SUSTAINABLE
DEVELOPMENT
GOAL
13

CLIMATE ACTION

CONTRIBUTIONS OF EMBRAPA

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Embrapa

Brazilian Agricultural Research Corporation
Ministry of Agriculture, Livestock and Food Supply

Sustainable Development Goal 13

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Embrapa
Brasília, DF
2020

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1st edition
Digital publication - PDF (2020)

Cataloging in Publication (CIP) data
Embrapa

Climate action : contributions of Embrapa / Santiago Vianna Cuadra ... [et al.], technical editors. – Brasília, DF : Embrapa, 2020.

PDF (70 p.) : il. color. – (Sustainable development goals / [Valéria Sucena Hammes ; André Carlos Cau dos Santos] ; 13).

Translated from: Ação contra a mudança global do clima: contribuições da Embrapa. 1st edition. 2018
ISBN 978-65-86056-40-2

1. Climate change. 2. Brazilian agriculture. I. Heinemann, Alexandre Bryan. II. Barioni, Luís Gustavo. III. Mozzer, Gustavo Barbosa. IV. Bergier, Ivan. V. Collection.
CDD 551.68

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Foreword

Launched by the United Nations (UN) in 2015, 2030 Agenda for Sustainable Development is powerful and mobilizing. Its 17 goals and 169 targets seek to identify problems and overcome challenges that affect every country in the world. The Sustainable Development Goals (SDG), for their interdependent and indivisible character, clearly reflect the steps towards sustainability.

Reflecting and acting on this agenda is an obligation and an opportunity for the Brazilian Agricultural Research Corporation (Embrapa). The incessant search for sustainable agriculture is at the core of this institution dedicated to agricultural research and innovation. Moreover, sustainable agriculture is one of the most crosscutting themes of the 17 goals. This collection of books, one for each SDG, helps society realize the importance of agriculture and food in five priority dimensions – people, planet, prosperity, peace and partnerships –, the so-called 5 Ps of 2030 Agenda.

This collection is part of the effort to disseminate 2030 Agenda at Embrapa while presenting to the global society some contributions by Embrapa and partners with potential to affect the realities expressed in the SDG. Knowledge, practices, technologies, models, processes, and services that are already available can be used and replicated in other contexts to support the achievement of goals and the advancement of 2030 Agenda indicators.

The content presented is a sample of the solutions generated by agricultural research at Embrapa, although nothing that has been compiled in these books is the result of the work of a single institution. Many other partners joined in – universities, research institutes, state agricultural research organizations, rural technical and extension agencies, the Legislative Power, the agricultural and industrial productive sector, research promotion agencies, in the federal, state and municipal ranges.

This collection of books is the result of collaborative work within the SDG Embrapa Network, which comprised, for 6 months, around 400 people, among editors, authors, reviewers and support group. The objective of this initial work was to demonstrate, according to Embrapa, how agricultural research could contribute to achieve SDGs.

It is an example of collective production and a manner of acting that should become increasingly present in the life of organizations, in the relationships between public, private, and civil society. As such, this collection brings diverse views on the potential contributions to different objectives and their interfaces. This vision is not homogeneous; sometimes it can be conflicting, just as is society's vision about its problems and respective solutions, a wealth which is captured and reflected in the construction of 2030 Agenda.

These are only the first steps in the resolute trajectory that Embrapa and partner institutions draw towards the future we want.

Maurício Antônio Lopes
President of Embrapa

Preface

With population growth and increased demand for food, fiber and biofuels, the agricultural sector will face enormous challenges to ensure sustainable rural production. Specially in Brazil, demand for exports has placed the country as one of the main agricultural producers in the world. Therefore, Brazilian agroecosystems should adopt technological innovations to assure food security for current and future populations, and to create wealth from exports of commodities and higher value-added agroindustry products.

In order to extend the range of global sustainable development, 17 Sustainable Development Goals (SDG) have been defined by the United Nations in 2015. The SDGs evoluted from the 8 Millennium Development Goals, proposed in 2000, and from Rio + 20, held in 2012. The goals comprise 169 targets, several of which related to the agricultural sector, such as food security and agriculture, health, sustainable production and consumption standards and climate change. Actions related to SDGs are focused on promoting prosperity and human well-being, while preserving the environment and reducing global warming threats.

Because of its mission to seek and promote solutions for agribusiness in Brazil, Embrapa plays an important role in the context of all SDGs. Accordingly, Embrapa was required to present its contributions to the SDGs as part of Brazil's progress towards achieving its goals.

In this book, Embrapa presents contributions to SDG 13, whose theme is: Take urgent action to fight climate change and its impacts.

SDG 13 has five targets: 13.1 – Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries; 13.2 – Integrate climate change measures into national policies, strategies and planning; 13.3 – Improve education, awareness-raising and human and institutional capacity of climate change mitigation, adaptation, impact reduction and early warning; 13.a – Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change (UNFCCC) to a goal of mobilizing jointly $ 100 billion annually by 2020, from all sources, to address the needs of developing countries, in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible; 13.b – Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.

Embrapa has sought to highlight the challenges posed by climate change, which can lead to reduced agricultural productivity in several regions, and then to provide technological strategies and innovations to promote sustainable development, and to invest in research and strategic planning to mitigate greenhouse gases (GHG) emissions and ensure the adaptation of Brazilian agroecosystems. Therefore, widespread understanding of risks posed by climate change and social awareness about the theme will be of paramount importance.

This publication aims to summarize some of the most important contributions that Embrapa has given to society on these issues. In Chapter 1, context is briefly presented, followed by problem identification in Chapter 2. Contributions to SDG 13 targets were organized in the following three chapters: Chapter 3 regarding Brazilian agriculture resilience and adaptability to risks posed by climate change; Chapter 4 discusses integrated actions to fight climate change within national plans by means of public policies. Chapter 5 deals with the contribution of the agricultural sector to mitigate GHG emissions and to adapt to climate change. Finally, in Chapter 6, a summary of the contributions of Embrapa to SDG 13 is presented and the major challenges on the subject are outlined, considering the 2030 strategic vision documents of Embrapa.

Technical Editors

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Chapter 1

Climate change: global, national and institutional contexts

Gustavo Barbosa Mozzer
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Introduction

Sustainable development and climate change are inseparable. Sustainable development, which brings together economic, environmental and human spheres, is an essential condition for maintaining the global climate balance. The use of the planet's natural resources by the human population cannot exceed its support capacity (Rockström et al., 2009). Therefore, in order to meet population demands (to grow from 7 billion to 9 billion by 2050), reformulating the means of production, which are now overly dependent on fossil-based inputs, accelerate unsustainable use of natural resources and aggravate the greenhouse effect through greenhouse gas emissions (GHG), is necessary.

Brazilian and world agricultural productions have reached surprising productivity levels by adopting technological and biotechnological innovations since the 1960s, which have largely reflected on population growth and improved quality of life of people throughout the world. Current concern is to adapt agroecosystems to mitigate the risks from climate change impacts. Among adaptation actions is the strengthening and provision of environmental services (e.g., carbon sequestration), as well as food, fiber and energy, from agroecosystems. Therefore, achieving global food security depends on adapting negative impacts and mitigating GHG emissions. Brazil plays an increasingly prominent role in world food security, and, in this sense, Embrapa has been aligning its research, development and innovation actions with the challenges of United Nations Sustainable Development Goals (SDG).

SDG 13 and the world

International cooperation and development were key words in 2015. By adopting the 2030 Agenda and the 17 Sustainable Development Goals (SDG) – under the Convention on Biological Diversity (CBD) and the Paris Agreement, within the

United Nations Framework Convention on Climate Change (UNFCCC) –, the Addis Ababa Agenda, at the *Third Conference on Financing for Development*, and the Sendai Framework for Disaster Risk Reduction, member countries made a political statement to reduce social inequality, poverty and its adverse effects on human populations and on the availability and quality of natural resources throughout the world. These agendas are complementary and will require coordinated actions at local, national and global levels, both in the public and private spheres, so that they can be effectively implemented and lead to expected results.

At the 23rd UNFCCC Conference of the Parties (COP23) held in Bonn, Germany, in 2017, there was progress on discussing the need to ensure connections between SDG and actions defined in the UNFCCC. Climate change impacts are a major threat to successfully achieving SDGs, as they pose a high risk to human populations dependent on energy supplies, clean water and food. Climate change threatens, above all, the conservation of the natural resources currently available.

Choosing climate change as the theme for one of its SDGs (SDG 13) reveals member countries recognition of the importance and crosscutting relevance of this theme in their agendas. In summary, SDG 13 reinforces that the UNFCCC is the main international and intergovernmental forum for negotiating the mitigation of GHG emissions and the adaptation to the adverse effects of climate change. In order for Brazil's involvement in this forum to be successful, domestically building networks of cooperation and coordination among various national agencies and institutions is necessary. Budget planning, coordination and predictability are fundamental for developing integrated actions and monitoring and assessing results of implemented actions.

The fundamental principle that guides sustainable development since the 1987 release of *Brundtland Report*, prepared by the United Nations World Commission on Environment and Development, is economic development that meets human needs in the present, without compromising the ability of future generations to meet their own needs.

Based on this premise, SDG 13 becomes urgent: taking urgent measures to fight climate change and its impacts.

The urgent nature of SDG 13 translates the detailed assessment of the Intergovernmental Panel on Climate Change (IPCC) in its *Summary for Decision Makers of the 5th Assessment Report* (AR5), published in 2014, which provides strong scientific evidence that the climate system is influenced by anthropogenic

GHG emissions into the atmosphere. This report highlights that GHG emissions from human activities are expected to result in an average increase in global temperature and increase the frequency and intensity of extreme weather events over coming decades.

Recent climate-change-related climate extremes have already impacted ecosystems, the countryside and urban areas in various parts of the planet. IPCC reports and summaries point out that maintaining or increasing anthropogenic GHG emissions over a short (in terms of the geological scale) period of time can lead to irreversible and large-scale changes in the planet's climatic and environmental balance. The unpredictable nature of these extreme weather events puts future generations at risk, in direct opposition to the *Brundtland Report* principles.

The urgency in adapting to the adverse effects of climate change is further enhanced when one considers the cumulative effects of global warming. These effects are direct results of the increase of GHG concentration in the atmosphere over time (Lacis et al., 2013), climate inertia and allocation of financial resources on global economy innovation and decarbonization. Unlike climate change extreme effects, cumulative effects are more predictable by current methods of scientific research; therefore, lacking plan and actions to create a robust adaptation plan for climate change predictable impacts is inexcusable.

In this sense, it is urgent to define consistent strategies for changing energy sources and mitigating GHG emissions. It is mandatory to raise modern society's awareness of the risks and challenges posed by climate change, in order to avoid losing this opportunity still available to adjust our behavior to what is established in the *Brundtland Report*.

Action must be taken on multiple fronts: encouraging the development of decarbonization technologies, more efficient processes in various human activities, and sharing resources and innovations to empower future generations on climate change diffuse risk and potential adverse effects. Joint actions of countries, governments, and various spheres of states and organized civil society is, therefore, important to consolidate sustainable economic development models in the short and medium terms.

This sense of urgency was expressed in 2014 by former US President Barack Obama at the *United Nations Summit on Climate Change* in New York: "We are the first generation to feel the effects of change climate and the last generation that can do something about it".

One of the greatest challenges for our societies will be the relationship between countries in the context of trends and pressures for economic decarbonization. In addition, changes required for implementing the Paris Agreement should create opportunities for nations capable of producing innovations in Circular Economy models (Stahel, 2016). Countries that invest in human and technological resources to innovate and that are able to communicate the manifold benefits of adopting more efficient new means of production will lead the Circular Economy.

SDG 13 and Brazil

As innovative products and processes emerge, adhering to Circular Economy, traditional economic sectors may resist because this can affect their market positions. Among the expected responses to a possible risk of obsolescence, misinformation (Vosoughi et al., 2018) is perhaps one of the most plausible. In this context, efforts to manipulate information aiming at collective disinformation and distortion of reality through social networks are increasingly evident.

Collective misinformation has already affected political decisions and directions worldwide. Concerning misinformation about climate change, it is, therefore, of utmost importance that institutions and governments communicate their goals and actions in a very transparent way, encouraging and fostering, within and outside their borders, collaboration in research, development and innovation of products and processes of Circular Economy. This is why Brazil should determine consistent national and international mechanisms to encourage the development of emission mitigation and adaptation to climate change impact technologies as priorities.

According to O'Connor et al. (2003), the perception of a given society on the theme "climate change" is not homogeneous. It depends on the social context of individuals or groups of individuals, and on their openness to a more sustainable attitude. In the United States of America, for example, the risk perception associated with climate change is greater among higher income and better educated classes (O'Connor et al., 2003). In Brazil, however, most studies and academic efforts have focused on mitigation of emissions (Gouvello et al., 2010; Motta et al., 2011; Brasil, 2016; Schaeffer et al., 2015), without due attention to the adaptation of production systems as a key component of Circular Economy to deal with future and probably harder climatic conditions. Only recently an adaptation plan focused on a strategy agenda for the Política Nacional de Mudanças Climáticas (National Policy on Climate Change – PNMC) (Brasil, 2015) has been calling attention.

Circular Economy models focused on adaptation are a great opportunity for the Brazilian agricultural sector. Investing in new climate change adaptation technologies for the sector based on legal instruments, many of which are already in force, and on concepts of sustainable development may take Brazil to a great national and international visibility status. In this sense, Código Florestal (Brazilian Forestry Code), Cadastro Ambiental Rural (Rural Environmental Registry – CAR) based on an integrated landscape management, and Plano de Agricultura de Baixo Carbono (Low Carbon Agriculture Plan – ABC) are already a reality in Brazil. These governmental programs are in line with international commitments to comply with SDG 13. The fact that these actions have already been implemented places Brazil at a leading, legitimate and robust position in terms of the Nationally Appropriate Mitigation Actions (Namas), and Brazil sustains this leading position in the context of the Paris Agreement, as a country that has acknowledgedly presented a set of domestic policies and strategies regarded as one of the most ambitious Nationally Determined Contributions (NDC).

Additionally, scientific methods to monitor integrated landscape management must be consolidated, so that large data and robust analysis can be performed to attest to the multiple benefits of adopting more efficient and conservationist agricultural models. Strategically using this information may benefit the management of Brazilian natural resources, foster economic gains, thus revealing the strategic importance of resilience in managing agroecosystems, and consolidate the Circular Economy model that seeks to develop more climate change risk adapted systems and, therefore, more efficient systems to contribute to agricultural GHG emissions mitigation.

Consistent information about the multiple benefits derived from the previously mentioned governmental programs and the adoption of agroecosystem conservation practices, also including the Zoneamento Agrícola de Risco Climático (Climatic Risk Agricultural Zoning – Zarc), the ABC Plan, the CAR and the Forestry Code, should support the international promotion and strengthening of commercial and financial partnerships for the development and consolidation of sustainable integrated and intensive agriculture in Brazil.

SDG 13 and Embrapa

The commitment of Embrapa to addressing these challenges has been a priority over the past decades. A Climate Change Research Portfolio was designed to foster and develop sustainable agricultural research in the tropics in the following areas:

genetics, environmental management and soil and water resources conservation. The socioeconomic area has been standing out over the years as the basis for sustainability in order to adapt agroecosystems to climate change impacts.

Embrapa has been playing a proactive and systematic role abroad by supporting ministries of Foreign Affairs and Agriculture, Livestock and Supply in decision-making, especially in multilateral negotiations within the framework of the UNFCCC. In November 2017, the participation of Embrapa in the Brazilian delegation in these negotiations had a very promising result to the agricultural sector, a decision called "Koronivia" Joint Work on Agriculture. This understanding has opened space for discussions on implementing agricultural actions taking into consideration agricultural vulnerability in relation to climate change, ability and importance of this sector for food security.

Within UNFCCC, discussions on agriculture will continue to move forward, given the scientific development and the importance of specific strategies for transferring technologies, practices and experiences to farmers. Expanding this idea, during COP23 in Bonn, the following elements were prioritized in the context of discussions on agriculture:

- Methods and approaches to assess adaptation, its co-benefits and resilience.
- Improvement in stocked carbon, soil health and fertility in pastures, agricultural land, as well as integrated systems, including water resource management.
- Improvement in nutrient use and animal waste management in sustainable and more resilient agricultural systems.
- Improvement in beef production systems management.
- Inclusion of socioeconomic and food security dimensions.

Final considerations

The risks of climate change to food security and economic sovereignty are imminent, especially for nations located in tropical and less developed regions, which are likely to be more affected by the increased incidence of extreme temperature, flood and drought events. Therefore, in the absence of measures to adapt and mitigate emissions, especially those from burning fossil fuels in Annex I countries of the UNFCCC, climate change must be seen as a concrete threat to

Brazil. Therefore, it is necessary to quickly adopt emission mitigation measures and to have a strongly based climate change impact adaptation plan in Brazil. For this purpose and in accordance with SDG 13, Embrapa has been consolidating relevant information by means of research and innovation in order to accelerate the emergence and adoption of new agricultural practices and technologies strongly connected to Circular Economy, which is a great opportunity for Brazil.

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Chapter 2

Climate change and Brazilian agriculture

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Introduction

Anthropogenic greenhouse gas (GHG) emissions and land use and land cover changes are expected to impact global climate in the coming decades (Intergovernmental Panel on Climate Change, 2013). For example, increasing global average temperature, average sea level and the frequency and intensity of rainfalls and drought, causing floods and heat waves, are expected as results of anthropogenic activities. Such changes should significantly impact a number of agroecosystems across the globe (Stocker et al., 2013; Stevanović et al., 2016; Moore et al., 2017; Zhao et al., 2017; Scott et al., 2018).

As population grows and consumption of food, fiber and biofuels increase, the agricultural sector will face enormous challenges to maintain production growth and to adapt to climate change (Stevanović et al., 2016). Particularly in Brazil, the demand for exports has placed the country as one of the main agricultural producers in the world. Agriculture plays a prominent role in Brazilian Gross Domestic Product (GDP), and amounts to 23% of industrial GDP and 42% of exports (Escola Superior de Agricultura Luiz de Queiroz, 2018), and creates 37% of direct and indirect jobs in Brazil. In turn, the Brazilian sector of planted trees, with an area of 7.84 million hectares of reforestation, is responsible for 91% of all wood for industrial purposes and 6.2% of the industrial GDP of Brazil. Unlike countries at high latitudes, agricultural commodity exporters in tropical regions, such as Latin America, are expected to experience more severe climate change impacts on crop yields, and consequently losses in consumer surplus may exceed potential gains in producers surplus, which may reflect on higher prices (Stevanović et al., 2016).

Therefore, Brazilian agroecosystems will have to seek technological innovations that simultaneously allow mitigating GHG emissions and adapting to climate change, in order to guarantee production of food to its current and future populations in the medium and long terms, as well as income generation from commodity exports, especially of higher added value agroindustry products.

Direct impacts

Climate is the main environmental factor associated with production variability in agriculture, especially for rainfed systems, which occupy large areas in Asia and most of the agricultural areas in Africa and Latin America (Hijmans; Serraj, 2008). Climatic risks that potentially cause significant or total production loss can be divided into two groups: those related to extreme events (e.g. low and high temperatures, intense rainfalls and strong winds, among others) and those related to cumulative events (e.g. long droughts, temperatures limiting growth for long periods, etc.). Recent studies have emphasized that, while changes in average climate conditions affect agricultural productivity and require adaptation policies, most agricultural crop losses and food security risks will be associated with increasing annual variations of climatic conditions thanks to extreme climatic events (Alexander et al., 2006; Stevanović et al., 2016). For example, drought in the central region of Brazil in 2016 caused a rise in maize grain prices and its supply shortage in some Brazilian regions. By the end of 2016, 39.6 million tons of corn were harvested, 29.5% less than in the previous year (56.3 million tonnes), despite a 10.3% increase in planted area (Produção Agrícola Municipal, 2018). Additionally, 3 years of rainfall below the historical average in the Southeastern region damaged around 100 thousand hectares of eucalyptus forest, leading to losses of 10 million cubic meters of wood between 2013 and 2015.

Research, development and innovation efforts have been seeking solutions so that increasingly sustainable agriculture can adapt to climate change impacts and mitigate GHG emissions. Economic, social and environmental feasibility of technologies for sustainable development is fundamental to reduce social inequalities and to guarantee food and water security for all, like the Circular Economy (Stahel, 2016). Advancing scientific and technological knowledge in recent years and promoting education and research institutions interaction play a fundamental role in the proposition and successful adoption of public policies to increase the adaptive capacity to face climatic risks, thus creating opportunities and opening paths for climatic resilience. Adapting agriculture to Circular Economy creates opportunities to mitigate GHG emissions in more productive and socioenvironmentally-efficient agroecosystems (Stahel, 2016). This is why strengthening actions to reduce climate-change-inherent impacts and risks, creating opportunities in low carbon economy and promoting sustainability in the rural environment are crucial.

Indirect impacts

Climate change may have many indirect impacts on plant stress in ecosystems and agroecosystems. Another great impact on crop productivity over the next decades can be the effect of increasing atmospheric CO_2 partial pressure on plant photosynthesis, especially C3 ones (e.g., wheat, rice and soy), and on the nutritional value of plant-based foods. Recent results have indicated that non-legume C3 crops have lower protein concentrations when grown in a high CO_2 concentration environment, while C4 crops appear to be less affected (Myers et al., 2014). These effects on productivity and quality of plants have been highlighted in Embrapa research agenda. For example, atmospheric CO_2 excess may eventually benefit irrigated rice yield in the state of Rio Grande do Sul, the main producing state of Brazil (Cuadra et al., 2015).

Climate change may intensify abiotic as well as biotic stresses. For example, it is extremely important to estimate how plant pathology problems can be affected by climate changes, since pathogens and pests cause drastic productivity reductions and may jeopardize the economic and environmental sustainability of various agricultural activities. In the case of animal production, the incidence of ectoparasites, such as ticks, a very common health problem in livestock, may increase. However, adaptation measures can only be incorporated after knowledge on the relations between climatic elements and distribution of plant diseases in time and space has been produced. In this sense, several simulation (models) and experimentation studies have been carried out in recent years (Pereira, 2008; Bettiol et al., 2017).

Impacts of agriculture on climate change

Agriculture will not only be affected by climate change, but may contribute to its intensification; therefore, ways to mitigate agricultural GHG emissions must be developed. The scientific community has agreed to the term Low Carbon Emission Agriculture (ABC), which aims to encourage the adoption of a set of actions and technologies to mitigate GHG emissions, combining CH_4 (methane), N_2O (nitrous oxide), and CO_2 (carbon dioxide), or to sequester atmospheric CO_2 in vegetation and soils. ABC occurs in agroecosystems in which plant and animal biotechnology, chemical engineering and mechatronics are gradually integrated, thus promoting better productivity rates and material recycling processes, whether or not associated with generation of renewable energy (biomass, biodiesel, biogas, etc.). Among these, combinations of integrated plant-animal systems, no-tillage with crop rotation and cover crops / green manure, Biological Nitrogen Fixation (BNF) and improved pastures are prominent examples (Sacramento et al., 2013; Brandão et al., 2017). Mitigating emissions through agricultural integration and intensification in agroecosystems allows the conservation of natural resources and provides environmental services from remaining ecosystems (Silva et al., 2015). Combinations of agricultural technologies and practices that favor enhanced productivity gains and certified mitigation of GHG emissions should be priorities.

In addition to producing commodities and food, Brazilian paper, pulp and biofuel industries occupy an outstanding position. Along with photovoltaic and wind power, energy crops are viable economic and environmental alternatives for the gradual replacement of fossil energy sources for renewable energy, mainly for the transportation sector. Several crops have been used for producing varied types of biofuels, such as ethanol from sugar cane and corn, biodiesel from soybean, and biomethane and biokerosene from animal waste. The forestry sector, in turn, has great potential for GHG reduction by promoting carbon sequestration in commercial tree plantations (for non-energy purposes) and by recovering Legal Reserves, Permanent Protection Areas and Private Reserves of Natural Heritage, in order to comply with the Forestry Code and the Rural Environmental Registry.

Conservation of ecosystem services

The opportunity to leverage Circular Economy technologies for emission mitigation and agricultural adaptation to climate change should trigger the conservation of natural resources and safeguarding the provision of environmental services from agroecosystems in Brazil. Agroecosystems provide various ecosystem services, such as regulation of soil and water quality, carbon sequestration, maintenance of biodiversity and insect pollinators or pest controllers, as well as cultural services (Power, 2010). These services include the “blue water” cycle, which is responsible for forming rivers, and “green water”, which represents the interaction of rainfall water and terrestrial ecosystems, giving rise to evapotranspiration, percolation and recharging of subterranean aquifer processes (D'Odorico et al., 2010). In this context, one of the main ecosystem services is water resources.

Climate change may affect water resources in a number of ways in Brazil. In the northeastern Semi-arid region, increased water demand due to increased evapotranspiration and reduced rainfall, thus enhancing a desertification-like process, is expected (Cavalcanti et al., 2005; Gondim et al., 2012). In turn, climate change has been increasing extreme rainfall events in the Pantanal (Bergier et al., 2018). Under pressure from expanding urban areas and advancing large-scale agribusiness in rural areas, many human populations have been migrating and settling in peripheral and other areas intrinsically more vulnerable to climate change. There are also indications that climate change could increase the number of asylum applications (refugees from climate change) in developed and developing countries (Missirian; Schlenker, 2017). These vulnerable populations will increasingly need support and public policies that create opportunities to reintegrate them into society or enable them to migrate and resettle in safer regions.

Public policies

The Política Nacional de Mudanças Climáticas (National Policy on Climate Change – PNMC) made official the voluntary commitment of Brazil to the United Nations Framework Convention on Climate Change (UNFCCC) to reduce between 36.1% and 38.9% of its projected GHG emissions by 2020. Presidential Decree nº 7.390/2010 (Brasil, 2010) regulates the PNMC and sets GHG emission baseline for 2020 at 3.2 Gt CO_2-eq (1 Gt = 10^9 tons of CO_2 equivalent). Therefore, the corresponding absolute mitigation commitment is between 1.2 Gt CO_2-eq and 1.3 Gt CO_2-eq. In 2012, agriculture accounted for 37% of national emissions. From 2005 to 2012, agricultural emissions increased by 7.4%, from 415.7 Gg CO_2-eq to 446.4 Gg CO_2-eq (1 Gg = 10^9 grams or 10^3 tons of CO_2 equivalent). However, from 1995 to 2005, agricultural emissions had increased, from 335.8 Gg CO_2-eq to 415.7 Gg CO_2-eq, that is, a 23.8% increase. In land use and forestry sectors, 1990 emissions (815.96 Gg CO_2-eq) increased by 138% in 1995 (1,940.42 Gg CO_2-eq), coinciding with the peak of deforestation in the Amazon. Public monitoring and control policies to contain the progress of deforestation have been very successful and effective, thus bringing emissions to 175.7 Gg CO_2-eq in 2012, a 91% reduction in relation to 1995 figures. In addition to the PNMC, the federal government established sectoral strategies, such as the ABC Plan (Plano..., 2012) and the Plano Nacional de Adaptação (National Adaptation Plan – PNA). Embrapa has proactively joined by means of doing research, developing new technologies and supporting the design of these public policies for emission mitigation and adaptation to climate change.

Process integration as agricultural response

Mitigating emissions and adapting to climate change essentially require the efficient and integrated use of natural resources available on a rural property, thus maximizing land potential, low impact on natural resources and, preferably, local generation of renewable energy. Currently, the Nexus approach, which links energy, water and food sectors in agriculture, as proposed by the Food and Agriculture Organization (FAO) of the United Nations (Flammini et al., 2014), has been increasingly adopted. FAO has developed Nexus to inform and guide decision-making and public policy-making processes to improve the socio-environmental and economic conditions of nations, thus offering participatory support for countries in designing and implementing such actions. Embrapa research and development studies related to agricultural emission mitigation and adaptation to climate change are adherent to FAO water-energy-food Nexus. Given that energy, water and food management are closely connected, they must be managed and governed in an integrated way to effectively meet the needs of a growing world population.

Final considerations

Agriculture is fundamental for Brazilian economy and food security. It is a worldwide consensus that financial gains and food from tropical agroecosystems are threatened by worsening climate change in the coming decades. However, deforestation and inadequate use of deforested areas for food production significantly contribute for this increase due to GHG emissions. Several public policies adopted in the last 20 years have been helping to mitigate Brazilian emissions from deforestation, particularly in the Amazon and Brazilian savanna (Cerrado), and to encourage the adoption of more sustainable technologies and productive arrangements. Embrapa research, development and innovation efforts, in partnership with other research centers and private companies, have resulted in major contributions and advances in designing these policies.

Given that most GHG emissions originate from burning fossil fuels, it is realistic to expect that the average temperature of the planet exceeds the +2 °C threshold, even if Annex I countries achieve their emission reduction targets. In this case, the need to adapt agroecosystems to climate change is fundamental.

Therefore, Brazil needs to take immediate action to strengthen public and private partnerships that allow significant advances in knowledge. These advances must necessarily be translated into technologies aimed at simultaneously increasing agricultural productivity and environmental services (water production, carbon sequestration, biodiversity, etc.) from agroecosystems already established in different biomes, thus avoiding further deforestation. Embrapa will certainly play a leading role in these actions, thanks to its nationwide reach and its ability to weave large collaboration networks in an increasingly open and more competitive economy (Brasil, 2018).

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Chapter 3

Resilience and adaptation of agriculture to climate change

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Introduction

From a strategic point of view, it will be extremely important to anticipate how agro-ecosystems will sustainably respond to the increasing global demand for food, fibers and energy in a context in which agricultural productivity can show stagnation or reduction associated with climate change (Challinor et al., 2014; Zhao et al., 2016). Climate variability accounts for about one-third of agricultural productivity variability around the world (Ray et al., 2015). Climate change should, therefore, increase agricultural productivity variability, which could be drastically reduced during the second half of this century if measures to adapt to and mitigate greenhouse gas emissions (GHG) are lacking. The *5th Assessment Report* (*AR5*) of the Intergovernmental Panel on Climate Change (IPCC) suggests that tropical rice productivity is likely to decline at a 1.3% to 3.5% rate for each 1 °C average global warming (Porter et al., 2014). Increased average global temperature may lead to increased thermal and water stresses and, consequently, decreased productivity (Zhao et al., 2017). It is estimated that climate change is already reducing global crop production by 1% to 5% per decade over the past 30 years, and will continue to pose challenges for agriculture in the coming decades (Challinor et al., 2014; Porter et al., 2014).

Therefore, climate change poses a very high risk for food security without adequate measures to mitigate and adapt agroecosystems in the world and in Brazil (Magrin et al., 2014). This chapter discusses how Embrapa has contributed to achieve target 13.1 – Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

Adaptation of agriculture to climate change

To ensure greater resilience and adaptability to climate risks, it will be important to quantify the risk to which agroecosystems will be exposed in the different ecological regions of Brazil. This task is extremely complex given the continental dimension of Brazil, its diversity of crops and production systems and the availability of natural resources. In this context, a tool that stands out to assess how agricultural productivity responds to climatic conditions are empirical (statistical) models and models based on biophysical processes that simulate agricultural productivity and its interactions with the environment and management practices (Lobell et al., 2008; Jones et al., 2017). Models allow to identify and assess agricultural production uncertainties due to average conditions and climatic variations and to explore different adaptation actions, especially those related to management practices (Boote et al., 2013; Paixão et al., 2014). For example, models allow improving crop efficiency by analyzing the performance of cultivars in different soil and climatic conditions, sowing dates, plant populations, irrigation management and nitrogen fertilization times (Paixão et al., 2014; Heinemann et al., 2017b). However, in spite of the great advances over the last decades, development, parameterization and validation in regional, national and global scales are still insufficient. Initiatives such as The Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Intercomparação, Aprimoramento, e Adaptação de Modelos de Simulação de Culturas Agrícolas para Aplicação em Mudanças Climáticas (Intercomparison, Improvement and Adaptation of Simulation Models of Agricultural Crops for Application in Climate Changes – AgMIP-BR), coordinated by Embrapa, seek to accelerate parameterization and validation of these models.

Although these initiatives are underway, determining the potential impacts of climate change is still limited to a number of agricultural crops in Brazil. Field and modeling surveys have shown that climate change could impact a variety of agricultural crops. Modeling studies have projected a systematic decrease in climatic adequacy for bean cultivation in most of South America (including the state of Goiás, Brazil); high temperatures and water stress are the main limiting factors to increased productivity (Ramirez-Cabral et al., 2016; Heinemann et al., 2017a). For subtropical rice grown in Southern Brazil, the main changes are associated to: 1) reduced cold risk; 2) shortening of the cycle thanks to temperature increase; 3) increase in productivity in colder regions, with lower losses due to cold sterility; 4) in warmer regions, decrease in yield due to climate change for some sowing dates and cultivars, because of higher daytime and nighttime temperatures (Marques et al., 2005; Steinmetz et al., 2005; Cuadra et al., 2015).

Current climate impacts and global warming projections on maize crops in the state of Minas Gerais, Brazil, were also studied using models (Amorim et al., 2008). It was observed that reduced rainfall and increased temperature tend to substantially decrease crop cycle duration and leaf area index and, consequently, maize crop yield. Magalhães et al. (2016) evaluated mitigation strategies for maize in Minas Gerais and found that keeping crop residues on soil surface is more efficient than deep rooting systems to attenuate the effect of reduced rainfall indices. On the other hand, stimulating maize deep rooting system, either by using aluminum tolerant cultivars or by correcting soil profile, was more effective to attenuate the effect of high air temperatures. With regard to climate change adaptation strategies, Grossi et al. (2013) suggest that the recommended sowing window for grain sorghum be delayed in Janaúba and Sete Lagoas, in the state of Minas Gerais, and Rio Verde, in the state of Goiás, Brazil.

As for the adaptation of pastures, results obtained by Santos et al. (2014, 2015) suggest that climate change will have a positive impact on the annual forage yield of Tanzanian grass (*Panicum maximum*) and Marandu grass (*Urochloa brizantha*) in most of Brazil's Midwestern and Southeastern regions. Despite the increase in annual forage yield of these pastures, results suggest that there may be a greater production seasonality. The most vulnerable areas of these regions, for which some scenarios point to a reduction in annual production, are located between the Brazilian states of Minas Gerais and Goiás and in areas near the Northeastern Semi-arid area. In the case of Pantanal, where cattle breeding activities on native pastures are predominant (Santos et al., 2002, 2015; Abreu et al., 2018), summer rainfall has become more extreme over the past 90 years thanks to global warming

(Bergier et al., 2018). Plain areas covered with native pastures may be affected in cases of avulsions followed by break-ins of marginal dikes of distributary rivers (Assine et al., 2016), which can be induced by extreme rainfall events in the Brazilian Cerrado areas, where there are high amounts of deforested agroecosystems and where springs of Pantanal rivers are located (Galdino et al., 2005).

Embrapa has sought to incorporate this knowledge to construct scenarios of the climate changes impacts on animal and pasture production, in order to find adaptation measures for the sector. In animal production, with the aid of climatic aptitude and empirical production models, Santos et al. (2014, 2015) analyzed the conditions of cultivation in Brazil for Marandu grass (*U. brizantha* cv. Marandu), Tanzania grass (*Panicum maximum* cv. Tanzânia-1), forage palm (*Opuntia* sp.), buffel grass (*Cenchrus ciliaris*) and annual ryegrass (*Lolium multiflorum* Lam.). Embrapa has been working with the DSSAT and APSIM biophysical model development teams to adapt and parameterize simulation models for tropical pastures, in order to improve scenario studies for animal production in pastures in Brazil (FAO, 2009; O'Mara, 2012).

Technologies, products and services for agricultural adaptation

Management alternatives to enhance resilience

Embrapa and its partners have sought to develop new technologies, products and services to minimize the risks of losses and increase agroecosystems productivity gains. Examples are plant breeding programs for developing new genetic materials adapted to different production environments, or recommending alternative crops in locations where current production systems are becoming less sustainable. Adopting good agricultural practices is one of the most viable methods for promoting resilience, reducing exposure to climatic risks, and reducing current productivity gaps (Cassman, 1999; Ittersum et al., 2016). For example, the Zoneamento Agrícola de Risco Climático (Climatic Risk Agricultural Zoning – Zarc) can contribute to reducing risks because of its recommended more favorable dates for implementing various agricultural crops (Santos; Pezzopane, 2010a, 2010b; Santos et al., 2010a, 2010b).

In addition to recommending the best sowing dates, it is important that plants used in stress-prone regions be adapted to these conditions. For example, for perennial grasses grown in sites subject to severe water shortage, it is often more important to ensure grass survival than short-term high yields. In these situations, it is important that perennial pastures be able to withstand long-term dehydration to survive and regrow until groundwater availability is again adequate. This strategy to respond to water shortage is related to mechanisms of plants to protect its regrowth points from dehydration.

To ensure competitive and sustainable animal production in a climate change scenario, Brazilian agroecosystems must undergo technological adaptations. Diversified genetic material, supplementary feeding, forage conservation, animal and plant selection and breeding, adequate pasture and soil management, adoption of integrated and intensive systems and using controlled irrigation are among the most plausible technological adaptations. Among the most indicated technologies are pasture recovery and intensification (FAO, 2009; O´Mara, 2012).

Genetic plant breeding

In addition to recommended management practices and integration and intensification, plant breeding programs will play a fundamental role in developing cultivars adapted to climate change conditions (Challinor et al., 2014). Several research groups are focused on developing cultivars with higher tolerance to water deficit, higher photosynthetic and nutritional efficiency, and resistance to aluminum toxicity in acid soils. In order to reduce these limitations, several studies seek alternatives such as exploring genetic variability of crops and related species to identify molecular markers for Quantitative Trait Locus (QTLs) or favorable alleles for assisted selection, perform a broad genomic selection, incorporate exotic variability traits via genetic transformation, or gene editing. For example, identifying genes of tolerant plants, such as some native semi-arid species – which survive in situations of water stress and high temperatures –, can contribute to generate biotechnological alternatives for improving cultivated plants (Aidar et al., 2017). However, greater effectiveness and promptness in developing and providing more adapted and stable cultivars in environments with abiotic stresses will only be achieved if funding is maintained for collaborative research joining basic research, pre-breeding and development of cultivars in the final breeding phase (Gilliham et al., 2017).

In the case of perennial pastures, Embrapa has been assessing forage plants in terms of their response mechanisms to water deficiency to develop, select and recommend accessions for different water stress conditions. Preliminary experiments in greenhouse indicate that, under conditions of short-term mild water deficit, root deepening, together with other mechanisms of delay to dehydration, allows Marandu grass (*Urochloa brizantha* cv. Marandu) and brachiaria grass (*Urochloa decumbens*) to continue to grow and maintain good productivity standards. On the other hand, 'BRS Paiaguás' grass (*U. brizantha* cv. BRS Paiaguás), besides its ability to deepen its roots, activates water saving mechanisms that drains soil water at a slower pace, thus maintaining hydration of parts of the plant important for survival; it may be recommended for regions with extreme water stress events for long periods (Beloni et al., 2017).

In the forestry sector, vulnerability varies over time according to species sensitivity, their phenological stages and the worsening of extreme climatic phenomena of prolonged droughts and above average temperatures. Therefore, each phenological stage must be observed in order to understand their sensitivity, and vulnerability, and to improve characteristics that promote their adaptation. These observations should be incorporated into breeding programs, especially for forestry monocultures (Higa; Pellegrino, 2015).

Animal farming

Raising animals adapted to heat and humidity in conventional or integrated production systems contributes to reducing thermal stress. For example, zebu breeds (*Bos taurus indicus*) and their crosses are more heat tolerant than bull breeds (*Bos taurus*) of European origin, with positive effects on reproduction (Paula-Lopes et al., 2013), although these animals are not always associated with high production (Santana Junior et al., 2015). Embrapa has been looking for molecular markers and genes that can be used in genomic selection or gene introgression, so that, in the long run, it is possible to increase the population of animals better adapted to heat and humidity, and with better reproduction and productivity indices. Thus, animal breeding programs developed by Embrapa and partners have provided phenotypes adapted to climatic extremes, positively affecting agro-systems resilience (Campos et al., 2017). Today Brazil is a reference in zebu genetics, a race known for rusticity, heat and parasite tolerance, opening the way for sustainable production in the tropics (Santana Junior et al., 2015), either with purebred animals or at crossings with bulls.

Intensive and integrated production systems

The integration of agricultural, livestock and forestry production systems (integrated crop-livestock-forest – ICLF) allows intensifying land use for food, fiber and energy productivity gains (Cordeiro et al., 2015). Adopting ICLF with the forest component (crop-forest-livestock, crop-forest or forest-livestock) (Oliveira et al., 2017) contributes to mitigating GHG emissions and to adapting agricultural systems. This paradigm shift also contributes to reducing deforestation, since unproductive agroecosystems such as degraded pastures, can be recovered, thus reducing the pressure for opening new areas, mainly in the Amazon, with countless economic and socio-environmental benefits. However, long-term studies are still needed to better assess the impacts of intensification by integration on soil attributes, water resources, GHG emissions, among others. Embrapa has been investing in implementing and maintaining large-scale and long-term experiments in its Technological Reference Units (TRU) with multidisciplinary and interinstitutional studies in order to produce more knowledge on interactions that result from intensification / integration in agroecosystems. It is common sense that ICLF and forest-livestock integration (ILF) are efficient in mitigating emissions, since they carry out a greater carbon sequestration in soil and tree stems (O´Mara, 2012; Cunha et al., 2016; Figueiredo et al., 2017; Oliveira et al., 2017). In addition, Embrapa has been actively participating in initiatives for developing and adapting models for the simulation of ICLF systems (Bosi, 2017).

ICLF systems are agroecosystems that intensively use a part of the farm, which is aimed at producing food, fiber and/or energy. This model allows to keep isolated and untouched the remaining areas of the farm, thus complying with the Forestry Code legislation for each biome. This agricultural practice is also named Land Sparing (Green et al., 2005) or "spared lands". Other integrated but less intensive production models share the farm resources without isolating part of them. This model is called Wildlife-Friendly Farming Systems (Green et al., 2005), Land Sharing, Agroecological Systems or Agroforestry Systems (SAFs) (Phalan et al., 2011).

In general terms, ICLF seeks to maximize productivity through integration and intensification (using biotechnology combined with non-renewable resources such as agrochemicals) and isolate native areas protected by law. In turn, SAFs integrate environmental services production and conservation in the same area, however, with minimal use (or zero, depending on certification requirements) of agro-industrial or biotechnological inputs (agrochemicals for soil fertilization or pest control, usually combined with genetically modified organisms, so-called

GMOs). Certification must be a formal statement of evidence, issued by anyone with credibility or legal / moral authority, and should be done following protocols embodied in a document.

In terms of nature conservation, some studies show that Land Sparing is more efficient (Phalan et al., 2011), while others suggest that choosing between one of these models will depend, for example, on the presence and size of urban areas (Soga et al., 2014), on environmental conditions and/or restrictions such as floods (Silva et al., 2016), or even on socioeconomic factors (Grau et al., 2013).

Environmental systems

Climate vulnerability resulting from global changes implies the need to diversify production and to better explore opportunities and aptitudes of each ecosystem. In this context, climate change impacts can also be minimized by adopting diversified ecological systems or SAF (International Policy Centre for Inclusive Growth, 2016). Creating such a system based on the available local natural resources meets a growing demand of part of the population for agroecological or strictly organic food production and meets a number of requirements linked to farmer's comfort and animal welfare. SAF is a social inclusion mechanism for low-income small farmers through the valuation of "natural" products associated with biodiversity conservation and environmental services.

An alternative is to incorporate the ecological landscape approach, based on intelligent use of natural features offered by ecosystems (Giongo et al., 2016) in order to design multi-functional agroecosystems by incorporating technologies developed over the years, such as selection of plant species tolerant to thermal, water and saline stresses; inoculant use; symbiotic efficiency of diazotrophic bacteria (Marinho et al., 2017); consortia of species; adoption of no-tillage system; planting of native tree species; and technologies for collecting, storing and using rainfall water with high efficiency and productivity for economic and environmental benefit.

Functional agroecosystem models are sustainable and comprise increasingly complex relations between and within their multiple components as strategies to increase resilience and food security. In this sense, searching for more sustainable systems can minimize the fragility of traditional production systems, thus increasing their resilience and population adaptability. It should be noted that several farmers are using agroforestry systems as land use options in several regions (Ngegba et al., 2007; Wick; Tiessen, 2008; Martins et al., 2013). Using native species in agroecological and agroforestry systems is an important tool to recover degraded areas and preserve endangered species, thus adding more value to family communities local products.

Fish farming

Aquaculture is the fastest growing branch of animal production in Brazil and the world. The use of large bodies of water for fish production has been encouraged by national public policies; therefore, in Brazil, fish farming in net pens has been adopted in several water reservoirs for electricity generation. Because it is an activity that also depends on other sectors and shares the use of water for other purposes, assessing climate change impacts on this productive activity becomes highly complex (Ehsani et al., 2017; Ho et al., 2017). Limnological and bathymetric information of reservoirs in geographic information systems will be essential to identify areas of reservoirs less susceptible to aquaculture in terms of water quantity and quality (Lima et al., 1997).

Digging tank aquaculture is on the rise in the states of Mato Grosso and Mato Grosso do Sul using underground aquifer water. The impact of increasing use of aquifers, coupled with climate change, may compromise groundwater dependent activities in the long term. In this sense, there are also good examples of Circular Economy in Embrapa, such as the adaptation of aquaculture by integrating it with plant production for small farmers (Sistema..., 2012). This system, also called aquaponics – *aquaponics*, see Love et al. (2015), allows cleaning and reusing system water after removing solids by filtration and decanting and nutrients dissolved by the root system of edible plants or for fiber and bioenergy purposes. Water is thus recycled and can return clean to the fish tank. This economically and environmentally efficient model has been improved by industrial automation and adopted at different scales of production abroad. Aquaponics should be understood as one of the most promising socio-economic markets in the world and one of the greatest adaptations to climate change for integrated animal and plant production.

Indirect impacts

In addition to the direct effects of climatic changes on climate and, consequently, on agroecosystems, increasing CO_2 concentration in the atmosphere directly impacts photosynthetic efficiency. One of the main techniques to evaluate the effect of CO_2 increase in agroecosystems is performing experiments with high CO_2 concentration in open environments called Free Air CO_2 Enrichment (Face), which allows in natura assessing the effects of increased atmospheric CO_2 concentration. The first Face experiment in Brazil was implemented in 2011 in the experimental area of Embrapa Environment with coffee crops as part of the Climapest project (Ghini et al., 2013). Results show an increased photosynthetic rate of Catuaí Vermelho IAC-144 coffee cultivar, mainly in hot and humid periods, and a greater efficiency in water use in increased atmospheric CO_2 treatments. Increased plant height, stem diameter and yield for the cultivar studied were also observed.

Costa et al. (2009) and Heinemann et al. (2016), by means of simulations for the Southeastern region and the state of Goiás, respectively, have shown that there may be a positive interaction between increased concentration of atmospheric CO_2 and increased air temperature, thus increasing bean productivity. However, the same magnitude of response was not verified for the maize crop, because it is a C4 plant with greater energy efficiency. It should be emphasized that the effects may be greater when there is more than one abiotic factor preventing plant development, such as reduced rainfall associated with increased temperature (hydric stress). Cuadra et al. (2015) assessed climate change impacts on irrigated rice in the state of Rio Grande do Sul, the main Brazilian producing state, and suggested that income gains will be mostly associated with CO_2 fertilization effects.

Other indirect factors may also significantly affect agricultural production, such as risks associated with increased occurrences of fires and pest outbreaks (Ghini et al., 2013), which deserve to be better quantified and evaluated.

Final considerations

Quantifying risks related to climate change impacts on agriculture is of utmost importance for developing strategies to improve resilience and adaptation of agriculture. In this context, Embrapa, together with its partner institutions, has been working on the development and application of tools and models for simulating crop growth and productivity. In addition, technologies, products and services are being developed to support knowledge transfer and policy design for agricultural resilience and adaptation. Among these products, the most important are: the Zoneamento Agrícola de Risco Climático (Climatic Risk

Agricultural Zoning – Zarc) – which contributes to reduce risks by recommending more favorable times for sowing agricultural crops; genetic and animal breeding programs – which seek to adapt plants and animals to adverse climatic conditions; and intensive and integrated production systems such as ICLF, functional agroecosystems and aquaponics – which integrate aquaculture with plant production. Climate change poses a very high risk for food security if adequate mitigation and adaptation measures are not taken; it is, therefore, fundamental to continuously develop and improve technologies, products and processes that ensure Brazilian agroecosystem resilience and adaptation.

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Chapter 4

National policies, plans and strategies to fight climate change

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Introduction

The transformation of agriculture is taking place amid a technological paradigm shift and institutional evolution, to which Embrapa contributes by applying scientific knowledge both in technological processes and in encouraging public policies and their instruments. By means of assertive public choices, sustainable development can be effectively encouraged, thus implying a technological transformation of Brazilian agriculture to ensure greenhouse gas (GHG) emission mitigation and to promote efficient adaptation of its practices and systems to climate change. This chapter discusses how Embrapa has been contributing to achieve target 13.2 – Integrating climate change measures into national policies, strategies and planning.

Technological and organizational innovations to address agricultural vulnerabilities to climate are a significant part of agribusiness development, and, therefore, an important part of the work of Embrapa. The Corporation and its partners provide unique contributions for technological innovation and public policy design. Understanding and reducing crop susceptibility to climate factors, identifying how different production systems are exposed to climatic events and enhancing the adaptive capacity of agriculture are systematically addressed in Embrapa research programs. Consistent studies on vulnerability (Deconto, 2008) and support to construct risk management scenarios are provided to society and continuously updated, thus consolidating and transferring knowledge at different levels throughout the Brazilian territory.

Embrapa focuses on research areas and promotes training and technology transfer on different climate change related topics. Embrapa's portfolio of research projects includes seven domains and main themes and over 45 lines of research, development and innovation for which the submission of competitive projects is encouraged. Approximately 150 projects and results are associated with these domains. Three large nationwide network projects focus on vulnerability and adaptation analysis (Program 7 of ABC Plan), namely: Simulação de Cenários Agrícolas Futuros (Simulation of Agricultural Scenarios – Scaf), which analyzes the vulnerability of agricultural crops; Impactos das Mudanças Climáticas Globais sobre Problemas Fitossanitários (Impacts of Global Climate Change on Plant Pathology Problems – Climapest), which analyzes how climate change affect plant pathology problems; and Rede AgroHidro (AgroHidro Network), which analyzes the relationships between agriculture, water resources and climate change.

Development and climate changes

The development of agriculture reveals that ways have been found to innovate and transform production processes. With an active role in this domain, Embrapa provides both technological solutions for farmers and technical knowledge for designing and implementing public policies. Basic information, information systems and support for Embrapa's decision makers have promoted good governance and the balance of public and private interests. Under the pressures of climate change, the focus is on countless global and local negotiations, many of which are advised by Embrapa.

The uncertainty and complexity of agriculture pose challenges that go beyond the inherent capacity of farmers to evaluate their production conditions. As part of its mission to generate knowledge and information, Embrapa interprets climate changes and the sensitivity of productive systems in each part of Brazil, so that technical-scientific challenges are coherent with demands. Competitive agribusiness, technically and economically efficient use of natural and financial resources, social equity and food security and quality must all be equally promoted, although this has been one of the major challenges for Brazilian agriculture (Alves, 2014).

Thus, in the coming years, agriculture will need to adapt to information technology in planning, managing, monitoring and evaluating processes. The digital transformation of agro-industrial chains and the rural reality will raise possibilities of risk transfer and management. By anticipating the need for this technological adaptation, Embrapa and partner institutions will develop technologies and innovations that will naturally address GHG emission mitigation and risk control.

Biophysical processes will be known in depth and controlled like never before in food production. Risks and opportunities will be less uncertain, and decision-making processes will be driven by a priori knowledge of production externalities. An example of a product that integrates information on climate, soil, cultivars and management is the Zoneamento Agrícola de Risco Climático (Climatic Risk Agricultural Zoning – Zarc). Started more than 20 years ago and conducted with Embrapa support, it has been one of the most important tools to encourage sustainable agriculture and food security in Brazil. Supporting risk information available for more than 44 agricultural crops, there is a close connection between empirical knowledge, meteorological monitoring and model validation and approximation, which are compared with data observed in each Brazilian municipality.

In addition, Embrapa has been acting directly to support the main governmental actions of agricultural climate change mitigation and adaptation, for example, through the Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas Visando à Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura (Sectoral Plan for Mitigation and Adaptation to Climate Change Aiming at the Consolidation of a Low Carbon Economy in Agriculture – ABC Plan) (Brasil, 2016a) and the Plano Nacional de Adaptação à Mudança do Clima (National Plan for Adapting to Climate Change – PNA) (Brasil, 2016b). Embrapa has been asked for and provided technical information, experimental data and simulation and optimization studies to support the definition of Brazilian proposals for GHG emission mitigation.

At the international level, the main Brazilian proposals for GHG emission mitigation are Brazil's Nationally Appropriate Mitigation Actions (NAMAs) and Nationally Determined Contributions (NDC). In both cases, Embrapa contributed, for example, with numbers and estimates of degraded pasture areas to be recovered by crop-livestock-forest integration – ICLF (Brasil, 2013) or cultivated pastures; Embrapa also helped calculating the direct costs of adopting technology and the potential for mitigating emissions. Embrapa studies were also essential for designing the ABC Plan, the main policy of the Ministry of Agriculture, Livestock and Supply (Mapa) focusing on environmental issues aligned with natural resources territorial management.

Critical information for designing public policies

Which agricultural systems can be more resilient, mitigate more GHG emissions and should be encouraged in the National Adaptation Plan (PNA)? How different are crops and cultivars performances in adverse climatic conditions? Which technological advances should be made as adaptations to situations of high climatic vulnerability?

New information to help answer these questions is typically expensive to be produced and cheap to be copied and disseminated. Its first version is costly, and recovering investment to produce it takes long or is even impossible. This is why climatic, agronomic and socioeconomic information for agribusiness should be fostered by state policies, such as the Políticas Nacionais de Biocombustíveis (Brazilian National Biofuel Policies – RenovaBio) (Brasil, 2017a) and of ICLF (Brasil, 2013). The crosscutting character of information in public policies also includes private sector decisions, so as to always contribute to implement productive systems suitable for breaking old paradigms due to the need to respond to climate change.

Public policies for adaptation

Public policies promote social and economic well-being by effective actions. In order to address climate change issues, Embrapa should focus on identifying, developing and adapting agricultural practices; developing and characterizing new cultivars (for a wide range of crops); designing and recommending new integrated animal and plant production systems; assessing alternatives for soil fertilization and recycling management; using irrigation and soils in a smart way; controlling pests and diseases; and introducing new technologies, especially in the context of automation and precision agriculture. Embrapa plays an important role in promoting public policies, because it is present in the most diverse Brazilian ecoregions and holds regional knowledge, structure and laboratory logistics to open Technological Reference Units (URTs) focused on technologies tailored for each ecoregional development hub.

Monitoring and assessing public and private programs

Governmental action involves integrating large plans and policies into programs and projects, which support public policy design to help defining NAMAs, ABC Plan and Nationally Determined Contributions (NDCs) of Brazil (Oliveira et al., 2018), as well as Brazil's participation in important studies, such as those of the World Bank (Gouvello et al., 2010).

Embrapa has been effectively contributing to disseminate Brazil's emissions and removals and to conduct a number of quantitative agricultural systems emission studies, thus evidencing, as a rule, lower emissions of our production systems in relation to those estimated by analyses with tier 1 or default models and factors. The work of Embrapa focuses especially on:

- Recovery of degraded pastures.
- Integration of crop-livestock-forest and agroforestry systems.
- Implementation and strengthening of no-till systems.
- Treatment of animal waste.
- Adaptation to climate change and crosscutting actions.

Emphasis should be given to monitoring the ABC Plan. In order to support emission mitigation actions in livestock, forestry and grain systems in the various Brazilian biomes, Embrapa has been encouraging network projects, such as Pecus, Saltus and Fluxus. In order to gain a deeper understanding of the relationship between livestock and climate change, Embrapa designed the international project FP7 Animal Change, co-funded by the European Union.

Embrapa has a significant number of projects for agricultural crops genetic adaptation to climate change. Emphasis should be placed on corporate initiatives such as the Climate Risk Agricultural Zoning and the Special Project on ABC Platform Governance, and projects, such as ICLF, Biological Nitrogen Fixation (BNF), Pastures, Sugar-ethanol sector, Irrigated Agriculture, Coexistence with Drought, Native Forestry Resources, Genetic Resources and Genetic Engineering in Agribusiness, to list only the most relevant portfolios on the subject.

In climate change themes, Embrapa also carries out projects to develop techniques for remote sensing and mapping of crops and degraded areas in Brazil. Its training and technology transfer initiatives are performed through field days, lectures, seminars, workshops, technical visits of farmers in pasture recovery areas, farms, events in 79 Technological Reference Units (URTs) and/or in Test and Exhibition Units (UTDs), in research centers, etc., among other strategies, such as its own YouTube channel.

Agricultural vulnerability and resilience analyses should guide the identification of areas and alternatives for production adaptation. Risk management is one of Embrapa's most important areas of strategic action, and which should be strengthened in the coming years. So is encouraging the added value of integrated production validated by emission reduction certification standards. Embrapa projects improve the Life Cycle Analysis (LCA) of livestock products, thus strengthening effective communication in domestic and foreign markets. Embrapa develops tools that improve the technical and economic efficiency analysis of production systems, that support their management and that encourage the achievement of goals amplified by the NDC, since the Paris Agreement ratification.

Negotiations and institutional ability to adapt

Embrapa has actively contributed to international negotiations, which resulted in plans and programs such as ABC Plan, Carne Carbono Neutro (Neutral Carbon Meat) (Suleiman, 2016) and the PNA. Specifically within the latter, two national strategies for adapting Brazilian agriculture to climate change were supported by Embrapa. Assuming that actions within PNA connect emission mitigation policies and strategies, two strategic targets must be included in the agenda of Embrapa: a) the development of an Agricultural Risk and Vulnerability Monitoring and Simulation System; b) Center for Agricultural Climate Intelligence for Climate Risk Management in Brazilian Agricultural Policy.

These targets improve the adaptation of agro-industrial systems, thus enhancing the industry's capacity and competitiveness in terms of biotechnology, new inputs, recycling and crop technologies, and integration of processes with higher value-adding potential, by means of certification, management and risk transfer.

Putting in operation sector policies and strategies for adaptation to climate change requires modernization, enhanced competitiveness, integrated risk management and value delivery. Food safety and nutritional quality of food are ensured by large-scale, quality production that suits sustainable development in its different dimensions. Such efforts must occur simultaneously at local, regional and national levels. This understanding must be systemic and should encourage Science & Technology networks that facilitate information integration and sharing. In tune with policy management, it is necessary to foster the ongoing digital transformation in agriculture by introducing new means for data and metadata acquisition, processing, sharing and security between private and public institutions, as well as between users and companies.

Some of the main technical lines of interest are:

- Developing big data storage, retrieval, analysis and synthesis systems (Crawford, 2011).
- Organizing and cataloging data and their respective metadata.
- Agroecosystems modeling, simulation and optimization.
- Monitoring by remote and orbital sensors.
- Integrating environmental, socioeconomic, legal and technological information, among others.
- Developing applications in "Internet of Things" (Santos et al., 2016) (interconnecting autonomous devices/sensors and people), "Artificial Intelligence" (Byrum, 2017) (complex problem solving) and Blockchain (Ge et al., 2017) (safer legal and commercial transactions).

The main products should be:

1) Monitoring, Risk Assessment and Agricultural Vulnerability System: it aims at designing indicators, information integration, result simulation and scenario analysis. It is expected to be an information bank that integrates and sums up different scale big data, including local, regional and national programs and actions. Information will be available and will be especially relevant for result dissemination and observation, such as the case of interactive platform MapBiomas.
2) Computational algorithms: they aim at providing technical and economic assessment of agroecosystems in different contexts and regions. These solutions, implemented through simulation, optimization, data assimilation and artificial intelligence, will allow analyzing mitigation and adaptation strategies and supporting public policy design.
3) Result communication and visualization system (Data visualization, 2018): it aims to make available to different public and private sector actors useful information to support decision-making regarding climate change, in particular as regards to indicating agricultural production models and assessing the impact of adopting these models to redesign public policies. Information generated should support public policies in international negotiations, induce demand for relevant scientific data production and, finally, assist in discussing commercial litigations or technical non-tariff barriers.

4) Storage, curation, data processing and information retrieval infrastructure: it aims to establish rules for security, access control and information use. This infrastructure should use modern means of communication and information exchange that allow the integration with other research networks and databases, so as to guarantee broad access to information in a secure way, through collaboration at the individual and institutional levels.

Final considerations

Various changes have been affecting agriculture, whether in terms of technology, consumer perception and demand, or changes caused by climate change. In this context, scientific knowledge is essential for decision-making in public and private sectors, for designing encouraging policies to promote the establishment of new practices and technologies to guarantee sustainable agriculture.

Embrapa has been effectively dealing with climate change-related issues and has been contributing significantly to technological innovation and knowledge production. Through its research projects, Embrapa provides society with consistent studies on agricultural vulnerabilities and produces knowledge to expand its adaptive capacity. Thus, Embrapa fulfills its role of consolidating and transferring knowledge to farmers living in practically all the municipalities of Brazilian states.

Knowledge provided by Embrapa affects the farmers decision-making and has been leading to countless innovations in information technology, computer simulation, Big Data, "Internet of Things", artificial intelligence, among others areas. Brazilian agricultural policy relies on Embrapa to maintain its plans, programs and projects connected with the productive reality and to keep encouraging sustainability and food security. Embrapa's interaction with governmental technical staff is essential for successfully designing and managing ABC Plan and of National Plan for Adapting to Climate Change (PNA). International negotiations and Brazilian proposals for greenhouse gas emission mitigation – NAMAs (Compromisso..., 2014) and NDC (Brasil, 2017b) – are directly supported by Embrapa studies that quantify, model and analyze emission factors.

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Chapter 5

The role of agriculture in mitigating greenhouse gas emissions

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Introduction

Agriculture will not only be affected by climate change, but it will also play a central role in reducing greenhouse gas (GHG) emissions and, consequently, mitigating climate change impacts. Mitigating actions relevant for agriculture are also important actions to adapt to climate change, because increasing carbon sequestration fundamentally depends on reducing agroecosystem nutrient losses and increasing biomass and soil carbon stocks (Oliveira et al., 2014), which contribute to maintain high production standards and better use of natural resources, especially soil and water. Mitigating emissions lead to more favorable GHG balance in agroecosystems, which may occasionally turn into carbon neutral systems or even as GHG sinks. In any of these cases, reducing GHG emissions and increasing (mainly organic) carbon sequestration are one of the main objectives of transitioning to low carbon emission agriculture.

Agriculture and livestock

Embrapa has been carrying out several network projects in order to develop GHG emission mitigation practices and technologies for livestock, forestry and grain systems in varied Brazilian biomes, respectively Pecus, Saltus and Fluxus are the most outstanding. Embrapa has been identifying relevant strategies for GHG emission mitigation in agriculture. In crop systems, for example, biomass not harvested for food should be kept on the soil surface instead of being incorporated into the soil. This process was called No Tillage System (NTS), which should be combined with crop rotation (including leguminous species), cover plants, green manuring, and soil conservation and management practices. NTS increases productivity, soil organic carbon sequestration (Madari et al., 2005; Corbeels et al., 2016) and is beneficial to the health of cultivated soils (Salton et al., 1998). In addition to helping GHG emission mitigation, NTS improves soil biophysical conditions, prevents salinization processes, and reduces temperature and evaporation ranges, thus enhancing agroecosystems resilience (Giongo et al., 2014). Increasing nitrogen in the soil by Biological Nitrogen Fixation (BNF) is crucial because the carbon cycle is closely linked with that of nitrogen and other nutrients (Sisti et al., 2004).

In aerobic crop systems, the most important greenhouse gas is nitrous oxide (N_2O) mainly due to inorganic nitrogen fertilizers applied (Brasil, 2014). Technologies to promote the efficient use of these fertilizers, such as nanotechnology for slow release fertilizers (Kottegoda et al., 2017), or those to partially or totally avoid their use by stimulating BNF, can significantly reduce N_2O emissions. In anoxic agroecosystems of irrigated rice, methane (CH_4) emission can be reduced by intermittent management of flooding irrigation or by selecting rice cultivars for this purpose (Scivittaro et al., 2014, 2015). Using biochar can contribute both to carbon sequestration and to mitigating N_2O and CH_4 emissions in aerobic and anoxic agroecosystems (Karhu et al., 2011; Han et al., 2016; Sun et al., 2017).

One of the most suitable technologies for mitigating livestock emissions is pasture recovery and intensification (FAO, 2009; O´Mara, 2012; Oliveira, 2015), because of its great potential for soil carbon sequestration, given the vast areas used for this purpose in Brazil. Another important technology is reducing enteric CH_4 emission. The most indicated and impacting technologies to achieve this objective are improved zootechnical indexes and production efficiency (reduced age at slaughter, interval between calvings, animal performance). Related Embrapa projects are Novilho Precoce (Early Steers) and Inseminação Artificial em Tempo Fixo (Fixed Time Artificial Insemination – IATF) (Melo Filho; Queiroz, 2011). Additionally, balanced and better quality diets (well-managed pastures and forages, use of mineral, protein and energy supplementation) and ruminal fermentation modulating additives, may also contribute for mitigating enteric CH_4 emission (Oliveira et al., 2015; Moura et al., 2017). Biophysical modeling is a useful tool to help in agricultural GHG emission mitigation. Projects carried out by Embrapa have revealed that simulation models and GHG emission scenarios currently available fail to present satisfactory results due to lacking parameterization for Brazilian conditions. This is why new models are being constructed based on Embrapa's Pecus Network database, which gathers data sets collected in Brazilian biomes.

Combining crops with livestock and the forestry sector has been encouraged to even more effectively mitigate GHG emissions by agriculture. Low-carbon emission agricultural production should be based on integrated livestock-forestry (ILF), crop-forestry (ICF) and crop-livestock-forestry (ICLF) systems and should combine recycling processes with minimal soil turnover and native vegetation conservation (Sacramento et al., 2013). Integrated production models allow higher tree carbon sequestration rates, which, in turn, provide greater thermal comfort to animals (Lemes et al., 2015; Botta et al., 2017), thus contributing to improved productive and reproductive zootechnical indexes. Studies on ICLF systems and sustainable management of swine (biodigesters, renewable energy generation and fertigation) in the state of Mato Grosso do Sul showed promising results, both in terms of socio-environmental aspects and GHG emissions mitigation (Buller et al., 2015). Adopting intensive ILF systems that combine forestry and no-tillage systems (Figueiredo et al., 2017; Oliveira et al., 2018) can potentially enhance organic carbon sequestration and GHG emission mitigation. Embrapa has encouraged important initiatives for livestock, such as carbon neutral meat and milk production, in which GHG emissions are neutralized by carbon sequestration during the production process. Mitigation is essentially due to the presence of trees in integrated systems and to certification.

Integrated management of agroecosystems, by incorporating and combining certified technologies from various areas of knowledge (integrated pest management, rational use of inputs and water, etc.), can further reduce water and carbon footprints of productive systems (Carmo et al., 2016). The main challenge has been the economic arrangement to provide bonuses for products with reduced or neutralized GHG emission, or by organic carbon sequestered in soil, for example in the form of carbon credit, an important mechanism for guaranteeing long-term sustainable agriculture.

Energy crops

Energy crops are economically and environmentally viable alternatives in addition to fossil sources. Biomass production potential depends on the crop, and the type of biofuel produced varies, from sugarcane or maize ethanol, soy biodiesel, to electrical energy from waste bio digestion (Bergier et al., 2012). Avoided burning of fossil fuels is already good reason to use these crops in the world energy mix. However, adopting production systems that are more efficient in terms of productivity and are more adjusted, such as no-tillage, inoculants to optimize BNF, waste management and effluent recycling, also helps mitigating GHG emissions. As between 60% and 85% of emissions related to biofuel production originates in or are related with the agricultural phase of its making, any changes in the practices involved in this phase are significant to improve the final carbon balance. Therefore, automation and process integration in agroecosystems will be crucial for effective refinements in correctives and fertilizers use, dosage and sources in order to significantly mitigate emissions and maximize productivity. In sugarcane fertilization, for example, substituting urea for ammonium nitrate reduces N_2O emissions, depending on soil characteristics, time of application and region. Using BNF with energy crops can further contribute to mitigating GHG emissions, because it can make N_2O emissions equivalent to those from soils with no fertilizer. For soybeans, the use of inoculant instead of mineral nitrogen fertilizer is already routine and contributes significantly to mitigating GHG emissions. In terms of soil management, the use of no-tillage during sugarcane fallow period can reduce CO_2 emissions between 11% to 20%, compared to conventional tillage.

Forestry sector

The forestry sector also has great potential to reduce GHG emissions. Planting trees, especially those for the furniture sector, and native vegetation areas in Legal Reserves, Permanent Protection Areas, and Private Reserves of Natural Heritage contribute to maintain carbon, water and biodiversity in agroecosystems. The United Nations launched, in 2008, a deforestation and forest degradation emissions mitigation program called REDD. Another important contribution of this sector is to use forest-based products to keep carbon stocked for a long period of time or to replace the use of fossil fuels. In addition, flood-free forest soils are CH_4 sinks. There are observations in Southern Brazil that the oxidation of CH_4 in soils under *Pinus taeda* plantations, even though it is of smaller size when compared to adjacent native forests (intermediate stage of succession), is significant (Higa et al., 2017).

Ecological systems

Encouraging the adoption of diversified and (certified) organic production systems meets a clear societal demand for healthy food that mitigates global warming impacts. Sustainable functional agroecosystem models will use increasingly complex relations between and within their multiple components. Using agroforestry systems as land use options relying on plant – soil interactions in different magnitudes presents great potential for mitigation and is also an important measure of adaptation to climatic risks, assigning greater resilience, food, energy and water security. Using native species is an important tool to recover degraded areas and conserve endangered species, thus adding even more value to local products. This may raise issues of public policies related to payment for environmental services and particularly climate regulation services (Anderson-Teixeira et al., 2012), that may be one among other measures for mitigating and adapting to climate changes.

Fish farming

Generally, water dams are sources of CH_4 (Deemer et al., 2016) and also store carbon in its sediments (Mendonça et al., 2017). Adding food in net pens directly impacts on the carbon balance of these confined aquatic environments, given that primary productivity, linked to use and occupancy, affects emissions (Bergier et al., 2014; Deemer et al., 2016). Further studies are needed to determine whether large-scale net-pen farming may result in anoxia and increased CH_4 emissions, aquatic cyanobacteria or macrophytes bloom and the consequent risks to aquatic life. Preliminary studies by Embrapa Environment provided first insights into the influence of aquaculture on GHG emissions. In the reservoir of Furnas in the state of Minas Gerais, three areas with production of Nile tilapia (*Oreochromis niloticus*) in net pens were monitored. Emissions of CH_4 were significantly higher when compared to an area without aquaculture production. Samplings were also carried out in net-pen fish farming areas Padre Cícero Reservoir, known as Castanhão, in the state of Ceará, and at the Chavantes reservoir, along the Paranapanema River in the states of São Paulo and Paraná. In both cases, significant CH_4 emission was observed in the area of net pens. On the other hand, no difference was noted in terms of CO_2 emission between farmed and non-farmed areas in the same reservoir. Preliminary results suggest that organic matter from fish farming promotes methanogenesis and consequent CH_4 emission to the atmosphere, while CO_2 emission/removal is more associated with the reservoir degree of eutrophication.

Therefore, it is fundamental to better describe aquaculture systems, to monitor water quality and better assess CH_4 emissions in net pens. Furthermore, and similarly to what has been done in more sustainable agroecosystems, it is necessary, depending on the scale, to integrate aquaculture with hydroponics (aquaponics) and/or with photovoltaic electric energy generation. In Asia, there are very interesting initiatives integrating photovoltaic and aquaculture industries, which can be repeated in Brazil as an adaptation to and mitigation of climate change strategy in both the energy and aquaculture sectors. Placing solar panels on the surface of reservoirs generates renewable energy, increases the albedo and reduces sensible and latent heat, thus minimizing water loss due to evaporation.

Final considerations

Embrapa, with its partners, has been working on the development of solutions to reduce greenhouse gas (GHG) emissions in agriculture and, consequently, to mitigate climate change impacts. Some technologies, such as recovery of degraded pasture, crop-livestock-forestry integration, no-tillage system, biological nitrogen fixation, planted forests and agroforestry systems, as well as animal waste management, are already part of national public policies, such as the ABC Plan, which are aligned with international policies and initiatives for mitigation and adaptation to climate change. However, studies to describe the impact of agricultural systems are still needed to identify problems and to fill gaps in our knowledge of this aspect of productive systems. There is also room for developing or improving technologies already recognized as mitigators. There are some areas, such as fish farming, in which technologies for GHG emissions reduction must be developed or adapted. Among the future challenges, we can still mention that incentives for the productive sector to adopt large-scale GHG emission mitigating technologies are still lacking. It is also a significant challenge to develop mechanisms to encourage long-term (for 20 years or more) adoption of such technologies; this is the time frame needed to achieve Brazil's reduced GHG emission targets as suggested in international agreements. In addition, monitoring the adoption of mitigating technologies is in itself a complex challenge. The long-term adoption of mitigating technologies would also be favorable in order to avoid a possible increase in GHG emissions, thus enhancing climate change. However, challenges of adopting and maintaining technologies in use require solutions that go beyond scientific research and technological development, because they involve especially political and economic issues that encourage varied processes of GHG emission mitigation and fight against climate change.

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Chapter 6

Challenges and solutions to fight climate change

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Introduction

Climate change is a major threat, thus reinforcing the importance of the Sustainable Development Goals (SDG). If SDGs are not achieved, health risks, water supply, food production, nutrition, biodiversity and energy security of human societies around the world would be worse, especially for societies living in densely populated urban zones and vulnerable areas. Embrapa has been revealing how significant challenges posed by climate change are (they have been reducing agricultural productivity in recent decades in several regions) and proposing strategies to promote sustainable development by investing in the development of new technologies and strategic planning to mitigate greenhouse gas (GHG) emissions and ensure the adaptation of Brazil's agroecosystems. Achieving a universal understanding of the risks posed by climate change and social awareness on the topic will be of paramount importance. In this context, Embrapa, with its national reach and ability to produce and adapt technologies to varied realities, will be fundamental for the sustainability of Brazilian agriculture.

Embrapa

Embrapa is a national reference when it comes to measuring GHG emissions and conducting mitigation studies because it holds a framework of experimental data, organized knowledge and analytic tools for strategic planning and construction of scenarios to quantify the effects of adopting technologies. Embrapa has been active in disseminating agricultural GHG emissions domestically and in leading several quantitative studies of agricultural system emissions, evidencing, as a rule, lower emissions of Brazilian agroecosystems than those estimated by analyses based on models and default factors produced abroad. Embrapa also stands out in supporting public policy design having supported the definition of Nationally Appropriate Mitigation Actions (NAMAs), ABC Plan and Nationally Determined Contributions (NDC) of Brazil, and in joining important studies coordinated by the World Bank. By expanding and adopting technological solutions recommended in these policies, agroecosystems may have increased adaptive capacity to climate change impacts and reduced GHG emissions. Monitoring the long-term effectiveness of these actions is also critical, as changes in carbon stocks are measurable over the decades. The increase in carbon stocks is one of the main bases of agricultural contribution to Brazilian NDCs. In order to support such initiatives, the Plataforma Multi-institucional de Monitoramento das Reduções de Emissões de Gases de Efeito Estufa (Multi-Institutional Platform for Monitoring Greenhouse Gas Emission Reductions) was created in 2016 at Embrapa Environment in Jaguariúna, state of São Paulo, in order to monitor Brazilian agriculture greenhouse gas emission reductions and soil carbon stock changes.

Promoting resilience and adaptation to climate risks requires planning and developing human resources, as well as technological tools to produce knowledge and estimates about the risks to different agroecosystems in different Brazilian regions. This task is extremely complex given the continental dimension of Brazil and the diversity of crops and productive systems. Although national and international research initiatives are under way, Brazilian capacity for determining potential climate change impacts is still limited to a small number of agricultural crops. Expanding crops included in the Zoneamento Agrícola de Risco Climático (Climatic Risk Agricultural Zoning – Zarc) and developing and parameterizing new biophysical models will be key in this process. However, the lack of experimental data for model parameterization for several agricultural crops is still an important bottleneck for reducing the uncertainties of such models. In order to advance in this area, the following are needed: increasing investments in basic research, in organizing long-term experimentation networks at Technological Reference Units (URTs) – with public and private partners – for monitoring environmental conditions (agro/micrometeorological experiments); expanding the capacity of phenotyping platforms; and expanding experiments on Free Air CO_2 Enrichment (FACE), also considering the effects of warming concomitantly to atmospheric enrichment of CO_2 (Free-Air Warming and CO_2 Enrichment) and including additional crops and different production environments. These actions may help better understand

and model growth/productivity interactions, abiotic factors and management practices in agroecosystems.

Advances and challenges

Once climate risks to agricultural production systems are identified and quantified, technologies, products and services will be adapted to minimize exposure to these risks and, at the same time, enhance the resilience of agroecosystems in a climate change context. Along with integrated and intensive management practices, plant and animal breeding programs will be fundamental to develop genotypes adapted to future climatic conditions. In plant production, research groups have been focusing on efforts to advance knowledge and create agricultural practices and processes to develop cultivars that are water deficit tolerant, photosynthetically and nutritionally efficient, and resistant to aluminum toxicity in acid soils. For this, continuous funding of basic research, pre-breeding and final stage development of cultivars is fundamental.

Animal genetic breeding, particularly of zebu and its crossbred groups, is expected to generate animals more tolerant to thermal stress and more resistant to parasites associated with high temperatures, at the same time as improving meat quality and animal productivity. Gains related to soil and rumen microbiology, particularly with respect to non-symbiotic biological nitrogen fixation, thus reducing synthetic sources input, and reduced enteric methane emissions are important knowledge frontiers in which Embrapa must invest and whose potential future contribution is promising. Today, Brazil sets the standard for zebu genetics, known for rusticity, heat and parasite tolerance, thus opening the way for sustainable production in the tropics.

Improvements in adopting integrated and intensive systems of production (integrated crop-livestock-forestry system – ICLF) should significantly contribute to mitigating GHG emissions and adapting Brazilian agriculture to climate change. Continuing research and studies in long-term URTs will be necessary to support public policies to encourage the adoption of integrated and intensive systems. Embrapa has been creating and keeping multidisciplinary URTs with interinstitutional experiments, in collaboration with several universities and the private sector, in order to contribute to a better understanding of integrated and intensified agroecosystems. Diversified production and better use of local skills will contribute to regional adaptations of the agricultural sector to climate change. Adopting agroforestry systems and maintaining native species in agroecosystems are important for recovering degraded areas and conserving biodiversity and environmental services, which may open up debates on public policies related to payment for environmental services, and particularly climate regulation services.

One of the great advantages of aquaculture production systems (mariculture, fish farming, etc.), both in freshwater and brackish or salty environments, is the fact that it is more energy efficient than meat production sectors. In Brazil, there are large areas available and not occupied by this activity. However, there are few studies on GHG emission balance for these systems. Integrating aquaculture and vegetable production (aquaponics) is a great opportunity for sustainable food production to adapt to climate change with low impact on Brazil's GHG emissions.

Final considerations

The sustainable transformation of Brazilian agriculture increasingly involves actions to adapt to climate change impacts and to mitigate GHG emissions or increase GHG sequestration. Because of the scope of the problem in space and time, advancing knowledge by Embrapa over the last decades and the interaction with society and other education and research institutions are crucial to support public policy design aiming at developing viable alternatives for Brazilian production. These policies will be instrumental in enhancing the adaptability of society and the economy to climate risks by creating conditions and opportunities for businesses linked to climatic resilience.

Embrapa will play a major role in supporting the evolution and design of new sectoral policies, which should, in the near future, evolve into programs and projects supported by systemic, scientifically grounded and integrated analyses that allow the continuous and transparent quantitative monitoring of results. Research results should lead to innovations and technologies for Brazilian agribusiness that allow efficient management of natural resources so as to improve socioeconomic conditions and promote greater social equity. Brazilian agribusiness should be coherent and integrated with SDGs and the objectives of multiple public policies, in which climate change issues will evolve in tune with the efficient use of public and private resources for sustainable development of varied local realities of Brazil.

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MINISTRY OF
AGRICULTURE, LIVESTOCK
AND FOOD SUPPLY

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ISBN 978-65-86056-40-2

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CGPE 016276