balance).

Table 5. Logistic regression model fit for the joint analysis.

Parameter	Coefficient**	Standard deviation	z	p-value	95 % confidence interval	
δ_0 (constant)	-1.0818	0.3388	-3.19	0.001	-1.7459	-0.4178
δ_1 (*ABC*)*	0.0009	0.0004	2.37	0.018	0.0002	0.0017
δ_2 (t)	0.5549	0.1509	3.68	0.000	0.2590	0.8507
δ_3 (C_1)	0.1640	0.1824	0.90	0.369	-0.1935	0.5215
δ_4 (C_2)	0.1296	0.1894	0.68	0.494	-0.2416	0.5007
δ_5 (θ)	1.1482	0.3314	3.46	0.001	0.4986	1.7978
δ_6 (UF_1)	-0.2269	0.2452	-0.93	0.355	-0.7075	0.2537
δ_7 (UF_2)	0.6917	0.1816	3.81	0.000	0.3357	1.0477
δ_8 (UF_3)	-0.8443	0.2253	-3.75	0.000	-1.2858	-0.4029

* *ABC* is the rank of the area in the ABC Project; t is a dummy time; C_1 is a dummy of the 'training in sustainable practices' treatment; C_2 is a dummy of the 'training in sustainable practices + local technical and managerial assistance' treatment; θ is the efficiency score; UF_1, UF_2 and UF_3 represent the states of Goiás, Maranhão and Mato Grosso do Sul, respectively. ** Coefficient refers to the value of the parameter δ of each variable in the model; z is the ratio 'coefficient/standard deviation'; p-value is the significance level.

Table 6. Greenhouse gas emissions regression fit for the joint analysis.

Parameter	Coefficient**	Standard deviation	z	p-value	95 % confidence interval	
α_0 (constant)	0.8051	0.0392	20.56	0.000	0.7282	0.8819
α_1 (*ABC*)*	-0.0001	0.0000	-2.92	0.004	-0.0002	0.0000
α_2 (t)	-0.0999	0.0175	-5.72	0.000	-0.1342	-0.0656
α_3 (C_1)	-0.0185	0.0210	-0.88	0.380	-0.0597	0.0228
α_4 (C_2)	-0.0500	0.0218	-2.29	0.022	-0.0927	-0.0072
α_5 (θ)	-0.2344	0.0386	-6.07	0.000	-0.3102	-0.1586
α_6 (UF_1)	-0.0064	0.0291	-0.22	0.827	-0.0635	0.0508
α_7 (UF_2)	-0.1065	0.0202	-5.26	0.000	-0.1462	-0.0667
α_8 (UF_3)	0.2842	0.0270	10.54	0.000	0.2312	0.3371

* *ABC* is the rank of the area in the ABC Project; t is a dummy time; C_1 is a dummy of the 'training in sustainable practices' treatment; C_2 is a dummy of the 'training in sustainable practices + local technical and managerial assistance' treatment; θ is the efficiency score; UF_1, UF_2 and UF_3 represent the states of Goiás, Maranhão and Mato Grosso do Sul, respectively. ** Coefficient refers to the value of the parameter α of each variable in the model; z is the ratio 'coefficient/standard deviation'; p-value is the significance level.

The overall results show that there was an improvement in the environmental performance of farms assisted by the ABC Cerrado Project, which reflects the efforts of farmers to adjust their production processes and to incorporate good agricultural practices disseminated by the technology transfer process.

The analyses considering the three dimensions of impact show that the results of the training acivities are not homogeneous in the states. Socioeconomic characteristics, as well as specific soil and climate conditions, may explain the differences and must be considered if the training activities are to be continued.

CONCLUSIONS

1. The preparation and presentation of reports on the balance of emissions and carbon stocks in the soil should be included in the next cycle of the ABC Plan. As a part of the protocol to be followed, the users of these programs must present their balance of greenhouse gas emissions and carbon stocks in the soil and in the biomass as a way of ensuring transparency and traceability to their consumption and/or supply chains. In this context, the beneficiaries of public policies such as the ABC Plan are fulfilling their commitments to mitigate greenhouse gas emissions;
2. The ABC Cerrado Project is economically and environmentally viable. After twenty years of the Project, the farms in the training in sustainable practices group and in the group that received training in sustainable practices coupled with local technical and managerial assistance will have captured 3.1 million tCO_2e. The cost-benefit analysis of the Project indicates that the carbon value estimates at the beginning ($ 22.00/tCO_2e) and at the end ($ 33.6/tCO_2e) of the Project are low-cost, if compared to other carbon pricing initiatives around the world. This represents a comparative advantage for financing Brazilian nationally determined contributions by using internationally transferred mitigation outcomes.

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