Revista Brasileira de Ciência do Solo

Division - Soil, Environment and Society | Commission – Soils and Food Security

Climate change adaptation and the agricultural sector in South American countries: Risk, vulnerabilities and opportunities

Miguel Ángel Taboada[1,2], **Alejandro Oscar Costantini**[1,3]*, **Mercedes Busto**[3], **Michelle Bonatti**[4,5] **and Stefan Sieber**[4,5]

[1] Instituto Nacional de Tecnología Agropecuaria, Instituto de Suelos Hurlingham, Buenos Aires, Argentina.
[2] Consejo Nacional de Investigaciones Científicas y Tecnológicas, Buenos Aires, Argentina.
[3] Universidad de Buenos Aires, Facultad de Agronomía, Buenos Aires, Argentina.
[4] Leibniz Centre for Agricultural Landscape Research, Müncheberg, Germany.
[5] Leibniz Centre for Agricultural Landscape Research, Müncheberg, Germany.

ABSTRACT: South America covers a vast area with diverse climates and landscapes, with high participation in the global production of food and fibers. It is crucial to understand the risks, vulnerabilities, and opportunities that climate change brings to this region. We analyzed the increasing tension between agribusiness models and smallholder models, the risks, opportunities, and main adaptation measures that can be adopted in the agricultural sector of the South American countries facing climate change. This study is a review of adaptation actions in the agricultural sector for the different regions of South America. Vulnerability exists, firstly, because rural populations are exposed in many of the countries, often with high rates of poverty and low rates of socioeconomic development. Concerning the adaptation measures already taken, there are numerous cases of interventions by national, provincial, and municipal states for planned measures. Farmers are very active in adopting autonomous measures. Many adaptation measures show co-benefits with climate change mitigation or the prevention of land degradation and desertification, but other adaptation measures do not go in this direction. In the forthcoming times, the region's rich natural resources are going to be subjected to strong market pressures and climate change threats. It is key to generate strategies for the care of these resources for their permanence for future generations.

Keywords: food production systems, risk areas, poverty rates, autonomous measures, government measures.

*** Corresponding author:**
E-mail: costantini.alejandro@inta.gob.ar

Received: June 23, 2021

Approved: August 10, 2021

How to cite: Taboada MA, Costantini AO, Busto M, Bonatti M, Sieber S. Climate change adaptation and the agricultural sector in South American countries: Risk, vulnerabilities and opportunities. Rev Bras Cienc Solo. 2021;45:e0210072.
https://doi.org/10.36783/18069657rbcs20210072

Editors: José Miguel Reichert and João Tavares Filho.

INTRODUCTION

South American countries present remarkable heterogeneity regarding the climate threats facing the agricultural sector. This heterogeneity can be classified into three axes or sectors: a) the risks of exposure to damage or deterioration due to climate change; b) vulnerabilities that affect populations and ecosystems; and c) the opportunities that climate change can provide (Figure 1). Latin America also presents important differences in its social development indicators and the rural sector, with nearly 130 million people inhabiting rural areas, outside urban centers (FAOSTAT, 2019). Although the largest rural populations are found in Brazil, eight other countries exhibit strong rurality, defined as more than 30 % of the population living in rural areas, while less than 10 % of the population in both Uruguay and Argentina are rural.

Due to South America's importance as a global food producer, it is crucial to understand the risks, vulnerabilities, and opportunities that climate change is bringing to this region, therefore, it is the main objective of this study. Based on a literature review, this research also aims to contribute to the definition and exemplification of potential climate adaptation strategies. As shown in the following, this research presents an update of adaptation actions in the agricultural sector since the last general studies were carried out by Magrin et al. (2014) within the framework of the 5th IPCC Climate Change Report (IPCC WGIIAR5, Chapter 27).

MATERIALS AND METHODS

The bibliographic search was carried out through the Scopus databases, (http://www.scopus.com), Science Direct (http://www.sciencedirect.com), Scimago (http://www.

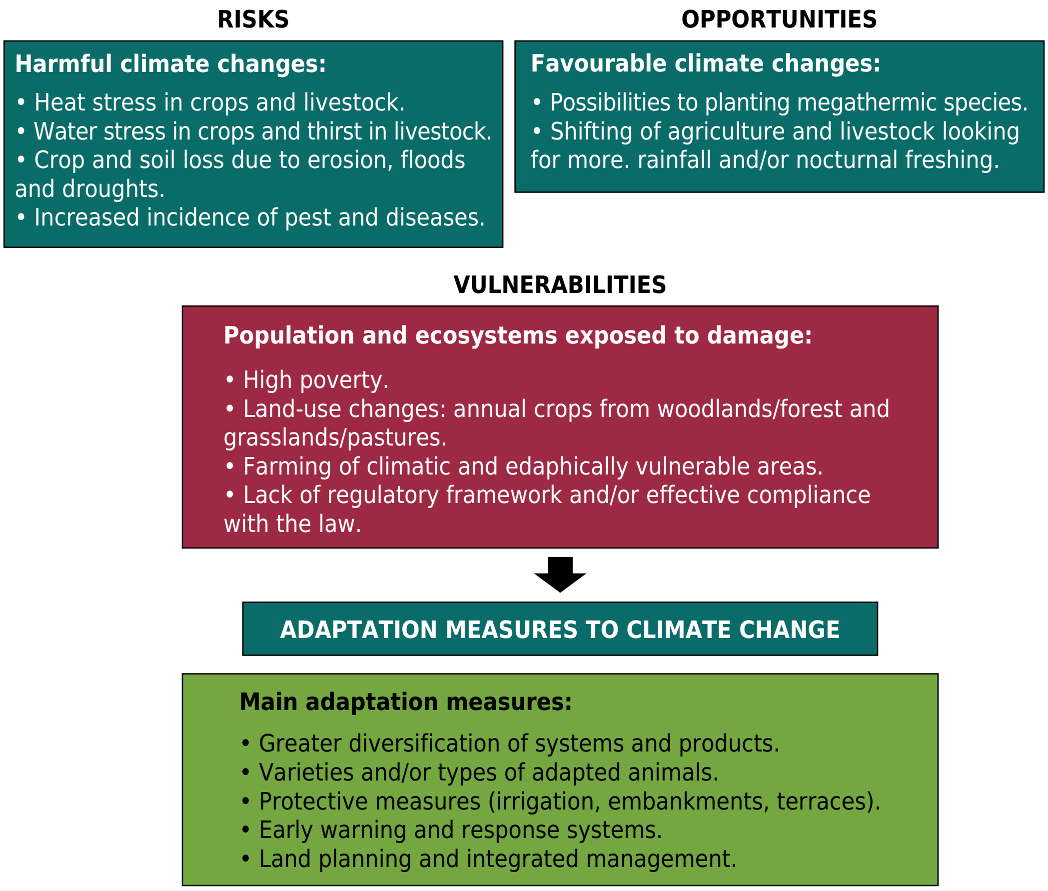

Figure 1. Conceptual framework that describes the risks, opportunities, vulnerabilities, and main adaptation measures that can be adopted in the agricultural sector in the context of climate change for South American countries. Adapted from Taboada et al. (2020).

scimagojr.com). In addition, searches were carried out using the Google Scholar search engine (https://scholar.google.com). Bibliography that was not found in the databases above was consulted in the libraries of the Faculty of Agronomy of the University of Buenos Aires and the Natural Resources Research Center (CIRN) of INTA. Firstly, a general framework of the problem was given, and then bibliographic material available for the problems of various countries in the area addressed by this study was searched.

DISCUSSION

Relationship of the sector or system with climate and with climate change. Types of agriculture and conflicts in the region

South America is experiencing increasing tension between agribusiness models and smallholder models. Agribusiness-production models are exportation oriented and with fixed products (e.g., coffee, soybeans, cocoa, beef, etc.), and whose commercialization responds to market forces. Smallholder models defend another type of rurality: sometimes subsistence, sometimes with greater product diversification; based more on family production units, agroecology, and peasant movements; in which women play an important role in farm management (Kay, 2006; Segrelles Serrano, 2007; Schejtman, 2008; Grau and Aide, 2008; Altieri and Nicholls, 2017). These tensions underly increasingly strong social and political controversies regarding development models, ethnicity, social exclusion, urban-rural conflicts, rural work, etc. In particular, peasant-type agriculture defends values like land tenure security and food sovereignty based on knowledge of local and traditional origins (Mastrangelo et al., 2014).

It should not be thought that agribusiness production models are less susceptible to climate change injuries: they cover a wide range of climates and cause changes in the climate, per se. Smallholder farmers are usually more vulnerable because they have fewer tools to cope with the negative impacts of climate change. However, it is still not clear whether climate change will affect this different kind of productive system.

Components of risk concerning the sector or system

Threats

As stated in the regional chapters of the 5th IPCC Climate Change Report, increases in temperature, especially daily minimums and the lack of nocturnal cooling, will be generalized across most countries in the region. Changes in agricultural productivity associated with climate change are expected to exhibit great spatial variability. A large part of the plains in the region will see their productivity increase toward the middle of the century due to greater rains. In contrast, decreased rainfall can negatively affect crop production in most northeast Brazil and the Pacific coast (Magrin et al., 2014; Magrin, 2015).

Thus, food production faces a variety of risks: as described in figure 2, the main threats arise from the occurrence of thermal and water stress for crops and domestic livestock, while erosive processes, drought, floods, as well as the increased spread of pests and diseases will lead to crop and farm losses. However, some regions face opportunities provided by increased rains, changes in seasonality, and the possibility of cultivating megathermic or tropical species.

Exposure

The level of exposure to threats is highly variable, mainly depending on the socioeconomic level of the affected population (Cardona, 2004; Lavell et al., 2012; Bonatti et al., 2016), the relative rigidity or flexibility with which their production systems may vary or adopt technology, and the possibility of assistance or availability of technology including, for

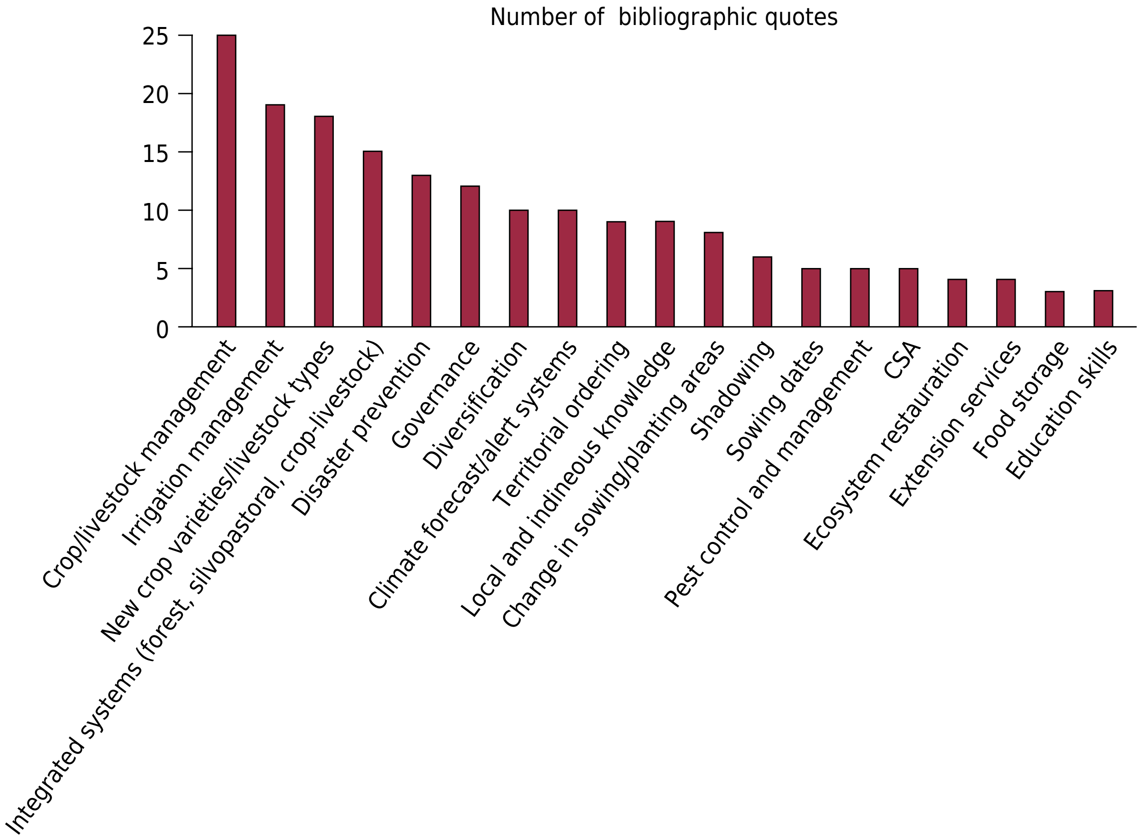

Figure 2. Frequency of the different types of measures observed among the actions reviewed for the period 2013-2018. Adapted from Taboada et al. (2020).

example, climate forecasts, early response systems, or access to new varieties resistant to pests or stresses. In less developed countries, the strength of technical assistance and extension systems is also crucial.

Vulnerability

Vulnerability is the inability to resist a threatening phenomenon or the inability to recover after a disaster has occurred (Cardona, 2004). Vulnerability is also defined as the degree to which a system is susceptible and unable to cope with the adverse effects of climate change, including climate variability and extremes (IPCC, 2014). Taking into account the above, in South American countries, the vulnerabilities of agricultural production is determined by where the production is based and the ability to move it to other places (e.g., searching cooler temperatures at higher altitudes); access to technological resources that allow anticipating responses or responding to extreme events, such as access to irrigation or climate forecast systems; and, finally, the economic capacity to make investments. Poor rural populations are more susceptible to the impacts of climate change either because they are in risky places (e.g., mountain slopes, waterlogged environments, etc.) or because they have less capacity to respond to extreme weather events (i.e., heavy storms, droughts, fires, floods, hurricanes, etc.).

Adaptation strategies

Adaptation options

There is high heterogeneity in the public policies across South American countries, concentrated in sectors like water, biodiversity, forests, agriculture, infrastructure, and human settlements (Sánchez and Reyes, 2015). Following the criteria established by the IPCC WGIIAR5, Chapter 14 (Noble et al., 2014), actions for adaptation to climate change based on agriculture are presented in table 1. As it is sometimes difficult to separate those actions based specifically on agriculture from those based on ecosystem management, in this case, reference is only made to the actions of managed ecosystems. Adaptation actions can be classified into three categories: a) structural physical; b) social; and c) institutional.

Physical structures

Three options are identified: a) those that require the use of engineering and changes in the physical environment, such as the construction of irrigation systems, pumping water, or the construction of water tanks for animal watering or irrigation; b) ecosystem management, which refers to the increase or conservation of biological corridors, migration of endangered species, afforestation, management of protected lands, among others. In general, most of these options are oriented or planned; and c) technological options are usually autonomous; although they may also be planned, they correspond to the adaptive response generated by the farmers themselves. These include the adoption of new varieties and types of crops and animals, incorporation of genetic improvements, the displacement of growing areas, changes in planting dates, adoption of adapted germplasms, better use of local knowledge, new farming systems to improve water conservation, nitrogen capture from the atmosphere, waste recycling, integrated productions (silvo-pastoral systems, integrated crop-livestock), agroecological systems, improvement of the efficiency of water use, reuse of drainage and fertigation water, as well as management of grazing and stocking rates, among others.

Institutional

Here three types of planned options are presented: a) the merely economic, such as payment for ecosystem services, or the non-payment or discount of fees and taxes;

Table 1. Categories and options of actions for adaptation to climate change based on agriculture. Adapted from Noble et al. (2014)

Class (or category)		Examples of options
Structural / physical	Engineering and construction of the environment	Water storage and pumping; improving drainage
	Ecosystem based	Increased biodiversity; afforestation and reforestation; reduction of fires and prescribed burns; shading trees; assisted migration; biological corridors; seed bank conservation; adaptive land management
	Technological	New varieties and types of crops and animals; genetic techniques; traditional methods and techniques; efficient irrigation; water-saving technologies, including water harvesting; mapping and risk monitoring technologies
Social	Information	Risk and vulnerability maps; early warning and response systems; systematic monitoring and remote monitoring via sensors
	Behavior	Soil and water conservation; change in livestock practices; change of crops, systems and planting dates; forestry options
Institutional	Economics	Payment for ecosystem services; incentives and tax breaks
	Laws and regulations	Land zoning laws; water agreements and regulations; definition of property rights and land tenure security; protected areas
	Government policies and practices	Preparation and planning of disaster areas, including integrated water resource management and basin and landscape management; adaptive management; ecosystem-based management; sustainable forest management; community-based adaptation

b) laws and regulations at the regional, national or municipal level, in matters such as land use, property rights, and tenure; and c) government practices and policies that regulate or protect the use of soil, water, and vegetation resources.

Planned action differs in its execution times. For example, most of the structural or physical measures require the execution of long-term works, while other measures are of a "flexible" type, typically those of a technological nature, requiring planning over a shorter time, such as establishing plantations of forest species with a shorter cut time (Galindo et al., 2013).

From a policy implementation perspective, a key action is education, providing all farmers with information that helps them adapt to climate change using appropriate agricultural practices and technologies. In Chile, a study by Roco et al. (2015) shows the importance of education and access to meteorological information for the perception of climate change: younger producers, those with more academic training, and those who own their lands tend to have a clearer perception of climate change than older, poorly educated farmers, or tenants.

In Uruguay, one of the goals for 2030 in the "National Environmental Plan, is the "Agricultural production based on the elements of Agroecology", which is led by the Ministry of Housing, Territorial Planning, and Environment. This includes lines of action and specific indicators for this goal (Ministry of Housing, Territorial Planning, and Environment, 2018).

Adaptation actions in the agricultural sector

Since the general studies carried out by Magrin et al. (2014), within the framework of the 5th IPCC Climate Change Report (IPCC WGIIAR5, Chapter 27), an update of adaptation actions in the agricultural sector was carried out by this study, presented in table 2. It lists and classifies the studies reviewed in the literature from 2013 to 2020. More than 30 studies were surveyed from peer-reviewed articles, technical reports, National Communications to the UNFCCC of the countries, as well as the so-called "grey literature". Most of these actions are framed within the institutional type options. Many of the Physical Structural actions are also planned, while most of the technology types are unplanned, "bottoms-up", or mixed. In other words, in response to a demand for the production environment, a technical or regulatory response emerged from the States or companies in the sector.

Planned adaptation activities

Technological actions are based on improvements to climate information and warning systems for use by farmers (Bouroncle et al., 2015) as well as on various actions that seek to increase diversification and biodiversity, as a way of improving the resilience to climate stresses (Alencastro, 2014; Bouroncle et al., 2015; Altieri and Nicholls, 2017). In several countries in the region (e.g., Brazil, Colombia, Ecuador, Peru, etc.), the so-called "Climate Smart Agriculture" (CSA) is being implemented (FAO, 2017). Climate Smart Agriculture is based on three fundamental pillars: (i) sustainable increase of agricultural productivity and income; (ii) adapt and develop resilience to climate change; and (iii) reduce and/or eliminate greenhouse gas emissions where possible.

The South American continent has one of the two main forest reserves on the planet: the Amazon, which has been suffering with intense deforestation since the beginning of this century. As the country that owns most of this reserve, Brazil passed laws controlling deforestation that were successful (Barretto et al., 2013; Lapola et al., 2013).

As management alternatives, integrated management with forest or agriculture is promoted by governments (Lemaire et al., 2014; Salton et al., 2014), with greater diversification of crops and forage resources (Franchini et al., 2007; Barros Soares et al., 2009b; Lapola et al., 2013). This diversification is also promoted by countries like Colombia, with

Table 2. Review of publications with examples of adaptation practices in the South America region between 2013 and 2018. Adapted from Taboada et al. (2020)

Country/ region	Adaptation option	Class (or category)	Source
Argentina	Recomposition of the livestock stock in the context of climate change and desertification. Inclusion and adaptation of the Neuquén Creole goat	Technological and social	Lanari et al. (2003)
	Hauling, distribution, and storage of water on farms, the re-functionalization and/or execution of drilling, the acquisition of community, and rotary pumping equipment	Structural physical, social, and institutional	Cáceres and Rodríguez-Bilella (2014)
	Germplasms adapted to climate variability in subtropical environments	Technological	Ermini et al. (2013; 2016)
	Advancement of agriculture along with increased rains. Conservationist agriculture and adoption of process technologies (management of crops with an ecophysiological basis, genetic improvement, etc.)	Technological	Viglizzo and Jobbagy (2010); Andrade (2017)
Bolivia	Reduce deforestation, coverage with irrigation systems. Territorial planning	Structural physical and institutional	Andersen et al. (2014)
	Scatter plots at different altitudes to reduce risks	Technological and social	Boillat and Berkes (2013)
Brazil	Pro-Alcohol program to produce ethanol from sugar cane	Institutional	Boddey et al. (2008); Barros Soares et al. (2009a); Nasar and Moreira (2013)
	Diversification of crops with sorghum and beans	Social	Barros Soares et al. (2009b)
	Laws that regulate deforestation. Intensification only when land resources are scarce	Technological and institutional	Barretto et al. (2013)
	Integrated crop-livestock systems	Technological	Lemaire et al. (2014); Salton et al. (2014)
	Agriculture intensification. Laws against deforestation	Technological	Lapola et al. (2013)
	Double crops for longer rainy season	Technological	Arvor et al. (2014)
	Greater diversification of crops and agroforestry systems	Social and technological	Franchini et al. (2007)
	Need to generate seasonal forecasts and warning systems	Technological and social	Marengo et al. (2017)
Chile	Support the sustainable use of water and soil resources by NAMAs. Early warning systems	Institutional	Ludueña and Ryfisch (2015)
	Implement water governance. Watering peasant	Institutional	Delgado et al. (2015)

Continue

Continuation

Colombia	Solar drip irrigation. New technology	Structural physical and social	Galindo et al. (2017)
	Management of shade in coffee plantations, renovation with rust-resistant varieties, association of crops, plant cover, staggered planting and reforestation	Technological	Turbay et al. (2014)
	Remediating effects of floods, soil management, risk awareness	Technological, social and institutional	Alencastro (2014)
	Livestock Plus Project: sustainable intensification of livestock farming in the tropics based on the use of improved forages	Technological and institutional	Serna et al. (2017)
	Consider the gender perspective in mitigation strategies, so as not to ignore traditional knowledge. Influence of war: female heads of household	Social	Tafur et al. (2015a)
	Silvo-pastoral intensive production. Agroecological principles	Technological	Murgueitio et al. (2013)
Ecuador	Diversification of production, gene banks, species for erosion control	Technological	Alencastro (2014)
Peru	Incremental adaptation: shade or irrigation; pest and disease management, soil and fertility. Adaptation with large adjustments: New varieties; diversification with Robusta or other crops	Technological	Avelino et al. (2015)
	Use of ancestral knowledge to improve water harvesting. Respect for biodiversity.	Structural, physical and social	Torres Guevara (2015)
	Irrigation and water use technologies; training of farmers	Institutional	Beekman et al. (2014)
	Reduce poverty by increasing women's participation in decision-making and ownership in the rural world	Social	Tafur et al. (2015b)
	Implementation of climate-smart agriculture: investments in irrigation infrastructure and conservation of water recharge areas; better pasture management, ancestral practices. Pest resistance in rice	Institutional	Banco Mundial et al. (2015)
Uruguay	Water management, sustainable land management, silvo-pastoral systems, germplasm reserves	Technological, social and institutional	Alencastro (2014)
Argentina, Brazil, Paraguay, Bolivia and Uruguay	Intensification of agriculture and neglect of vulnerable land (mountains, deserts and fertile soils in some areas)	Social and institutional	Grau and Aide (2008)
Argentina, Brazil, Paraguay, Bolivia and Uruguay	Decrease in deforestation and expansion of summer agriculture	Technological	Graesser et al. (2015)

Continue

Continuation

Colombia, Peru, and Ecuador	i) Conserve and restore the upper parts of the hydrographic basins; ii) Promote conservation agriculture in the upper and middle parts of the basins; and iii) Promote traditional and ancestral practices in family farming, identifying practices that contribute to resilience	Structural, physical	Magrin (2015)
Colombia, Central America and México	New varieties. New farming systems. Warning Systems	Technological	Avelino et al. (2015)
Venezuela, Colombia, Ecuador, Peru and Bolivia	Survey of fields (platforms) or ridged in ridges (chinampas, waru-waru)	Structural, physical	Altieri and Nicholls (2017)
Bolivia, Ecuador, Peru and Colombia	Strengthening mechanisms of adaptation and resilience	Social	Huggel et al. (2015)

several projects of sustainable intensification in the tropics based on improved forages (Murgueitio et al., 2013), integrating climate adaptation, and peacebuilding components (Castro-Nunez, 2018), or in Argentina, where the National Plan for Forest Management with Integrated Livestock (MBGI) promotes integration between production, conservation, and the people who inhabit forest areas (Borrás et al., 2017).

Climate early warning systems are among the most common planned measures, as a way of generating precautionary actions against extreme weather events, such as hail, early or late frost, heat waves, or prolonged droughts. As an example, in Colombia, unions like Fedearroz (National Federation of Rice Growers) and Fenalce (National Federation of Cereal and Leguminous Growers) have agrometeorological teams and generate agroclimatic information for their producers with the support of the Colombian meteorological service (IDEAM) and CIAT (International Center of Tropical Agriculture) scientists.

The Pro-Alcohol Program of Brazil promotes the use of sugarcane biomass to produce ethanol (Boddey et al., 2008; Barros Soares et al., 2009a; Nasar and Moreira, 2013). It is not so much an action to adapt to climate change, but rather mitigation by reducing the burning of fossil energy sources. However, its impact on biodiversity is not without controversy due to the risk of generating waste while cultivating sugarcane to produce alcohol and contamination by the destination of toxic effluents, like vinasse, from the industry. These threats are minimized or dismissed by Boddey et al. (2008).

Measures of the planned type are typically “top-down.” The options for adaptation to climate change involve a set of actors from different orbits (eg., government, companies, NGOs, farmers, etc.) that can be differentiated by their type of implementation. Uruguay, in 2017, approved its National Climate Change Policy (PNCC) and the First Nationally Determined Contribution (CDN), with the CDN being the instrument of implementation of the PNCC. The PNCC of Uruguay is a strategic and programmatic instrument with a 2050 horizon that seeks to incorporate climate change in all areas and sectors of the economy and society, promoting sustainable development for the country that is more resilient and low in carbon. In the productive dimension related to this policy, there are lines of action aimed at promoting agricultural production systems with greater capacity for adaptation and resilience to climate change and variability, to improve productivity and the competitiveness of value chains, contemplating ecosystem services, social equity, and food security (Ministry of Housing, Territorial Planning and Environment of Uruguay, 2018).

Also, in Uruguay, the GEF Project, "Intelligent climate livestock and restoration in Uruguayan grasslands," is being implemented to mitigate climate change and restore degraded lands by promoting climate-smart practices in the livestock sector, with an emphasis on familiar agriculture. This project involves the development and validation of a livestock strategy that does not just generate less net greenhouse gas emissions than the existing strategy, but is also more resilient and efficient while promoting small and medium-sized livestock establishments based on natural grasslands (Ministry of Housing, Territorial Planning and Environment of Uruguay, 2018; Ministry of Livestock, Agriculture and Fisheries of Uruguay, 2018).

In Argentina, a planned response to face the threat of deforestation is to implement the planned arrangement of the territory proposed by Law 26,331 on Minimum Budgets for Environmental Protection of Native Forests, the so-called "Forest Law," sanctioned in 2007 and implemented in February 2009 after claims by more than 70 social organizations were made (García et al., 2013; Lapola et al., 2013; Graesser et al., 2015). The Forest Law establishes that the provinces must carry out the territorial ordering of their native forests (OTBN) through a participatory process, which categorizes the possible uses for forested lands: from conservation to the possibility of transformation into agriculture, switching to the sustainable use of the forest.

Autonomous adaptation activities

This kind of adaptation strategy differs markedly from planned strategies, typically not requiring state involvement or planning at different levels. These are varied in nature, but technological adaptation measures predominate, taken not only individually but also at the community level. Frequent examples include changes in planting areas, adoption of varieties resistant to pests or drought, germplasm or types of native animals, water harvesting, or irrigation systems. Figure 2 shows the frequency of measurements carried out within the actions reviewed for the 2013-2018 period, indicating those of the planned type and those of the autonomous/mixed type.

Andean agriculture is fundamentally threatened by reduced water availability as a consequence of less rain and glacial retreat and the tropicalization and migration of crops. This is due to the increase and variability of temperature, which changes crop behavior and requires new fieldwork. The main adaptive responses are based on strengthening governance, resilience mechanisms (Huggel et al., 2015), and improving water governance, either through social or institutional actions (Delgado et al., 2015; Torres Guevara, 2015). Andean agriculture diversification is based on planting at different altitudes of the landscape, such as in the Bolivian altiplano (Boillat and Berkes, 2013). Actions that promote the use of traditional or ancestral knowledge are strongly present in this type of agriculture (Boillat and Berkes, 2013; Torres Guevara, 2015).

As already mentioned, business agriculture based on market forces generates countless autonomous adaptive responses. An eloquent example is the advances in the agricultural frontier operated in Brazil and Argentina, although for different reasons. The adoption of no-tillage soil management technology contributed to economically profitable work with the ability to plant crops like corn and soybeans in less fertile soils or in more climate-vulnerable areas (Álvarez et al., 2009). This results in a greater resilience of productions to climate variability, although it does not necessarily contribute to effective mitigation of greenhouse gas emissions (Powlson et al., 2014; Moraes Sá et al., 2017).

Business agriculture often generates unintended consequences, such as a lack of crop rotations and shifting of livestock to marginal areas, which generates little resilience to climate variability, biological imbalances, generation of new pests and diseases, and/or resistance thereof, as well as significant hydrological imbalances (Giménez et al., 2016; Salazar et al., 2016; Houspanossian et al., 2017). Undesirable autonomous responses were manifested, such as the unplanned construction of drainage channels, unsuitable irrigation methods in different areas, as well as the unplanned use of irrigation water (Taboada and Damiano, 2017). Another unintended consequence was the contamination of watercourses by the indiscriminate use of agrochemicals (Grau et al., 2005; Bolliger et al., 2006; Derpsch et al., 2010; Andrade, 2017).

Although so-called peasant agriculture is far from being homogeneous, it is subject to greater climatic risk and requires greater attention by the states at different levels due to the characteristics of the socioeconomic level of the affected populations. This includes Andean or mountain agriculture in environments ranging from tropical to desert climates (i.e., Puna), transhumant farmers and rangers based on slash and burning practices in rainforests areas, as well as periurban agriculture around the main populated centers of the region. A great difference with respect to other types of agricultural production models is that the adopters are rural people prone to apply actions based on ancestral practices. In the case of Brazil, for almost 20 years, there were differentiated policies for family farming, focused on access to land, rural credit, and support for production and marketing. In this way, it also sought to respond to the challenges posed by hunger and food insecurity through social and territorial policies (Sabourin, 2015).

Diversification is the most important strategy that farmers use to manage production risk in family farming systems. In most cases, farmers maintain diversity as insurance when facing environmental change or future social and economic needs (Altieri and Nicholls, 2009, 2017). There are four principles sets of strategies that seek to increase diversity: a) Multiple or polyculture cropping systems, which have greater stability and less decline in productivity during a drought than in the case of monocultures; b) Use of local genetic diversity, which exploits intraspecific diversity through the simultaneous sowing and in the same field of diverse local varieties that, in general, are more resistant to drought; c) Collection of wild plants as subsistence through collection around crops; and d) Agroforestry and mulching systems that use tree cover to protect crops against extreme fluctuations in microclimate and soil moisture (Altieri and Nicholls, 2009, 2017).

In the case of the Andean culture, ancestral techniques that inspire several important adaptations are preserved. For example, terrace farming is used, as embodied in the Andenes de Coctaca (Dpto. Humahuaca, Jujuy), a structure of Inca terraces of great cultural value (Ventura et al., 2010), and the Choquequirao platform in Peru (Ancajima Ojeda, 2013; Guzmán García, 2013). Terrace farming does not depend on large investments in infrastructure or technology and is particularly beneficial for peasant farmers who operate without either substantial resources or state support (Bocco and Napoletano, 2017). Another important cultural adaptation to environmental contrasts is systems based on local crops, animals, and agro-pastoral technologies that provide an adequate diet with local resources while avoiding soil erosion (Altieri and Nicholls, 2009).

Among the programs aimed at conserving native resources and agricultural heritage, it is worth mentioning the “Important Systems of World Agricultural Heritage (GIAHS)”. This program was created within the Rio + 10 Conference framework and inspired by the FAO to identify land-use systems of remarkable landscapes that are rich in biodiversity. Out of the 30 existing GIAHS systems, two are in Latin America: one in Chiloé (Chile) and the other is the Cusco-Puno corridor system, which integrates the Huaru Huaru systems, including the entire system typical of the Andean region. Among the relevant systems pre-identified in a first phase are the Moxo system, in the Bolivian Amazon, which is a system of ridges in the area that is flooded, close to the river bed, and that is used for crops, and the Sukakollos systems, which occupy around 50,000 hectares around Lake Titicaca, which are also a ridge system similar to that of the Moxo, under the same technological principle (Rodríguez and Mesa, 2016).

Some farmers already apply various strategies to help reduce weather and climate risks as well as other uncertainties, including multi-location agriculture, crop and variety diversification, finding alternative sources of income, and purchasing crop insurance. Such efforts often help farmers maintain a more stable income while protecting and preserving the productivity of the land. However, not all farmers have implemented basic risk management strategies despite their clear benefits.

Barriers, opportunities and interactions

Mitigation

There are obvious co-benefits of climate-smart agriculture (CFS) that promote coordinated actions toward greater climate resilience, prioritizing interventions that can improve productivity and incomes, help farmers adapt to current risk, and decrease greenhouse gas emissions in the present and future (Shirsath et al., 2017). On the other hand, no-till agriculture (direct sowing) is also recommended as an adaptation practice that contributes to soil conservation and resilience to extreme climatic events (Merante et al., 2017). Policies promoting the use of biofuels generally pursue the goal of reducing the use of fossil fuels. However, not only do these have significant adverse effects when they promote changes in land use and GHG emissions in other sectors, but they also threaten food security (Howden et al., 2007; Miyake et al., 2012).

Prevention of land degradation

A study of the state of the world's soils shows that global erosion is the main process of degradation, followed by nutrient imbalance (deficits and excesses), loss of carbon stocks, and salinization (FAO and IPTS, 2015). Adaptation measures related to changes in planting or planting zones or the displacement of productions may represent a risk of a vulnerable land invasion. For example, in central Argentina, aided by increases in rainfall and no-till agriculture, soy-based agriculture advanced to the west and north of the country, replacing the forests and pastures of these regions of the country, causing widespread increases in groundwater, floods, and salinization (Andrade, 2017).

Actions related to the adoption of new varieties or planting dates, the control of erosion or wind storms, as well as the incorporation of organic matter into the soil in its different forms, show clear benefits to prevent desertification. Effective conservation practices can reduce the risks of soil erosion, improve soil quality and water quality, increase the carbon balance of the soil and the ecosystem, while also adapting to and mitigating abrupt climate change (Lal, 2015). However, some adverse effects may also appear, for example, when lands vulnerable to erosion are put into cultivation by public policy decisions, or when freshwater sources decrease in volume and quality because of the excessive use of water (Elliott et al., 2014).

Food security

The impacts of climate change on food security will be greater in countries that already suffer from high levels of hunger and will worsen over time (Wheeler and von Braun, 2013). Adaptation actions seeking more resilience of agricultural systems show clear benefits for food security. Some examples are climate-smart agriculture, the combination of agricultural conservation practices, and integrated productions based on agroecology (The World Bank et al., 2014a,b). However, all of this might not be enough because the entire food system must adjust to climate change, paying particular attention to trade, stocks, nutrition, and social policy options (Wheeler and von Braun, 2013; Lipper et al., 2014).

Poverty reduction

In general, agriculture-based adaptation measures aim to either increase production or minimize disaster risks, so their impact on poverty reduction is neutral to positive. However, in cases where these adaptation measures involve migration of people between rural areas, something very common in cases of economies based on agriculture, this can generate greater poverty in the short term, unless there are local institutions that help and accommodate human mobility (Tacoli, 2009).

Water supply

Many adaptation measures in the agricultural sector positively affect water, especially those that imply better conservation and use of the resource or preserve the role of ecosystems in the hydrological cycle. However, other measures - especially structural ones that tend to ensure greater accessibility to sources of water available for irrigation - may conflict in the future, given the limitations of fresh water in some highly irrigated regions that may require moving much farmland back from irrigation to rainfed management (Elliott et al., 2014). An integrated approach is required between all components of the water, energy, food, and agriculture system. The water, energy, and food nexus, as well as adaptation responses, are interrelated in numerous ways.

Measures or indicators of adaptation effectiveness

In contrast to mitigation, where the effectiveness of policy action can be measured through the metric "tons of reduced CO_2 equivalent," there is no universally accepted metric to assess the effectiveness of adaptation. Without such a metric, adaptation financial mechanisms, like the Adaptation Fund or the Green Climate Fund, face challenges when comparing the adaptation effect of projects to achieve an efficient allocation of their funds (Stadelmann et al., 2015). Indicators of behavior adaptation by farmers, focusing on gender, social media, and institutions, are still underrepresented (Davidson, 2016).

CONCLUSIONS

South America is a continent with enormous environmental and human diversity. This diversity must be taken into account when analyzing the possible effectiveness of adaptation measures to climate change.

Among the identified climate threats, increases in average and minimum daily temperatures are the main concern, along with extreme weather events (e.g., heat waves, intense storms, hail, droughts, floods, decreased days with frosts, etc.). This climate change is already taking place and is expected to intensify in the coming decades, increasing the urgent need to adapt to these changes.

Vulnerability exists, first, because rural populations are exposed in many of the countries, often with high rates of poverty and low rates of socioeconomic development. Secondly, many of these settlers inhabit risk areas, such as mountain slopes or flood plains, and/or have limited possibilities to access strategic resources, such as irrigation water in quantity and quality, or land to move to.

Concerning the adaptation measures already taken, there are numerous interventions by national, provincial, and municipal states for planned actions, like irrigation systems, dams, and climate forecast systems. Farmers are very active in adopting autonomous measures, like changing planting dates and areas, providing shade for plantations and domestic livestock, installing animal troughs, or adopting native germplasm from local crops and livestock. There are also many experiences of associativism, often autonomous, but also with some degree of state intervention.

Many adaptation measures show clear co-benefits with climate change mitigation or the prevention of land degradation and desertification. Other adaptation measures do not go in this direction and generate significant adverse effects, such as changes in land use, as an example.

In the forthcoming times, regions with rich natural resources are being subjected to strong market pressures and climate change threats. It is a key to generate strategies to care for these resources for their permanence for future generations.

AUTHOR CONTRIBUTIONS

Conceptualization: Alejandro Oscar Costantini (equal), Mercedes Busto (equal), Michelle Bonatti (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (lead).

Data curation: Alejandro Oscar Costantini (equal), Mercedes Busto (equal), Miguel Ángel Taboada (equal) and Stefan Sieber (supporting).

Formal analysis: Alejandro Oscar Costantini (lead), Mercedes Busto (equal), Michelle Bonatti (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (equal).

Funding acquisition: Alejandro Oscar Costantini (equal), Michelle Bonatti (supporting), Miguel Ángel Taboada (equal) and Stefan Sieber (supporting).

Investigation: Alejandro Oscar Costantini (lead), Mercedes Busto (equal), Michelle Bonatti (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (lead).

Methodology: Alejandro Oscar Costantini (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (equal).

Project administration: Alejandro Oscar Costantini (equal), Michelle Bonatti (equal), Miguel Ángel Taboada (equal) and Stefan Sieber (supporting).

Resources: Alejandro Oscar Costantini (equal), Michelle Bonatti (equal), Miguel Ángel Taboada (equal) and Stefan Sieber (supporting).

Software: Alejandro Oscar Costantini (supporting), Miguel Ángel Taboada (equal) and Stefan Sieber (equal).

Supervision: Alejandro Oscar Costantini (lead), Michelle Bonatti (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (equal).

Validation: Alejandro Oscar Costantini (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (equal).

Visualization: Alejandro Oscar Costantini (equal) and Stefan Sieber (lead).

Writing - original draft: Alejandro Oscar Costantini (lead), Mercedes Busto (supporting), Michelle Bonatti (equal), Miguel Ángel Taboada (lead) and Stefan Sieber (supporting).

Writing - review & editing: Alejandro Oscar Costantini (lead), Mercedes Busto (supporting), Michelle Bonatti (equal), Miguel Ángel Taboada (equal) and Stefan Sieber (supporting).

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