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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