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Virtual experiments using a participatory model to explore interactions between climatic variability and management decisions in extensive grazing systems in the basaltic region of Uruguay

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ABSTRACT

Agricultural production in "open-sky systems" such as extensive cattle ranching on natural grasslands is subject to inter-annual climatic variability and other market fluctuations. To tackle the dependency of livestock breeding on these factors, we conducted participatory modeling with cattle producers in Uruguay. The methodology consists of simulating possible scenarios to collectively evaluate the different herd management practice alternatives. In this paper, we present an Agent-Based Model built with stakeholders and designed to represent a breeding system on a typical extensive grazing area in the basaltic soils region (BR) of Uruguay. This model has three main modules: environment, biophysical and decisional sub-models. This modularity allows the conducting of virtual experiments to reveal how some herd management decisions (such as seasonal stocking rate adjustments) combined with a climatic series can result in resilience against drought periods and market movements. Long-term simulations were implemented to analyze the sensitivity of the model to key management parameters with varying climate conditions. The inter-annual climatic variability can seriously affect cattle production, even with conservative stocking rates. Rigid strategies are bound to fail and cause systems to break. Adaptive management emerged as a critical option for the sustainability of livestock breeding. The inter-annual climatic variability can seriously affect cattle production, even with conservative stocking rates. This result highlights the importance of adaptive management, one that can react to a changing environment, for the sustainability of livestock breeding.

1. Introduction

Generally speaking, grassland beef production involves complex systems that are not always easily understood (Vayssières et al., 2011; Turner et al., 2013). Forage production in those systems, which determines animal production, is controlled primarily by precipitation (Gillard and Monnypenny, 1990; Diaz-Solis et al., 2005). Moreover, in extensive systems, the most representative kind of beef farms in Uruguay (DIEA, 2003), climate variability is a significant stress driver at the farm level beyond animal, forage and soil management.

As reviewed by Thornton et al. (2009), changes in the frequency and severity of extreme climate events (e.g., increasing frequencies of heat stress and drought events) will have significant consequences for food production. There is a general agreement that when facing such hazards, the grass growth and animal responses are very complex, and changing variances in the system may be as important as changing means. Moreover, Thornton et al. (2009) noticed a strong relationship between drought and animal death in rangelands areas. For instance, in Uruguay, a historic drought episode (summer 1988/1989) caused a 15.6% mortality increase in the national herd (OEA/BID/OPP, 1992), and in recent drought episodes (2006, 2008 and 2009), the economic losses were severe at the national level, with estimations of losses in the several hundreds of millions of dollars (OPYPA, 2009). This phenomenon was particularly pronounced in the north-east region of the country, an area with predominantly basaltic soils (Fig. 1) and comprising

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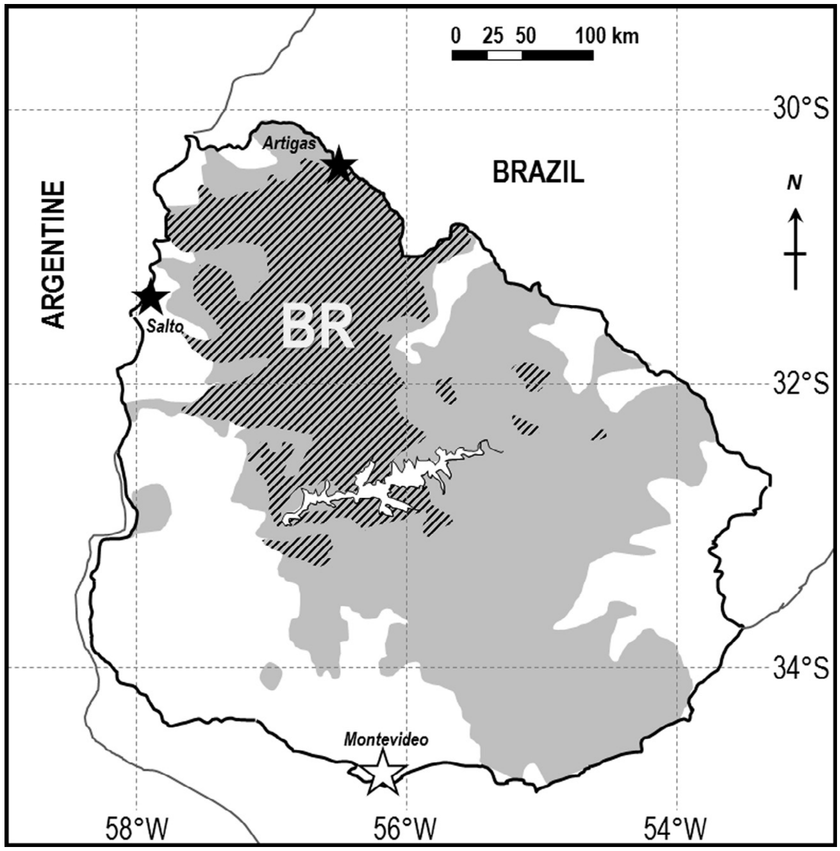

Fig. 1. The Basaltic Region of Uruguay (BR: diagonal bar-filled area). The gray, filled area represents the location of extensive cattle farms (adapted from DIEA, 2000).

25% of the total area of the country. As a reference, the basaltic soils region (BR) of Uruguay has an average carrying capacity of 0.8 Livestock Units ha^{-1} (Pereira, 2011), but this capacity can be seriously reduced by climatic stress. In agreement with Gillard and Monnypenny (1990) drought and stocking rate are interrelated because the downside risk during a drought is highest on heavily stocked farms.

The average BR annual temperature is 18.1 °C with a range of 24.1 and 12.5 °C (maximal and minimal mean respectively). Average rainfall is 1320 mm at year, with seasonal amounts of 365, 426, 180 and 350 mm for summer, fall, winter and spring, respectively. The inter-annual variability is large, with variation coefficients of 44, 41 45 y 29% for each season, respectively (Bettolli et al., 2010). In the BR, the water-holding capacity of soils is less than 40 mm, and evaporation can be five times above this figure in the summer months (INIA, 2013).

Considering the link between climatic parameters and natural pasture growth at the BR, Cruz et al. (2007) reported a large inter-annual variability coefficient (30–50%) in grass dry matter production. These results of pasture growth where statistically related ($p < 0.05$) with inter-annual climatic parameters like total rainfall volume, frequency of precipitations and maximal and minimal temperature records (Royo Pallarés et al., 2005). Even more, Cruz et al. (2007) concluded that water becomes a limiting factor to pasture growth in superficial soils of BR-mainly in spring- and it can affect the familiar farms sustainability enhancing their vulnerability to extreme climatic events.

In that sense, Bartaburu et al. (2009) note that the recent effects of climatic variability have created high levels of uncertainty and anxiety among many farmers in the BR, in agreement with Stafford Smith et al. (1998). These authors document that stock management during droughts is a major, anxiety-provoking decision; but if stock numbers are assessed and adjusted every year -as a tool to adaptation to climatic variability- then the drought year response is just one end of a continuum of regular decisions. Performance benchmarks are a route into this behavioral change. This farmer's anxiety, combined with increased interest from the scientific community, has resulted in an increase in the search for tools that can accelerate knowledge integration and improve adaptation (Stafford Smith et al., 1998; Lynam and Stafford-Smith, 2003).

According to Turner et al. (2013), the systems approach can be used to analyze management decisions about production that are not actually put in practice. Modeling is also an essential tool for representing the bio-complexity of agricultural systems and providing information that can assist farmers and stakeholders in making decisions in participatory research (Le Gal et al., 2010; Vayssières et al., 2011). Considering the development of tools for farmer adaptation to climatic variability, a strong antecedent is the "DrougthPlan" developed by the Commonwealth Scientific and Industrial Research Organization-Australia (Stafford Smith et al., 1998). Authors consider the need to manage all forms of risk in "good" and "bad" years, and to bear in mind drought management before, during and after the drought period itself. This was summarized in a framework for research, development and extension, in a context of participatory problem solving based on action learning principles and focused on real management decisions. Other authors (Johnston et al., 2000) mention that the management of stocking rate in rangelands with variable climate is very important for the sustainability of grazing enterprises, including the use of "safe" carrying capacity, flexible grazing management, tactical grazing management and tactical "rest" of pasture.

Since the 1970s, there has been a panoply of farm models built with several and different diverse aims (Joandet and Cartwright,