Chapter 14
Adaptive Strategies Building Resilience to Climate Variability in Argentina, Canada and Colombia

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Abstract Many regions of the world are experiencing the impacts of climate change, which include the increasing variability of weather as well as increased drought and flood. Although many areas have had a long history of this variability and have a strong historic practice of adaptation, increasing variability has had a significant impact on adaptive strategies of agricultural producers over the last several years.

Drawing on comparative vulnerability studies of agricultural producers in dryland river basins in Argentina, Canada, and Colombia, this paper presents an analysis of the adaptive strategies employed by agricultural producers in responding to climate change impacts and an analysis of how these adaptive strategies have built resilience and improved producers' living conditions. Common exposures and sensitivities, linked with increasing variability, isolate important new adaptive strategies. Particular attention to the connection of these strategies to social, economic and institutional capital and the inter-relationship of these provides important insight for future adaptation. These research findings will be useful for governments, policymakers, and organizations assisting with adaptation.

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Introduction

This work addresses farmers' adaptations to climate variability in three regions of Argentina, Canada and Colombia. The purpose is to inform institutions and communities in planning a sustainable adaptation agenda. In drought- or flood-prone regions, adaptation to these natural phenomena is not a new issue. However, changing environmental conditions engender new challenges, not only to social actors inhabiting the territories but also to institutions that manage natural resources. Climate variability (understood as climate fluctuations above or below a long-term average value) involves problems of water quantity and quality to meet human, productive and ecological demands in arid and semi-arid ecosystems, as well as increasing flood probability for many regions. The occurrence of climate extremes, such as drought and flooding, are expected to increase as anthropogenic change affects natural climatic variability (IPCC 2015). Climate extremes that seriously affect crops undermine the conditions and possibilities in which producers can become more resilient to weather contingencies and to varying adversities.

Adaptation has been defined as adjustments made to human-environmental systems in response to expected or experienced climate impacts (Smit et al. 2000). Effective adaptation can reduce the vulnerability of a system (such as a household, community, or institution, for example) to climate extremes. Although mitigation of future climate change is important, the irreversibility—and thus inevitability—of existing anthropogenic climate change means that adaptation to future climate extremes is necessary (IPCC 2015).

The dominant approach to climate change adaptation has emphasized "technology, institutions and managerial systems" as key to successful adaptation (Eriksen et al. 2011). However, technology and infrastructure are inherently social, and more recent analysis has acknowledged the importance of social, economic, and political factors in determining adaptive capacity and adaptive strategies (Adger 2003; Below et al. 2012; Field et al. 2012). Adaptive strategies largely depend on economic and technological resources, information, knowledge, skills, social capital and institutional capital (Wisner et al. 2003; IPCC 2007; UNEP 2013). However, these strategies, whether institutional or autonomously initiated by farmers, are not always effective enough to become sustainable adaptations that increase the resilience of the stakeholders. Sometimes, this is due to "misuse" or inefficient use of resources. Other times, farmers' adaptive capacity is limited by social, political, or economic factors and resource constraints. "The underlying social, economic, institutional, and cultural conditions that contribute to a wider context for vulnerability" must be understood (Eriksen et al. 2011, p. 11).

The conditions that affect adaptation are context-specific (IPCC 2015). A 2006 review of the literature on adaptation (Smit and Wandel 2006) found a shortage of context-specific studies investigating adaptation in particular regions or communities, particularly studies where key vulnerabilities and adaptive strategies are identified through research with the communities themselves and not *a priori* (Smit and Wandel 2006). Understanding of context-specific adaptation needs is important, as are the local and traditional knowledge systems that also determine adaptation in a given location (IPCC 2015).

Adaptation is not a linear process where social systems simply adjust to natural stimuli. It is a struggle for access and control of material and social goods, and participation in political processes that determine the management, access, use, and distribution of natural goods. In other words, adaptation has also a sociopolitical dimension (Dietz 2013). Therefore, the possibility of developing adaptations that foster resilience should address the transformation of the root causes that make social systems vulnerable. Many of these are not even directly associated with climatic or environmental issues. From this framework, the aim of this paper is to assess farmers' adaptations and strategies for coping with climate events as well as with other relevant non-climatic stressors in three case studies.

The Wide Spectrum of Adaptations

Despite the widely recognized importance of adaptation, not all adaptation strategies are equally effective or beneficial. Moreover, what is often not questioned is the purpose of adaptations or their consequences. As not all adaptations lead to the same results, it is necessary to take into account the possible impacts of each. For example, many are focused strategies (such as the incorporation of technology, placement of hail nets, modification of irrigation shifts) that simply seek to adjust to the new conditions exclusively through cushioning the *impact* of climatic events. Some adaptive strategies may actually prove detrimental to adaptive capacity over the long term; for example, some strategies may increase social differentiation or environmental degradation. *Climate risk management* based on scientific information is a broader strategy than the impact focus. Climate risk management builds a standpoint that enables informed decision-making. In this way, it provides long-term solutions (Lozoya et al. 2011). The effect of climate risk management approaches on resilience will not be automatic; instead, it will depend on how that information is "translated" and distributed among producers.

A step towards *building resilience* and *sustainable adaptation* is to recognize that adaptive responses should go beyond climate and aim at troubleshooting and addressing systemic problems (Bassett and Fogelman 2013). Examples of such resilience-building efforts include the improvement of intersectoral coordination (Mearns and Norton 2010) or the enhancement of producers' capacities (Agrawal and Perrin 2009) through livelihood diversification or educational and health promotion. These practices are not exclusively related to environmental change policies, and fall within the spectrum of development and poverty reduction programs. Thus, adaptation to climate variability is an indirect effect of these other kinds of policies. Given the diversity of strategies and their impact on actors' resilience, the role of institutions that manage water, climate and production also becomes fundamental for adaptation planning.

Methodology

The analysis of adaptation discussed here is part of a broader international research project called "Vulnerability and Adaptation to Climate Extremes in the Americas" (VACEA). The project developed a model for assessing vulnerability to extreme events in rural contexts from an integrative and interdisciplinary approach.[1] The interdisciplinary project brought together natural and social scientists to examine vulnerability and adaptation to past and future climate events.

Our analysis here is based on participatory community vulnerability assessments (CVAs). The CVAs involved semi-structured interviews conducted with rural producers in the three case study areas; our analysis is, therefore, based on qualitative data. In Argentina, the sample consisted of 41 farmers and irrigation water managers along the districts of the basin and 25 institutional representatives from water, environmental and production institutional areas at national, provincial and local levels. The Canadian study included 170 participants: 100 were farmers, ranchers, and rural residents, and 70 were governance representatives working in the agricultural industry in the study area. In Colombia, 20 coffee farmers were interviewed in Chinchiná and Villamaría municipalities as well as 14 officials from institutions identified as key for governance of climate variability at the regional level.

Informants were selected through theoretical, non-probabilistic sampling based on their theoretical relevance to the research question and considering key variables for each study area: location of the farm in the basin, type of productive activity, farm size, use of labour force, etc.

The interviews were guided by a set of open topics that inquired about the different dimensions of vulnerability: exposures (climatic and non-climatic) that producers face; adaptive capacities for coping with exposures, and their perceptions of the future. Their responses highlighted the importance of underlying social, political, and economic factors in determining adaptive capacity to extreme events. Interviews were conducted until theoretical saturation was reached, i.e., until no

[1]The VACEA project (see footnote #1) involves three sets of interrelated activities: (1) Evaluation of past, present and future vulnerabilities related to climate, agriculture and natural resources using climatological scenarios and future climate projections for the areas; (2) Analysis of the vulnerabilities of communities using a combination of in-depth interviews—which inquired about risk exposures, sensitivities and adaptation strategies of farmers—and secondary socioeconomic data. This activity also included a study of the role of institutions in adaptability. (3) Finally, bringing together the insights produced by the first two sets of activities in order to assess future vulnerabilities based on how the current vulnerabilities will be affected by the expected future conditions. The analysis of adaptive capacity in this chapter corresponds to the second set of activities within the larger research project (For further information about the conceptual framework of VACEA project, see Harry Díaz in this volume).

new information was being produced (Glasser and Strauss 1967). Results from each case study were analyzed with NVivo 10 software for qualitative data.

Findings

Variability and Adaptations in Mendoza

Mendoza is an Argentinian province located in the west-central part of the country, near the Andes mountain range. As it is a semiarid region (it is part of the South American arid diagonal), agriculture and most human activities are only possible by the intentional handling of water coming from rivers originating in the Andes as a result of snowmelt and glaciers. Thus, the provincial territory is fragmented between the irrigated oasis (fed by a dense network of surface irrigation and where agribusiness has concentrated wine emblematic enclaves and all their material and symbolic representations) and drylands, that is, the part of the territory that has been excluded from irrigation system, so-called "deserts".

Hail, frost and the decrease in available water for irrigation are the main events of climate variability in Mendoza. The strategies producers deploy to adapt to these events mainly correspond to their economic capacity. To prevent the impact of frost, producers apply fairly precarious techniques such as moistening the soil and crops and setting fire to raise the temperature. Hail damage is absorbed with expensive protective nets partially subsidized by the state. In addition to these focused methods some producers obtain insurance; however, such insurance is insufficient because it fails to cover the complete loss. When producers receive their share they have already failed to recover profitability. However, insurance allows producers to *survive* from one cycle to another.

Only some large producers develop their own information systems to plan adaptations. In most cases, public institutions are the ones that develop preventive plans through the use of specific information. With the exception of these institutional strategies from the State, large producers are the ones who can be more resilient to hail and frost because they have easier access to investment, credits and allowances demanded by these adaptations.

Although producers in Mendoza have historically employed these mechanisms to adapt to these events, they have become increasingly more insufficient and ineffective. Hail and frost indirectly threaten the living conditions of families who fail to gather enough capital to meet production losses cycle after cycle. The inability to adapt is a bottleneck to the resilience of these actors.

Climate variability also affects *water availability*. In a basin irrigated by water coming down the mountain, the snow decrease seriously affects available flows downstream. This produces a direct impact on the quality and quantity of production. In a similar way to hail and frost, the range of adaptations to the decrease in water for irrigation is mediated by access to resources. In addition, not all producers get the same results, not only with respect to obtaining water but with respect to the situation of vulnerability and resilience of the producers.

Through specialized information, the water authority anticipates the annual availability of water. Based on those forecasts, it establishes how the quantity of allocated water will change. Based on this information at the beginning of a cycle, the producers would have the possibility of planning their practices and adapt to the announced volumes. The effect of this reduction of allocated water on farmers' livelihoods is different, since not all the producers depend, in the same way, on surface water. This is because access to underground water is the most important adaptation to diminishing flows. It can mean the difference between a good harvest and a bad one, so that those who have access to this alternative source are much more resilient than those who do not. This adaptation not only depends on the ownership of a license for using ground water, but on the economic resources to operate the well since the construction, maintenance and operation costs are very high.

Other adaptations to water shortage are the construction of private water reservoirs and irrigation technology. These two strategies make producers more resilient because by these mechanisms they are untied from the "variability of nature". Those farmers without the economic resources to develop these practices rely on precarious practices of water management on the farms. Although not as crucial as resource availability, individual aspects are also important. While some small producers receive drought relatively passively, non-technological practices do demand dedication and expertise. This initiative of change is relevant to increase resilience. Predisposition to adapt is also the basis of another important strategy for small producers. Agreements to share wells create possibilities that these producers could not engage in individually. Even though these practices are not abundant, they produce an outcome beyond the impact focus and build capacities to creatively address lack of water. One of the main limiting factors is the lack of confidence based on bad experiences. At the same time the State reveals an ambivalent attitude towards non-technological adaptive practices. On the one hand it promotes these practices giving financial aid and priority to these collective orders above the individual ones. But on the other, it restricts this access because in practice it does not facilitate the procedures.

Adaptations and Resilience Beyond the Climate

Associative organizations for common use of water, technology and machinery contribute to the improvement of producers' adaptive capacity. But cooperative networks in Mendoza are also a successful adaptation in another sense, not directly related to climate variability but through strengthening networks that ensure the commercialization of crops. Cooperative networks function together as an integrated, collective actor that is able to interact with the State and stands as a consolidated and valid interlocutor in the sector. However, on the other side, the system for purchasing commodities has acquired the modality of an oligopoly in which only a few companies[2] decide the market value in a manner that prevents farmers from obtaining favorable prices. Despite the inability to obtain desirable prices, the cooperative networks make a difference with respect to small producers of fruit and vegetables who otherwise would not have secured the ability to market their products.

Up to 60 % of farmers in Mendoza rely on off-farm income (CNA 2002). Income diversification, creating alternatives to the agricultural economic activities (commercial, community, tourist services, etc.), is considered by mainstream adaptation literature as one of the adaptations that most contributes to building resilience. In the case of Mendoza, this correlation is not linear since these new revenues that producers get, usually come from precarious and not well-paid jobs. Therefore, it is probably an indicator of reduced climate exposures, but not necessarily an indicator of better life quality or less vulnerability (Montaña 2008). Whether diversification builds or not, resilience requires an assessment of the type of work these diversified incomes come from.

While some producers are forced to diversify their incomes due to the failure of investment that the market demands, others opt for changing activity drastically. This means their defeat as producers. The sale of land for the real estate business is one of the most drastic options for producers in response to low profitability of their production. In contrast, income diversification acquires another meaning for large producers, for whom it is associated with the investment in new economic areas. This places large producers in a better position to cope with the consequences of climate change.

Variability and Adaptations in the Canadian Prairies

The South Saskatchewan River Basin (SSRB) runs for 998 km across the Canadian provinces of Alberta and Saskatchewan (PSRB 2009). Large portions of the basin are located within Palliser's Triangle, a region known for severe and prolonged drought. Although 30 % of the basin is classified as arid (Wandel et al. 2010), the SSRB is an important site for agricultural production in Canada. Farmers and ranchers in the area produce cattle, grain, pulses, and vegetable crops. The Canadian study included four communities across the SSRB: the communities of Taber and Pincher Creek in the Oldman River Watershed (ORW) of Alberta, and the communities of Rush Lake and Shaunavon in the Swift Current Creek Watershed (SCCW) of Saskatchewan.

Farmers and ranchers in the SSRB are generally well adapted to drought and dry conditions. Strong adaptive practices have resulted from generations of knowledge sharing between farmers, as well as from government investment in agriculture.

[2]Most small and medium farmers sell their grapes to four large corporations that produce common wines: Peñaflor, Baggio, FE.CO.VI.TA and Catena.

Recent years have brought new adaptive practices, such as the use of drought-resistant crop varieties and zero-till agriculture; however, recent years have also brought new political and economic challenges for producers in the region.

The majority of farmers in the SSRB have embraced minimum-till or zero-till practices to reduce soil erosion. These practices have been driven, in part, by memories of the 1930s, when a combination of land-degrading cultivation practices and severe drought caused suffering and starvation in the prairie region (Marchildon et al. 2008; McLeman et al. 2013). As a response to the historic drought, the federal government created the Prairie Farm Rehabilitation Administration (PFRA) to facilitate sustainable development in the prairies. Over its almost 80-year lifespan the PFRA implemented a number of programs to reduce erosion and manage natural prairie grasslands. The PFRA also established drought adaptation infrastructure, including a number of irrigation projects across the driest part of the prairies.

Although the majority of agricultural producers in the SSRB still lack access to irrigation, the communities of Taber and Rush Lake are an exception. Some Rush Lake producers have access to a limited number of flood-irrigated acres, which are used mostly for hay. The community of Taber stands out as a key site for irrigation in the basin. High-tech irrigation infrastructure allows production of high-value but water dependent crops such as sugar beets, corn, and potatoes. Several large facilities are located in the Taber area to process these products. Although irrigation increases adaptive capacity in general, producers of water-intensive crops face the threat of a severe or protracted drought that depletes irrigation reservoirs; this poses a risk not only for producers but also for those employed in the local processing sector.

Producers also engage in farm-level adaptation. For ranchers, a major challenge is ensuring a sufficient supply of hay, a drought-sensitive crop used to feed cattle. Many ranchers prepare for dry years by stockpiling hay. Crop producers make decisions based on the drought tolerance of crops; the introduction of new pulse crops to the region (e.g., lentils) has added new rotational possibilities to the historically dominant drought-resistant crops like wheat and barley.

Adaptations and Resilience Beyond the Climate

Despite the number of adaptive practices employed in the region, producers' adaptive capacity is affected by underlying economic, social, and political problems. Financial issues, especially the high cost of inputs, were the most commonly mentioned stressor for the producers in the study. Farmers now pay more for patented and certified seed varieties that promise high yields and increased resistance to drought and excess precipitation. However, these adaptive strategies may paradoxically increase vulnerability: a crop produced with more expensive seed is a more expensive crop lost to a climate disaster. Minimum and zero-till technology saves time and money by reducing cultivation; however, it also causes farmers to rely heavily on specialized equipment and chemical herbicides for weed control. This can increase input costs and agro-chemical use.

A key adaptive response to financial challenges, for many farmers, has been to increase the size of the farm. Over the past decade, the overall number of prairie farms has dropped dramatically (Statistics Canada 2011, 2006), and many farms have grown larger in a quest for financial sustainability and others leave the industry. Many study participants discussed the social changes this phenomenon has caused. Rural communities in the SSRB are now faced with declining populations, loss of services, and the associated impacts on social capital.

Similar to the case of Mendoza, farmers in the Canadian prairies rely increasingly on off-farm work to supplement farm income and to stabilize risk (Alasia and Bollman 2009; Jetté-Nantel et al. 2011). Approximately half of all farm men and women in Canada hold off-farm employment (Statistics Canada 2011). While off-farm work may increase adaptive capacity by providing a reliable source of income, this work can also add stress and additional hours to farmers' already lengthy workday. Although livelihood diversification is a commonly promoted adaptive strategy for agricultural producers, it is important to examine how such diversification can affect farmers' quality of life in both positive and negative ways.

Agricultural producers also face challenges related to policy and institutional programming. Over the past two decades a number of farm support policies and programs have been eliminated. In 2009, the federal government announced plans to divest of its PFRA irrigation projects. This development has been a significant source of stress for irrigators in the Rush Lake area, who now face the cost of privately operating the irrigation system. Community pastures—a significant source of protection for native prairie grasses—are also part of the divestiture. Some farmers are concerned about the impacts of these changes on rural communities, future adaptation, and long-term environmental sustainability.

Variability and Adaptations in Chinchiná River Basin

The Chinchiná River basin is located on the central mountain range of the Andes, in the department of Caldas, Colombia. Within the river basin there are receding tropical glaciers, *páramos*, temperate regions, as well as desert semi-arid landscapes. The rainfall in the Chinchiná river basin is bimodal, which means that during the year there are two periods with high precipitation and two periods with less precipitation (Poveda 2004). This annual distribution of precipitation defines the flowering and harvesting periods in the Colombian coffee producing areas (Jaramillo Robledo and Ramírez Builes 2013). At inter-annual timescales, El Niño-Southern Oscillation (ENSO) is the most important phenomenon related to climate variability in Colombia. During the warm phase of ENSO—what is called El Niño—the country experiences negative anomalies in rainfall, soil moisture, and river discharges. During the cold phase of ENSO—called La Niña—there are positive anomalies such as heavy rainfalls and increases in the average level of the rivers (Poveda 2004; Poveda et al. 2001, 2011).

La Niña periods have negative consequences on the growth and flowering of coffee trees, as well as increasing the incidence of coffee rust (*Hemilea vastatrix Berk and Br*). There is also an increase in the frequency of landslides, which destroy roads, houses and crops (Poveda et al. 2014; García Pineda 2013). El Niño, on the other side, extends the drier season, which damages the coffee fruit harvest and increases the incidence of pests such as the *coffee* berry borer (*Hypothenemus hampei*), the "minador" of the cafeto leaves (*Leucoptera coffellum*) and the "red spider" (*Oliganychus yotherse*) (Ramírez Builes et al. 2014).

Given this climate variability, there are several risk-reducing strategies sponsored by the Colombian Coffee Growers Federation in order to attain "climate intelligent coffee production". These strategies include: (1) Replacement of existing coffee plants with the Castillo variety, which is resistant to "coffee rust" (*Hemileia vastatrix)*. This has been possible due to producers' better access to both financial credit and to a certain amount of free fertilizers provided by the state according to the number of new plants (García Pineda 2013; Silva Restrepo 2013). In total, 3250 million trees have been replaced between 2009 and 2014 (FNC 2015); (2) Sowing the coffee plants following the contour of the slopes, increasing plant density, and planting shrubs for both reducing rain erosion and the effect of the thermal amplitude (Ramírez Builes et al. 2014); (3) Cultural practices such as the integral management of weeds to maintain the coverage around each of the coffee plants, use of high quality seeds, timely and adequate fertilization, recollection of fruits left in the field after the harvest, gathering the fallen fruit to reduce the presence of "broca" (*Hypothenemus hampei*), monitoring of Lepidoptera, and use of miticide (Galindo et al. 2013; Ramírez Builes et al. 2014); (4) Ecologically beneficial coffee production processes, such as use of equipment that allows for the removal of pulp and the mucilage of the coffee seeds using less water, which reduce the amount of polluted water going into the local water sources (Oliveros et al. 2013); (5) Agro-forestry practices that allow for a control of shade in coffee plantations, diminish rain erosion, reduce the speed of the wind, and conserve soil humidity (Farfán Valencia 2013; Ramírez Builes et al. 2014); (6) Having fields with coffee plants of different ages to constantly maintain an area under production and avoid the same impact of extreme events over all the coffee plants (Turbay et al. 2014); (7) Creation of an agro-climatic website with data from the monitoring of climate in the coffee region during the last 65 years[3]; (8) Providing insurance against geological and climate risks.

The replacement of the coffee plants with the Castillo variety has allowed for an increase in coffee production from 7.8 million 60-kg bags in 2007 (Silva Restrepo 2013) to 12.3 million bags between April 2014 and March 2015 (FNC 2015). Small coffee producers have renovated their coffee plantations and increased both the

[3]http://www.federaciondecafeteros.org/particulares/es/buenas_noticias/nueva_plataforma_para_monitorear_el_clima (accessed April 6 2015).

density of plants in the fields and the area under technical management (Silva Restrepo 2013). The process has not been free of problems given the decline in production during several years due to the existence of young unproductive coffee plants. Fortunately, coffee prices were high during 2011, a situation that compensated the reduced incomes of the producers. Coffee exports have become normal during 2014 and coffee producers have reduced their use of fungicides, which were necessary to control the coffee rust.

It is important to emphasize that small producers have not always been able to keep their coffee plantations exposed to the sun due to the high costs of fertilizers and insecticides required by the monoculture. During periods of crisis, food insecurity has predominated among peasant households due to the need to eradicate all the food crops from the fields in order to ensure the supply of nutrients and sun exposure to the coffee plants. With low coffee prices in the market during 2012 and diminishing production, the only alternative left to many producers has been to protest for government subsides to maintain their families.

Different and more radical forms of adaptation among coffee growers are those that have converted traditional coffee farms to livestock or citric production, or to rural tourism. The results of these conversions have been the displacements of farm workers, who have no other alternative than to move into urban shantytowns.

The responses of coffee growers to climate variability do not automatically follow the technical recommendations of agronomists. Rather, they are related to the size of the farm, security of land tenure, the economic rationality that characterizes the unit of production (peasant or agri-industry), market coffee prices, the proportion of food crops produced by the farm, the availability of labor, the educational level of the grower, and his/her social networks. The producer balances all these dimensions in order to decide if he/she will ask for a loan to replace the old coffee plants, if it is possible to intensify the use of labor to establish new fields or to focus on the tasks required by the existing coffee fields, if he/she is in a position to increase the use of pesticides and fertilizers, if it is convenient to acquire a new water-efficient machine to remove the pulp, and other important decisions. In the meantime, government measures are limited to providing subsidies in the short-term and to strengthening the national system of risk management, which is still focused in prevention and mitigation of disasters rather than on the reduction of social and economic vulnerability and on the development of long-term adaptive strategies to climate variability.

Discussion and Comparison

Farm-level adaptation practices are very important in all cases. Some are technology-based, such as the use of new seed varieties to grow crops more resistant to extreme climates, use of zero-till, or the use of irrigation equipment. In both the Canadian Prairies and Mendoza, irrigation technology allows more efficient resource use and ensures better yields while causing an increase in water demand. However, because of the cost of these investments, mainly paid by producers—and, in the case of Canada, limitations on the number of water licenses available to producers—it is a restricted adaptation practice.

Other adaptation practices include strategic management of crops, land, and plantations, arising from the accumulation of traditional knowledge and generational inherited learning. This knowledge is expressed differently in each place. In Colombia, many farms still use coffee grown under shade combined with other food crops; in Mendoza and Canada, current practices make better use of water and withstand drought. These practices do not always coincide with the knowledge "handling" promoted by some agencies and government. Specialized information contributes to early management of climate risks, providing certainty and increasing resilience. However, we found that the mere existence of information is insufficient if its accessibility and usability is not ensured.

Beyond climatic events, high input prices and low commodity prices profoundly affect the profitability of producers' livelihoods, limiting the adaptability of producers and productive activity itself. A common process in the three case studies is to change productive activity within farms or more radically, the total abandonment of production. This enables, on one hand, a process of land concentration when small farmers are *forced* to sell their land to economically better positioned producers (Mendoza and Canada). On the other hand, it triggers a process of land use change, either from hand crop to livestock as in Colombia, or the urbanization of agricultural areas in Mendoza.

This analysis undermines the assumption, accepted by many in the scientific community on climate change, that income diversification is a form of sustainable adaptation. This is illustrated, for example, by the insecurity and instability of the off-farm income of small and medium farmers in Mendoza, and the increased work pressure on producers in Canada. This highlights the difficulties of making misleading theoretical generalizations without considering specific characteristics of contexualized cases.

Adaptation based on seed handling to get more resistant varieties deserves special attention. New seed varieties promising drought or flood resistance are often patented by corporations and this triggers an agricultural model that is technologically dependent and unsustainable (they demand many agrochemicals, usually petroleum-based), economically dependent (producers remain tied to royalties) and in broader terms this could lead to a food dependency model. In all three countries, the increasing dependence on patented seeds and agro-chemical inputs has important implications for future sustainable development. If adaptation and agricultural development practices are based on an environmentally unsustainable foundation, adaptation ultimately works against longer-term mitigation of future climate extremes, causing a cyclical effect that paradoxically increases vulnerability over the long term. Further, the high financial costs of such adaptation negatively affect farmers' economic capital, a key determinant of their adaptive capacity.

Government institutions acquire a similar character in Colombia and Mendoza, granting subsidies to producers, especially small ones. Such practices help, but are really insufficient and especially do not contribute to building producers' capacity or enhancing their access to critical resources necessary to generate genuine adaptations. In Canada, the divestment of government from agricultural support programs seriously affects the capacity to invest in irrigation and environmentally sustainable adaptive practices.

Conclusions

Farmers in the three basins have adopted a variety of adaptive strategies to reduce the negative impacts of climate variability. Many practices implemented by farmers help them to better cope with climatic events and do have a positive impact on crop yield. Access to improved seeds and irrigation infrastructure in the studied areas generate significant benefits for coping with extremes that affect each location.

But adaptation always has an economic cost. A number of factors associated with producers' economic and financial resources prevent (or facilitate) the implementation of adaptive strategies. Our comparative analysis illustrates that the impact of climate crisis (variability and extreme events) is strongly determined by economic conditions. One of the most important conditions in all three countries is the price of inputs. Commodity prices, which are determined primarily by international markets in all three countries, also have a powerful influence on adaptation. While high commodity prices may be able to save a poor harvest, as happened in Colombia in 2011, low prices can diminish or cancel out the success of certain adaptations.

Although the findings are specific have a limited and bounded extent to the studied areas, the analysis confirms the relevance of studying adaptation and resilience at the intersection of social, political and economic dimensions and physical factors. Adaptation assessment must be contextualized within broader socioeconomic processes that seriously condition adaptability. The paper reinforces a call to develop an approach that highlights certain dimensions that single discipline approaches fail to problematize, especially considering non-climatic aspects of the problem.

Further, another main finding of this study is the confirmation that not all adaptation strategies are equally beneficial. Our research also reveals that adaptations are not linear processes. Both the producers' own adaptations as well as adaptive policies have indirect impacts on actors, natural resources and ecosystems. Adaptation is a process of synergies and trade-offs: zero-till reduces soil erosion but may degrade it with agro-chemicals; the use of more resistant crop varieties generates technological dependence and increases input costs; efficient use of water or new water sources increases the demand for the resource.

Addressing this non-linearity of the adaptation process has critical implications for future studies and policies to foment adaptation: they must necessarily incorporate an assessment of those trade-offs. This indicates the need to seriously consider questions about *adapting to what, why, and with what consequences*.

While it is true that a measure of benefit to one group may disadvantage another, it should also be noted that the adaptive capacities of producers are often shaped by factors that, at the surface, appear to have little direct connection to the climate or environment but can dramatically affect both current and future vulnerability.

Our study supports the idea that there are no universal determinants generating sustainable adaptation in all cases. Technology, capital, institutional capital, and income diversification in general can strengthen adaptive capacities. However the actual impact of each of these determinants depends on the characteristics of local contexts. Therefore, it will not be possible to establish an all-purpose menu of practices and recipes that are successful in all cases.

Adaptation is a local and dynamic phenomenon. Therefore, practices that are successful in one place for coping with climate variability may not be feasible in other places; the measures that prove to be adaptive now may not be adaptive in the future. Hence, it may not be possible to replicate elsewhere the adaptation measures identified in this study. However, this work can alert other researchers and policy makers about going beyond the technical aspects of adaptation. Our study highlights the importance of context-specific social, economic and political factors that make some social groups more susceptible to climate variability than others and generate unequal access to adaptation measures planned by institutions. We must also anticipate the unexpected effects of adaptation as increasing production costs, the proportion of large holdings, the dependence on multinationals that provide seeds and agrochemicals and the loss of rural jobs. For this reason, it is necessary to explore further adaptation models based on agro-ecological principles that reduce the dependence on external inputs to the farm, enrich the biodiversity of the agricultural ecosystem, preserve natural ecosystems and ensure food sovereignty of communities.

Reduction of sensitivity to climate variability can only be achieved by reducing poverty and social inequalities. A rural population with high levels of resources, equality, and social infrastructure will be better prepared to cope with climate variability and may recover more quickly from the effects of extreme weather events. Adaptation, in these circumstances, is likely the result of a negotiation between the traditional knowledge that was successful to cope with climate variability in the past and the most innovative technical proposals of institutions dealing with issues relating to the environment, water and agriculture.

References

Adger WN (2003) Social aspects of adaptive capacity. In: Smith JB, Klein RJT, Huq S (eds) Climate change: adaptive capacity and development. Imperial College Press, London, pp 29–50

Agrawal A, Perrin N (2009) Mobilizing rural institutions: a comparative study of rural institutions for improving governance and development: Afghanistan, Ethiopia, India, Vietnam, and Yemen, Social development. World Bank, Washington, DC, p 80

Alasia A, Bollman RD (2009) Off-farm work by farmers: the importance of rural labour markets. Statistics Canada, Ottawa, ON, Retrieved from http://dsp-psd.pwgsc.gc.ca/collection_2009/statcan/21-006-X/21-006-x2008001-eng.pdf

Bassett TJ, Fogelman C (2013) Déjà vu or something new? The adaptation concept in the climate change literature. Geoforum 48:42–53

Below TB, Mutabazi KD, Kirschke D, Franke C, Sieber S, Siebert R, Tscherning K (2012) Can farmers' adaptation to climate change be explained by socio-economic household-level variables? Glob Environ Chang 22(1):223–235. doi:10.1016/j.gloenvcha.2011.11.012

CNA (2002) National agricultural census. National Statistics and Census Institute, Ministry of Economy. http://www.indec.mecon.gov.ar/agropecuario/cna_principal.asp

FNC (Federación Nacional de Cafeteros de Colombia) (2015) Colombia produjo 12,3 millones de sacos de café en los últimos doce meses. Retrieved from http://www.federaciondecafeteros.org/particulares/es/sala_de_prensa/detalle/colombia_produjo_123_millones_de_sacos_de_cafe_en_los_ultimos_12_meses1/. Accessed 6 Apr 2015

Dietz K (2013) Hacia una teoría crítica de vulnerabildad y adaptación. In: Ulloa A, Prieto AI (eds) Culturas, conocimientos, políticas y ciudadanías en torno al cambio climático. Universidad Nacional de Colombia, Bogotá, pp 19–46

Eriksen S, Aldunce P, Bahinipati CS, Martins RD, Molefe JI, Nhemachena C, O'brien K, Olorunfemi F, Park J, Sygna L, Ulsrud K (2011) When not every response to climate change is a good one: Identifying principles for sustainable adaptation. Climate Dev 3(1):7–20. doi:10.3763/cdev.2010.0060

Farfan Valencia F (2013) Guía para el establecimiento de barreras con árboles y sombrío del café. Avances Técnicos Cenicafé 428:8

Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (2012) Managing the risks of extreme events and disasters to advance climate change adaptation. Cambridge University Press, New York, NY

Galindo Leva LÁ, Villegas García C, Mantilla Afanado J (2013) Lepidópteros perforadores de los frutos del café. Avances Técnicos Cenicafé 434:8

Garcia Pineda AF (2013) Vulnerabilidad y adaptación al cambio climático en la caficultura colombiana. In: Ulloa A, Prieto AI (eds) Culturas, conocimientos, políticas y ciudadanías en torno al cambio climático. Universidad Nacional de Colombia, Bogotá, pp 107–142

Glasser B, Straus A (1967) The discovery of grounded theory: strategies for qualitative research. Aldine Publishing Company, Hawthorne, NY

IPCC (2007). In: Core Writing Team, Pachauri RK, Reisinger A (eds) Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Geneva, p 104

IPCC (2015) Climate change 2014: synthesis report. In: Pachauri RK, Meyer LA (eds) Contribution of working groups 1, II, and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Geneva

Jaramillo Robledo Á, Ramírez Builes VH (2013) Gestión del riesgo agroclimático. Fuentes de amenaza climática para el café en Colombia. In: Marín SM (ed) Manual del cafetero colombiano. Investigación y tecnología para la sostenibilidad de la caficultura. Federación Nacional de cafeteros de Colombia, Cenicafé, Manizales, pp 73–89

Jetté-Nantel S, Freshwater D, Beaulieu M, Katchova A (2011) Farm income variability and off-farm diversification in Canadian agriculture. Statistics Canada, Ottawa, ON

Lozoya JP, Sardá R, Gimenez J (2011) A methodological framework for multi-hazard risk assessment in beaches. Environ Sci Policy 14:685–696

Marchildon GP, Kulshreshtha S, Wheaton E, Sauchyn D (2008) Drought and institutional adaptation in the Great Plains of Alberta and Saskatchewan, 1914–1939. Nat Hazards 45(3):391–411. doi:10.1007/s11069-007-9175-5

McLeman RA, Dupre J, Berrang Ford L, Ford J, Gajewski K, Marchildon G (2013) What we learned from the Dust Bowl: lessons in science, policy, and adaptation. Popul Environ. doi:10.1007/s11111-013-0190-z

Mearns R, Norton A (2010) Social dimensions of climate change: equity and vulnerability in a warming world. World Bank, Washington, DC, p 319

Montaña E (2008) Central Andean foothill farmers facing global environmental change. IHDP 2: 32–40

Oliveros TCE, Sanz UJR, Ramírez GCA, Tibaduiza VCA (2013) ECOMILL. Tecnología de bajo impacto ambiental para el lavado del café. Avances Técnicos Cenicafé 432:8

Poveda G (2001) La hidroclimatología en Colombia. Una síntesis desde la escala interdecadal hasta la escala diurna. Revista Academia Colombiana de Ciencias Exactas, Físicas y Naturales XXVIII, 107:201–222

Poveda G, Jaramillo Á, Gil MM, Quiceno N, Mantilla R (2001) Seasonality in ENSO-related precipitation, river discharges, soil moisture, and vegetation index in Colombia. Water Resour Res 37(8):2169–2178

Poveda G, Álvarez DM, Rueda OA (2011) Hydro-climatic variability over the Andes of Colombia associated with Enso: a review of climatic processes and their impact on one of the Earth's most important biodiversity hotspots. Climate Dynam 36:2233–2249

Poveda G, Turbay S, Vélez JJ, Ocampo OL, Acevedo E, Bedoya M (2014) ¡No sé qué vamos a hacer con estos climas! Vulnerabilidad y adaptación a las variaciones climáticas extremas en la cuenca de la quebrada Los Cuervos, afluente del río Chinchiná. Universidad Nacional de Colombia, Universidad de Antioquia, IDRC-CIHR-NSERC, Medellín

PSRB Partners for the Saskatchewan River Basin (2009) From the mountains to the sea: the state of the Saskatchewan River Basin. Saskatchewan. Retrieved from http://www.saskriverbasin.ca/page.php?page_id=70. 12 Apr 2015

Ramírez Builes VH, Gaitán Bustamante Á, Benavides Machado P, Constantino Chaure L, Gil Palacio Z, Sadeghian Khalajabadi S, González Osorio H (2014) Recomendaciones para la reducción del riesgo en la caficultura en Colombia ante un riesgo climático de El Niño. Avances Técnicos. N. 445. National Coffee Research Center—Cenicafé Manizales, pp 1–12

Silva Restrepo S (2013) Evaluación de impacto de los programas de renovación de cafetales 2007–2011; efectos en la capacidad productive de los caficultores colombianos. Ensayos de Economía Cafetera 29:37–78

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang 16(3):282–292. doi:10.1016/j.gloenvcha.2006.03.008

Smit B, Burton I, Klein RJT, Wandel J (2000) An anatomy of adaptation to climate change and variability. Clim Change 45:223–251

Statistics Canada (2006) 2006 census of agriculture. Government of Canada. Ottawa, ON. Retrieved from http://www.statcan.gc.ca/ca-ra2006/index-eng.htm. 12 Apr 2015

Statistics Canada (2011) 2011 census of agriculture. Government of Canada, Ottawa, ON. Retrieved from http://www.statcan.gc.ca/daily-quotidien/120510/dq120510a-eng.htm. 12 Apr 2015

Turbay S, Cruz BN, Vallejo FJ, Vélez JJ, Ocampo OL (2014) Adaptación a la variabilidad climática entre caficultores de las cuencas de los ríos Porce y Chinchiná, Colombia. Investigaciones Geográficas 85:95–112. doi:10.14350/rig.42298

UNEP (2013) PROVIA guidance on assessing vulnerability, impacts and adaptation to climate change. http://www.unep.org/provia/RESOURCES/Publications/PROVIAGuidancereport/tabid/130752/Default.aspx. Accessed 13 Apr 2015

Wandel J, Pittman J, Prado S (2010) Rural vulnerability to climate change in the South Saskatchewan River Basin. In: The new normal: the Canadian Prairies in a changing climate. University of Regina Press, Regina, SK, pp 245–258

Wisner B, Blaikie P, Cannon T, Davis I (2003) At risk: natural hazards, people's vulnerability and disasters, 2nd edn. Routledge, New York, NY