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Adaptation and resilience of agricultural systems to local climate change and extreme events: an integrative review[1]

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ABSTRACT

Losses in agricultural production, mainly caused by extreme temperature, rainfall and drought, have demanded the adaptation of the Brazilian agriculture to the ongoing climate change. This study aimed to evaluate, through an integrative review, the effects of agricultural practices established by two Brazilian public policies (ABC Plan and Planaveg) on the resilience and adaptation of the country's agricultural systems, considering the effects on local climate and extreme events. All the Embrapa library collections were used as main sources, and the Google Scholar was used as a secondary source. The search included publications from 1998 to April 2022 and resulted in 334 data, extracted from 51 references, covering at least one factor and one practice. The review showed that the proposed practices may contribute to the resilience and adaptation of the Brazilian agricultural and forestry sectors to climate change in the main production regions. Studies have indicated that the incorporation of the arboreal component into production systems may provide an environment more resilient to droughts, increased air humidity, reduced temperature impact and reduced fire risks, among other benefits. The adoption of the ABC Plan and Planaveg practices by the agricultural sector is an option feasible, strategic and well-aligned with a low-carbon economy, while it increases the resilience to present and future climate change impacts.

KEYWORDS: Agroforestry system, climatic resilience, ABC Plan, Planaveg.

RESUMO

Adaptação e resiliência de sistemas agrícolas às mudanças climáticas locais e eventos extremos: uma revisão integrativa

Perdas na produção agrícola, causadas principalmente por temperaturas extremas, chuvas e secas, têm exigido a adaptação da agricultura brasileira às mudanças climáticas em curso. Objetivou-se avaliar, por meio de uma revisão integrativa, os efeitos das práticas agrícolas estabelecidas por duas políticas públicas brasileiras (Plano ABC e Planaveg) na resiliência e adaptação dos sistemas agrícolas do país, considerando-se os efeitos no clima local e eventos extremos. Todas as coleções da biblioteca da Embrapa foram utilizadas como fontes principais e o Google Acadêmico como fonte secundária. A busca incluiu publicações de 1998 a abril de 2022 e resultou em 334 dados, extraídos de 51 referências, abrangendo pelo menos um fator e uma prática. A revisão mostrou que as práticas propostas podem contribuir para a resiliência e adaptação dos setores agropecuário e florestal do Brasil às mudanças climáticas nas principais regiões produtoras. Estudos indicam que a incorporação de componente arbóreo nos sistemas de produção pode proporcionar um ambiente mais resiliente a secas, aumento da umidade do ar, redução do impacto da temperatura e dos riscos de incêndio, entre outros benefícios. A adoção das práticas do Plano ABC e Planaveg pelo setor agropecuário é uma opção viável, estratégica e bem alinhada com uma economia de baixo carbono, ao mesmo tempo em que aumenta a resiliência aos impactos presentes e futuros das mudanças climáticas.

PALAVRAS-CHAVE: Sistema agroflorestal, resiliência climática, Plano ABC, Planaveg.

INTRODUCTION

In Brazil, approximately 95 % of the agricultural production depends on rainfall. Climate change has exerted an important impact on temperature and rainfall (IPCC 2021), thus affecting production, yield and income, and increasing risks for the agricultural sector. Moreover, it leaves the poorest and the most vulnerable people and communities exposed. Developing countries are, in general,

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the most vulnerable to climate change impacts (IPCC 2001), and Brazil is especially exposed, considering its ecosystems and agriculture (Nobre et al. 2005). Among the several negative impacts on the agriculture sector stand out changes in crop development cycles and increase in the frequency and intensity of temperature and rainfall, as well as in the occurrence of droughts, dry spells, floods and other events (Assad et al. 2020).

To materialize the actions proposed by the Nationally Appropriate Mitigation Actions (NAMA) during the COP 15 in Copenhagen, Brazil established the Low Carbon Agriculture Plan (Brasil 2012), also known as ABC Plan. The original plan did not prioritize adaptation practices for two reasons: it was not the main focus of international negotiations and lack of international will to implement and finance adaptation practices in developing countries. Despite the main focus on mitigation, the sectorial policy on agriculture for climate change incorporated a full section dedicated to adaptation (section 7), listing 17 agricultural practices and targets planned for the periods 2011-2015 and 2016-2020. In fact, over the last years, studies have quantified the impact of adaptation (Pezzopane et al. 2015, Moreira et al. 2018) and mitigation (Manzatto et al. 2020) to various agricultural production systems.

This has reflected in the amount of investments. In 2016, the Federal Government made 183.8 billion reais available for the 2016/2017 harvest, of which 1.6 % were destined to the ABC Plan. In 2021, it launched the ABC+ Plan 2020-2030 (Brasil 2021a), stimulating science-based technological innovation aiming the consolidation of national agriculture supported by sustainable, resilient and productive systems. In the 2021/2022 Harvest Plan, of the 73.4 billion reais proposed, 6.8 % were for the ABC/ABC+ Plan.

The National Plan for the Recovery of Native Vegetation (Planaveg, in the Portuguese acronym) was established to support landowners in complying with Brazil's new Forest Code (Brasil 2017) and to help Brazil to fulfill its national and international restoration commitments while generating benefits for the entire Brazilian society.

In Brazil, studies have shown the effects of global warming on agriculture (Heinemann et al. 2009, Félix et al. 2020). However, the impacts of adaptation practices have not yet been fully addressed, although efforts have been made to overcome them (Brasil 2021b).

Currently, many review methods (Grant & Booth 2009) are used to address knowledge gaps, including integrative review, which allows a consistent and comprehensive overview of the knowledge available on a topic (Souza et al. 2010).

The objective of using integrative review in this study was to evaluate the effects of the practices proposed by the ABC Plan and Planaveg on the adaptation and increased resilience of the agricultural sector to the ongoing climate change, considering local climate parameters and extreme events, and to highlight the advantages and disadvantages of each one in comparison to conventional systems.

MATERIAL AND METHODS

Studies on several factors that could affect the adaptation of agriculture to climate change were searched: i) maximum, medium and minimum temperature, maximum and minimum air humidity, rainfall, strong surface wind and fires, all considered local climate parameters; ii) heat waves, frosts, droughts, dry spells, heavy rainfall and disaster impacts, considered extreme events. The selection of these factors was based on studies conducted to assess the impacts of climate change on agriculture (Pezzopane et al. 2015, Deniz et al. 2019, Assad et al. 2020).

Concerning the practices established by the ABC Plan (Brasil 2012) and Planaveg (Brasil 2017), the focus was on the following nine actions: recovery of degraded pastures, crop-livestock-forest integration, crop-forest integration, livestock-forest integration, crop-livestock integration, planted forests, agroforestry system, no-tillage systems, recovery of native vegetation and restoration of degraded landscapes (Restor).

It is important to highlight that the agroforestry system was not considered an integrated system (crop-livestock-forest integration, crop-forest integration, livestock-forest integration and crop-livestock integration), even though in the international literature integrated systems may be considered as agroforestry systems (Muchane et al. 2020). In the case of Brazil, agroforestry system is mostly practiced by family farmers (Gonçalves et al. 2021) and explores mainly native tree species (Gomes et al. 2020). On the other hand, integrated systems use mainly exotic tree species (such as *Eucaliptus grandis*, *Pinus taeda*, *Khaya ivorensis* and *Toona ciliata*). Nitrogen biological fixation and treatment of animal waste are practices provided for in the ABC Plan, but they were not included in this analysis because they are not highly associated with adaptation.

The search was carried out in English and Portuguese, using the Embrapa's Agricultural Research Database (BDPA, in its acronym in Portuguese), which includes 900 thousand items and collections of more than 40 libraries of the Embrapa Library System. It is composed by publications from the Embrapa's own research and other documents acquired through purchase and donation, in print and digital formats. As a supplementary source, the Google Scholar was also searched, which is considered a suitable source of evidence because it includes grey literature (Gusenbauer & Haddaway 2019) and is considered relevant in the agriculture scientific research (Haddaway et al. 2015). Eventually, the Web of Science and Elsevier were used to access a document published in an international journal that was not available at the BDPA and Google Scholar.

The search adopted the following sequence: 1) name of each one of the nine practices and Brazil, totaling nine search strings; 2) name of each one of the nine practices combined with each of the 11 specific factors, totaling 99 search strings; 3) the keywords "Brazil" and "climate change" combined with each one of the 11 specific factors, resulting in 11 search strings. A total of 119 search strings were thus defined.

The search strings were first applied as a spatial filter to the results in order to prioritize evidence from experiments in Brazilian ecosystems. Then, the broader aspects of the practice related to a specific factor in the context of climate change and the environmental and social conditions under which the study was conducted were considered. A temporal filter was applied to search for references published from 2016 onwards and removed missing entries. In the case of the Google Scholar, if there were few relevant references after the first five pages, the temporal and regional filters were removed to allow the search process to start again. The search was carried out between July and September 2020 and updated in April 2022 for references published from 2020.

All references were read by two authors, starting by the abstract, followed by the objectives, methods, results and conclusions. When reading the abstract, if a reference was not related to the practices of the ABC Plan/Planaveg or adaptation and resilience of agriculture to climate change, the reference was excluded. After excluding duplicates, all articles were read in full to evaluate methods, results and conclusions. The inclusion criteria were articles that included quantitative results of at least one of the selected factors. The exclusion criteria were articles without data and only referring to climate change mitigation. All references published between 1998 and April 2022 were incorporated into a worksheet to assess the quality and robustness of evidence.

By adapting the framework of the IPCC's AR5 guidance (Mastrandrea et al. 2011), each document was assessed and classified according to quality (positive, negative or neutral) and level of robustness (robust, medium and limited) of results, considered as evidence. At the end, each factor was evaluated considering the type and the number of documents available, and the robustness and the quality of each one. The adopted criteria were: a) high certainty, when the results left no doubt about a statement - for example, when the temperature measured in systems with trees was significantly different from those outside the system in open areas; b) medium certainty, when it was confirmed in the conclusions, but there were no significant differences or very small differences in the results; c) low certainty, when the results or discussion did not directly relate to the scope of the study, usually observed in themes with few published research; d) uncertain, when the results showed contradictory information or results that did not match the methods.

RESULTS AND DISCUSSION

The search returned 45 scientific articles published in national and international specialized journals, three book chapters, one document by the Embrapa, one report and one scientific article published in congress proceedings, totaling 51 references. All of them followed a peer review process, 67 % of the compiled studies were published between 2017 and 2020 (Figure 1), and references contributed with data for 85 % of the factors with at least one data (Table 1).

The volume of data for factors related to the practices is higher than the number of references included in the analysis because a single reference may cover more than one factor and practice. The distribution of data is heterogeneous (Table 1), and precipitation (3), heat waves (5), heavy rainfall (11) and fire risk (12) were the factors that showed the lowest volume of data. Regarding the practices (Table 1), recovery of degraded pasture had the lowest number of data (9).

The analysis of 51 references showed that there are gaps on the effects of local climate and extreme events, although research on technologies to improve agriculture adaptation to climate change has increased in the last years. Some effects require a longer time to be detected and others require a series of reliable data. Table 2 summarizes the changes identified in some local climate variables.

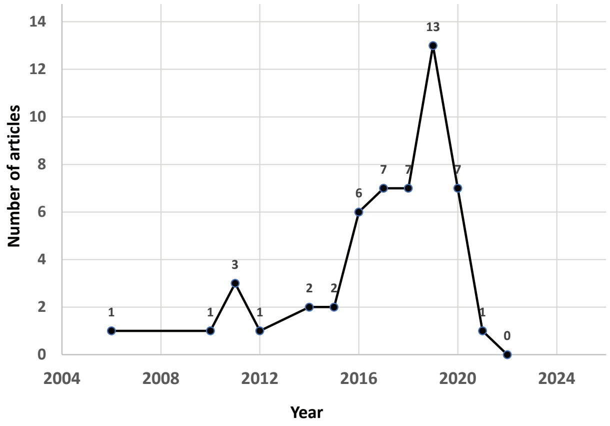

Figure 1. Number of references found between 1998 and April 2022. No data before 2006 were found.

After evaluating the references identified in this integrative review, it may also be highlighted that:

- Rainfall is an important local data gap and, to overcome this gap, it is necessary a dense network of pluviographs to detect variations in this parameter at the production system level;

- The greatest difficulty in measuring the effects of any production system on temperature lies in the misdistribution and the low density of meteorological stations for data collection over the territory. To fill this gap, it is necessary to combine data collected on the surface with satellite data. Most of the stations in Brazil are concentrated on coastal institutions; there is no national meteorological information network that measures temperatures in production systems. Data from experiments with local measures have been used by most studies and the official temperature readings collected at weather stations are from thermometers protected from direct sun rays;

- Practices with trees may reduce maximum and mean daily temperature, depending on the level of shading and the transmissivity of radiation through the understory tree canopy (and the lower amount of incoming solar radiation reaching the soil) (Magalhães et al. 2020);

Table 1. Number of data included in each factor and practice after the evaluation of 51 references.

	Factors	Systems with trees						Systems without trees			Total
		Restor	CLFI	CFI	LFI	AFS	PF	CLI	NT	RDP	
Local climate	Maximum temperature	5	12	2	8	10	4	3	2	1	47
	Mean temperature	5	11	2	8	8	4	3	2	1	44
	Minimum temperature	3	8	2	8	7	4	1	2	1	36
	Frost	1	3	2	1	5	3	1	1	1	18
	Maximum air humidity	5	8	2	7	4	3	1	1	1	32
	Minimum air humidity	5	8	2	7	4	3	1	1	1	32
	Rainfall	1	0	0	0	2	0	0	0	0	3
	Strong surface winds	2	6	4	5	7	2	1	1	1	29
	Subtotal	27	56	16	44	47	23	11	10	7	241
Extreme events	Heat waves	1	0	0	2	1	0	0	1	0	5
	Droughts	3	6	3	2	5	1	7	3	0	30
	Fire risks	5	1	1	1	1	2	0	1	0	12
	Dry spell	2	3	1	2	4	2	4	2	0	20
	Heavy rainfall	3	0	0	0	2	2	2	1	1	11
	Natural disaster impact	5	1	1	1	3	2	1	0	1	15
	Subtotal	19	11	6	8	16	9	14	8	2	93
Total		46	67	22	52	63	32	25	18	9	334

Restor: reforestation with planted forests; CLFI: crop-livestock-forest integration; CFI: crop-forest integration; LFI: livestock-forest integration; AFS: agroforestry system; PF: planted forests; CLI: crop-livestock integration; NT: no-tillage; RDP: restoration of degraded pastures.

Table 2. Changes identified in some local climate variables as a consequence of the adoption of agricultural systems using trees.

Variable	Compared systems	Change	Reference
Mean Tmax (ºC)	AFS to full sun coffee	Up to -2.9	Moreira et al. (2018)
		-1.7	Pezzopane et al. (2011)
	LFI to full sun pasture	-0.8	Pezzopane et al. (2015)
Mean Tmin (ºC)	AFS to full sun coffee	+1 to +4	Morais et al. (2006)
		Up to +1.2	Moreira et al. (2018)
	LFI to full sun pasture	0	Pezzopane et al. (2015)
Mean RH (%)	Shaded LFI to full sun	-4.4	Deniz et al. (2019)
	LFI under tree rows to between rows	Up to -2.7	Lopes et al. (2016)
	Restoring to degraded Caatinga	-1	Lucena et al. (2019)
	Forest border with eucalyptus barrier to without	+3.4	Nascimento et al. (2010)
	Forest to clearing	+9	White et al. (2016)
Mean wind speed	Shaded LFI to full sun	-11 % (-0.18 m s^{-1})	Deniz et al. (2019)
	LFI with distance of 0-5 m from the tree line	-14 % (-0.3 m s^{-1})	Hermes et al. (2018)
	LFI to full sunlight	-31 % (-0.8 m s^{-1})	Pezzopane et al. (2015)
	AFS to sun coffee	-35 % (-0.24 m s^{-1})	Pezzopane et al. (2011)
Dry spell	Long-term CLI to soybean crop	Support 15 to 31 days with dry spell	Alvarenga et al. (2021)

Tmax: maximum daily temperature; Tmin: minimum daily temperature; RH: relative humidity - the increase is additive, i.e., a 10 % increase shows that it ranges from 80 to 90 %; AFS: agroforestry system; LFI: livestock-forest integrated system; CLI: crop-livestock integrated system.

- In systems involving livestock (crop-livestock-forest integration and livestock-forest integration), it might be desirable to keep wind circulation to improve heat exchange and enhance animal comfort (Deniz et al. 2019);

- High temperatures along with low relative humidity and soil moisture are conditions that increase the risk of fires, and systems with trees potentially minimize these impacts and therefore reduce fire risks, such as on crop-livestock-forest integration and livestock-forest integration (Kichel et al. 2014), agroforestry system (Tscharntke et al. 2011) and native forest (White & Silva 2016);

- Trees, shrubs and litter may behave as fuel for wildfires, and planted forests are particularly listed as a potential land use that increases fire risk (Galizia & Rodrigues 2019);

- At a local scale, incorporating trees may be hydrologically advantageous in the long term (Zimmermann et al. 2006), but not immediately after implementation (Ferraz et al. 2014). In fact, water gains are from improved infiltration and higher storage of water in the soil and aquifers that overcome the evapotranspiration losses (Bruijnzeel 2004);

- Crop-livestock integration systems in the Cerrado region, in areas with longer dry spells (15 to 31 days) during the growing season, showed a greater resilience with little change in yield (Alvarenga et al. 2021);

- Intercropping systems with trees may be critical for crops during a drought event, due to the higher capacity of water absorption by trees (Souza et al. 2017).

Using the framework proposed by Mastrandrea et al. (2011) in systems with trees (recovery of native vegetation and to restore landscapes, crop-livestock-forest integration, livestock-forest integration, agroforestry system and planted forests), the effects had a higher level of certainty, regarding climate change adaptation (Table 3) and resilience (Table 4), in most factors, except for rainfall, heat waves, frost and heavy rainfall. It is possible that those exceptions occurred because of limited data.

It was observed, for example, that in crop-livestock integration and no-tillage systems without trees, the studies showed, with a high degree of certainty, that these systems reduce the drought effects (Table 3) and have a positive effect on climate resilience (Table 4). In fact, these are systems in which evapotranspiration is low and favors the retention of soil water by providing a high vegetation cover, in the case of crop-livestock integration, and a high straw cover, in the case of no-tillage systems. On the other hand, in pasture recovery, studies showed, with a medium degree of certainty, that this system decreases temperatures (Table 3) and has a positive effect on resilience (Table 4), mainly due to albedo changes.

Table 3. Effects and level of certainty on climate adaptation of productive systems with trees and without trees supported by Brazilian public financing.

Factors	Systems with trees						Systems without trees		
	REST	CLFI	CFI	LFI	AFS	PF	CLI	NT	RDP
Maximum temperature	↓	↓	↓	↓	↓	↓	●	●	↓
Medium temperature	↓	↓	↓	↓	↓	↓	●	●	↓
Minimum temperature	↓	↓	↓	↓	↓	↓	●	●	↓
Maximum air humidity	↑	↑	↑	↑	↑	↑	●	●	↑
Minimum air humidity	↑	↑	↑	↑	↑	↑	●	●	↑
Rainfall	●	?	?	?	●	?	?	●	?
Strong winds	↓	●	↓	↓	↓	↓	●	●	↓
Fire risks	↓	↓	↓	↓	↓	↑	?	↑	?
Heat waves	↓	?	?	●	●	?	?	●	?
Frosts	●	●	↑	●	●	●	●	●	●
Droughts	↓	●	●	●	●	●	●	●	?
Dry spell	↓	●	●	●	●	●	●	●	?
Heavy rainfall	●	?	?	?	●	●	●	●	●
Disasters impact	↓	↓	↓	↓	↓	↓	●	↑	↓

Systems: REST: recovery of native vegetation and to restore landscapes; CLFI: crop-livestock-forest integration; CFI: crop-forest integration; LFI: livestock-forest integration; AFS: agroforestry system; PF: planted forests; CLI: crop-livestock integration; NT: no-tillage; RDP: restoration of degraded pastures. Effects: ↓ - decrease; ↑ - increase; ● - no change; ? - unknow. Certainty level: high certainty; medium certainty; low certainty; uncertain.

Table 4. Effects and level of certainty on the climate resilience of productive systems with trees and without trees supported by Brazilian public financing.

Factors	Systems with trees						Systems without trees		
	REST	CLFI	CFI	LFI	AFS	PF	CLI	NT	RDP
Maximum temperature	POS	POS	POS	POS	POS	POS	NEU	POS	POS
Medium temperature	POS	POS	POS	POS	POS	POS	NEU	POS	POS
Minimum temperature	POS	POS	POS	POS	POS	POS	NEU	POS	POS
Maximum air humidity	POS	POS	POS	POS	POS	POS	NEU	POS	POS
Minimum air humidity	POS	POS	POS	POS	POS	POS	NEU	POS	POS
Frosts	POS	UND	NEG	POS	POS	POS	NEU	POS	POS
Rainfall	POS	UNK	UNK	UNK	POS	UNK	UNK	POS	UNK
Strong surface winds	POS	POS	POS	POS	POS	POS	NEU	POS	POS
Heat waves	POS	UNK	UNK	POS	POS	UNK	UNK	POS	UNK
Droughts	POS	POS	POS	POS	POS	NEG	POS	POS	UNK
Fires	POS	POS	POS	POS	POS	NEG	UNK	NEG	UNK
Dry spell	POS	POS	POS	POS	POS	NEG	POS	POS	UNK
Heavy rainfall	POS	UNK	UNK	UNK	POS	NEG	POS	POS	POS
Natural disasters	POS	POS	POS	POS	POS	POS	POS	NEG	POS

Systems: REST: recovery of native vegetation and to restore landscapes; CLFI: crop-livestock-forest integration; CFI: crop-forest integration; LFI: livestock-forest integration; AFS: agroforestry system; PF: planted forests; CLI: crop-livestock integration; NT: no-tillage; RDP: restoration of degraded pastures. Effects: POS: positive; NEG: negative; UND: undefined; UNK: unknow. Certainty level: high certainty; medium certainty; low certainty; uncertain.

For systems with trees, the studies showed, with a high degree of certainty, that these systems reduce temperatures, strong winds, fire risks, heat waves, droughts, dry spell and impact of disasters and increase air humidity (Table 3). They exert a positive effect on climate resilience (Table 4). This happens mainly because trees offer a high protection against changes on temperature, winds, humidity and other parameters.

CONCLUSIONS

1. In general, with a high level of certainty, agriculture production systems with trees are more resilient

and adapted to climate change, when compared to systems without trees;

2. Rainfall, heat waves, heavy rainfall and fire risks have the lowest volume of data, and it is necessary to further research these factors;
3. There is a lack of studies on effects of recovery of degraded pastures on climate change adaptation and resilience;
4. There is a need to intensify research of main production systems with and without trees in each biome supported by the joint use of satellite images and local meteorological information;
5. It is also important to produce evidence on how adapted production systems are more resilient to dry spells, and what their effects are on crop yields and socioeconomic gains, and to increase research aiming to reduce uncertainties about the effects of climate change and extreme events on agricultural production systems.

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