Journal of Arid Environments 147 (2017) 144–154

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Can warmer be better? Changing production systems in three Andean ecosystems in the face of environmental change

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ARTICLE INFO

Article history:
Received 6 February 2016
Received in revised form
27 August 2017
Accepted 31 August 2017
Available online 22 September 2017

Keywords:
Local knowledge
Climate change
Andean production systems
Adaptation
Risk perceptions
Bolivia

ABSTRACT

Andean farmers have always faced high levels of climate-related risk and have produced a wide range of resilient crops and animals to subsist under harsh ecological conditions. In recent decades, changing climatic and economic conditions have challenged farmers in the region. In response, farmers have changed their production systems. The present study outlines some of the risks farmers faced in four Andean ecosystems and examines how they have adapted production systems to changing risks over the past 20 years. Their adaptation strategies were evaluated using participatory research methods and cost benefit analysis. To date, most farmers have been able to successfully adapt to changing climatic and economic conditions in ways that usually improve their livelihoods. These improvements are largely due to their abilities to take advantage of warming trends and new markets to produce higher value crops than in the past. These strategies may not be as effective as temperatures continue to rise. Understanding farmer adaptation strategies at the micro-level can help policy makers and planners identify how they can assist adaptation in the future and will help point to challenges in the future.

Agriculture is one of the sectors most directly affected by climate change. The negative impacts of climate change on agriculture are likely to be greatest in developing countries because of weak disaster management and planning institutions, limited financial resources and a heavy dependence on rain-fed agriculture (Rockström and Falkenmark, 2000). A large number of studies, projections and reports have examined the average impact of climate change at global, regional and national levels (Jones and Thornton, 2003; Parry et al., 2004; Blázquez and Nuñez, 2013; Seo and Mendelhson, 2008). However there is limited information and effort addressing local climate change impacts and reactions to it, even though this is crucial for assisting farmer adaptation strategies. The scant amount of research may partly be due to a lack of historical and point climate data and associated problems (Thornton et al., 2010) and to site-specific constraints faced by producers which determine their actual adaptation capacities. Country-level assessments based on macroclimatic modeling need relatively modest information; micro level studies require finer more detailed data. This is even truer for mountainous areas where altitude is not the sole factor affecting the characteristics of local climates. They are also strongly shaped by solar exposure, orientation, ascendant fluxes, etc. As such, problems related to the uncertainty of climate projections and how this can be appropriately treated to obtain more realistic results are unsolved (Hallegatte, 2009; Wilby et al., 2009). This limits the value of quantitative forecasts of climate change crop yields and associated changes (Challinor et al., 2009).

Most studies of agriculture adaptation to climate change have focused on responses to disaster or promotion of actions in response to model projections. As such, climate impact studies have consistently predicted extensive effects of climate change on agriculture (Pearce et al., 1996; Tol, 2002). Other studies have indicated a reduction of crop yields when warmer temperatures occur, mainly due to average water deficits and/or the impacts of extreme events (Reilly et al., 1996; McCarthy et al., 2001). However, these studies assume that farmers are passive elements in production systems. These studies underestimate farmer's adaptive capacities by assuming they cannot change their cropping systems without significant outside help and that they have not already made significant changes to their cropping systems in response to changing environmental and market conditions. Thus, these studies predict large average yield and revenues losses due to climate change

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http://dx.doi.org/10.1016/j.jaridenv.2017.08.005
0140-1963/

because they disregard how impacts are nonhomogeneous and overlook successful local adaptations.

Climate and global changes are already impacting physical, biological and social systems. Consequently, farmers have already reacted to recent climate changes (Rosenzweig et al., 2008), often in positive ways. Understanding the logics, mechanisms and effects of these farmer's actions should indicate the direction that adaptation actions should take to be successful in the future. Thus more detailed information is needed, there is need for detailed information, particularly for developing countries, on the likely impacts of and responses to climate change (Moore et al., 2009). There are relatively few publications on the specific actions farmers have taken over to adapt to climate change in recent decades. The most common practices are the adoption of drought resistant crops and better water management techniques in Ethiopia (Kelbessa, 2001), Burkina Faso (Barbier et al., 2009), and South Asia (Kumar et al., 2016). There has also been a shift to higher crops in sub-humid tropical Africa (Sanchez, 2000); in Pakistan (Rahut and Ali, 2017), and South Asia (Kumar et al., 2016). Most studies of adaptation only describe adaptation strategies, but some such as Lei et al. (2016) have shown that adaptation can lead to improved livelihoods.

The impacts of climate variability on Altiplano farming systems has been documented (Valdivia et al., 2007, 2010; Perez et al., 2010; Sietz et al., 2012). Farmers in the Altiplano have always faced recurrent droughts, floods and frosts but climate change is presenting new challenges to crop production such as increased pressure from pests and plant disease and shifts in the onset and intensity of rains. Many of these studies conclude that adaptation strategies based on farmer's own decisions could have a higher probability of success.

Some reports indicate that climate change is leading to new forms of commercial agriculture in the Andes that can be seen as local autonomous adaptations. Several studies of the Bolivian Altiplano report production system changes in the last two decades, mostly in response to climate change (Valdivia and Jetté, 1996; Valdivia et al., 2010; Taboada et al., 2014), but little is written on the logics behind these changes. It is important to consider that temperatures and precipitation are not the only driving factors affecting farming decisions in the Andes and elsewhere in the world. Market changes have also strongly affected the high Andes farm decision process. As such, the effects of climate change on crop production and, by implication, on household livelihoods are not always clear-cut nor are they always negative (Chaplin, 2009). Understanding current adaptations can help policy makers and others charged with designing and implementing adaptation strategies at the national, regional and local levels to reduce the negative consequences of climate change and to benefit from the opportunities that these changes present (Smit and Pilifosova, 2001; Agrawala and Fankhauser, 2008).

The research presented here was conducted in four ecosystems in Bolivia's Northern and Central Altiplano. Its goals were to understand the changing conditions and risks small holders face in these ecosystems in Bolivia's Central and Northern Altiplano, describe changes in their production systems taken in response to these changes and to evaluate the efficiency of some adaptive strategies by using cost-benefit analysis (CBA). The research is based on participatory research processes designed to link local and scientific knowledge.

1. Background

Bolivia is a typical tropical mountainous country, where the Andean slopes dominate climate and topography. The Andes extend vertically from the highlands (6500–3500 m.a.s.l.) to the valleys (3500–800 m.a.s.l.) towards the lowlands (<800 masl.). The high Andes include a very important agricultural region and is home of most of Bolivia's rural population. This area is highly affected by the temperature changes related to altitudinal differences and exposure to sun radiation. The high altitude increases air transparency and reduces energy retention. Thus, direct sunlight strongly shapes daily maximum temperatures (Tmax); likewise, air humidity determines minimum nighttime temperatures (Tmin). Areas with higher humidity have higher Tmin, because they retain more energy during the night. Precipitation gradients are also of importance; on average, there is a rainfall gradient from North to South and from East to West. However, many inter-Andean valleys are prevented from receiving humid air from the East and are drier than nearby open western slopes. Consequently, high Andes locations at the same altitude but with different exposure may have different climates.

Previous studies have examined the processes of long term temperature and rainfall change in the Altiplano. García et al. (2004) and Valdivia et al. (2010) analyzed historical trends using a long term homogenous data set of monthly Tmax, Tmin, daily precipitation (PP) and Reference Evapotranspiration (ETo). We compared these trends to qualitative results coming from surveys conducted in several rural communities in the area. Trends in Tmax and Tmin (Fig. 1 Annex 1) indicated some general warming over the last 50 years. Interestingly, the spatial structure of these trends varies; some cooling in terms of Tmin occurred in the Southern Altiplano, while significant increases in Tmax and Tmin were found in the Central and Northern Altiplano. The cooling trends in Tmin in the Southern Altiplano may be related to the clearing of lands for quinoa production in response to booming quinoa prices which has increased the bare soil area and has reduced natural vegetative cover. This could be reducing relative humidity which would lead to increased radiative cooling at night. These phenomena are not observed in the Central and Northern areas where land use has not changed dramatically.

In contrast to Tmin, the authors report that Tmax has increased more uniformly across the entire region. Seiler et al. (2013) also analyzed Tmax trends over the past 30 or more years. They also found some cooling close to the Titicaca Lake. The overall warming trend in Tmax may be related to greenhouse warming. Finally, annual precipitation exhibited little total historical change in the entire area. As a result of increasing Tmax, a trend of rising values of ETo was found for the entire region, although the impacts are larger in the Southern and Northern Altiplano and less significant in the Central region. Unchanging rainfall tied to increasing atmospheric demand rates (ETo) results in increasingly drier air over the high Bolivian Andes (Fig. 1b annex), which could affect the water availability for crops in the soil.

Valdivia et al. (2010) and Garcia et al. (2013) also evaluated the results of 12 General Circulation Models for the Altiplano region. These results were similar to those obtained from analyzing historical temperature data. The projections show mean temperature increases of 1.5 °C by 2020–2030 and even greater increases by the end of the century. These models also show negligible changes in mean precipitation are projected (see Figs. 1 and 2). However, when seasonality was analyzed, the early rainy season (Sept. through Nov.) was projected to be drier and the peak rainy season (Jan. through Mar.) to be wetter than at present, suggesting that the dry season could extend into what is now the early rainy season. This could be due to the weakening of the tropical circulation (Seth et al., 2010) and implies a shift toward a later and stronger rainy season (Thibeault et al., 2010). A previous long term analysis of the rainy season duration in the Altiplano (García et al., 2007) suggests that a delayed onset of the rainy season would result in increased crop water stress during and after the planting period.