Agriculture, Ecosystems and Environment 199 (2015) 301–311

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Agricultural diversity to increase adaptive capacity and reduce vulnerability of livestock systems against weather variability – A farm-scale simulation study

G. Martin [a,*], M.A. Magne [a,b]

[a] INRA, UMR 1248 AGIR, Castanet Tolosan F-31326, France
[b] ENFA, UMR 1248 AGIR, Castanet Tolosan F-31326, France

ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form 29 September 2014
Accepted 1 October 2014
Available online 24 October 2014

Keywords:
Farming systems
Adaptive capacity
Adaptation
Resilience
Climate change
Agroecology

ABSTRACT

Greater diversity (i.e., variety, balance and disparity) within agricultural systems is often suggested as a solution to promote redundancy within such systems and therefore increase their adaptive capacity and reduce their vulnerability against climate change and variability. Yet this assumption relies upon the gathering and integration of field- and herd-scale results at the farm scale. We have conducted a farm-scale simulation-based study to evaluate the potential for increasing adaptive capacity and reducing vulnerability of livestock systems to weather variability through increase of their agricultural diversity. We manipulate in the simulation, factors of change in the livestock systems resulting in less diverse and more diverse livestock systems to be simulated. We assume, a priori, that certain combinations of the factored system components bring redundancy in the system and in turn increase its adaptive capacity and reduce its vulnerability against weather variability. Simulated factors of change are: F1: a change in the ratio of the area mechanically harvested (vs. grazed) to the whole farm area; F2: a change in the crops and grassland types grown or in the distribution of the area between crops and/or grassland types; F3: a change in calving periods from one season to another. The simulation plan includes a baseline scenario without changes and scenarios corresponding to all possible combinations of F1–F3. These scenarios are applied to four livestock systems located on a diagonal across France over a succession of four years with varying weather conditions. In these systems, self-sufficiency for forage is jeopardized by unfavorable years, and this may increase animal feeding costs. Thus we consider that adaptive capacity increases and vulnerability decreases as long as self-sufficiency for forage is achieved without increasing animal feeding costs. Results confirm the potential for increasing adaptive capacity and reducing vulnerability of livestock systems to weather variability through increase of their agricultural diversity. For instance, F2 has three main kinds of impacts on self-sufficiency for forage: (i) it yields significant average improvements by 34%, 43%, 36% and 36% across livestock systems for the four successive years, (ii) it buffers year-to-year variations and (iii) the final level of self-sufficiency is higher than the initial one even after two years with unfavorable weather conditions. Moreover, simulated changes do not increase animal feeding costs. Thus our results provide empirical evidence at the farm scale to supplement literature reviews based on field- and herd-scale results. They also confirm that through easily implementable on-farm changes, adaptive capacity can be increased and vulnerability of agricultural systems to weather variability decreased.

1. Introduction

One of the major challenges of the current century lies in the increase and security of food production in the context of climate change. Along with climate change, weather variability, i.e., the variation in the climatic parameters of a region about its long-term means, is growing (IPCC, 2007). Following this trend, heat waves and droughts as witnessed in 2003 are expected to increase by the end of the 21st century in central and southern Europe (Beniston and Diaz, 2004; Reidsma et al., 2010). In a changing climate, the primary and immediate effects on nature and human society result from variability rather than from averages (Katz and Brown, 1992). Applied to agriculture, climate change and weather variability directly and indirectly affect the biology of living organisms

* Corresponding author. Tel.: +33 5 61 28 54 52; fax: +33 5 61 73 55 37.
E-mail address: guillaume.martin@toulouse.inra.fr (G. Martin).

http://dx.doi.org/10.1016/j.agee.2014.10.006
0167-8809/

(plants, animals in pastoral and extensive livestock production systems, etc.) and as a consequence, their ability to produce food and fiber (Tubiello et al., 2007; Nardone et al., 2010).

An increasing body of literature aims at identifying ways to reduce the vulnerability of agricultural systems to climate change and weather variability (Howden et al., 2007; van Vuuren et al., 2011). The vulnerability of any system (at any scale) is considered as a function of the exposure and sensitivity of that system to a specified hazard or range of hazards and the adaptive capacity of the system to cope with, adapt to, or recover from the effects of those conditions (Smit and Wandel, 2006; Turner et al., 2003). More precisely, exposure usually refers to the duration, extent and frequency of climatic perturbations influencing the system (Adger, 2006). Sensitivity is the degree to which the system responds to such perturbations (Gallopín, 2006). Exposure and sensitivity determine the potential impacts that occur, given the projected climate change and variability, without considering adaptation. The actual impact is the impact that remains after accounting for adaptation (Reidsma et al., 2010). The adaptive capacity is the degree to which a system can adjust its practices, processes, or structures to moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate (Schneider et al., 2001). Vulnerability, its three constituent elements (exposure, sensitivity, adaptive capacity) and their determinants are dynamic and are manifested in specific places at specific times (Adger, 2006).

To reduce the vulnerability of agricultural systems against perturbations such as weather variability, there is a consensus for proposing to increase their adaptive capacity by increasing system diversity and as a consequence, redundancy within the system (Anderies et al., 2013; Biggs et al., 2012; Cabell and Oelofse, 2012; Lin 2011). Diversity refers to "variety: how many different elements, balance: how many of each element, and disparity: how different the elements are from one another" (Biggs et al., 2012). Redundancy means that system components or sub-systems have to display potential for overlapping functions in the face of different types of perturbations (Cabell and Oelofse, 2012). Redundancy is assumed to be brought in by diversity (Biggs et al., 2012).

Applied to agriculture, empirical evidence supporting this hypothesis is strong at the field scale (Loreau et al., 2003; Tilman et al., 2006) and at the herd scale (Lee et al., 2009; Tichit et al., 2011). For instance, Tichit et al. (2011) show that a herd including goats with a diversity of milk production potential and feeding regimes offers a win–win situation between production and efficiency. Empirical evidence supporting this hypothesis is far weaker at the farm scale, with two cases found in the literature (Funes-Monzote et al., 2009; Tengö and Belfrage, 2004). Most published articles on the topic are reviews gathering and integrating field- and herd-scale results at the farm scale (Frison et al., 2011; Lin 2011; Mijatović et al., 2013) and assuming that all field- and herd-scale outcomes will be reproduced at the farm scale without addressing threshold effects implied by scale changes.

At the farm scale, experimentation is hardly feasible to address the studied hypothesis. Simulation modeling is a suitable alternative to address the complexity of the interactions considered. Still, published vulnerability assessments in agricultural science are focused on exposure and sensitivity. They rather ignore adaptive capacity, which is at the core of this study and of major importance in reducing vulnerability (Reidsma et al., 2010). Indeed, simulation models are generally focused on the soil–plant–atmosphere system. When it comes to adaptive capacity, the lack of consideration for farmers' management and their local peculiarities (McCown et al., 2006; Kalaugher et al., 2013) precludes the test of adaptations. In this article, we conduct a simulation-based study at the farm scale to address the following question: can vulnerability of livestock systems against weather variability be reduced and adaptive capacity be increased by system change to a more diverse system? Our hypothesis is that by bringing agricultural diversity and as a consequence redundancy into the system, adaptive capacity is increased and vulnerability is

Table 1
Main characteristics of the four studied livestock systems.

Livestock system	SB	RY	VR	LC
Weather station location	St Brieuc	La Roche sur Yon	Villefranche de Rouergue	Lus la Croix Haute
Farm area (ha)	79	61	49	110
	26 ha crops: −10 ha triticale −14.5 ha meslin −1.5 ha fodder beet 53 ha grassland: *Lolium perenne x Trifolium repens*; *Lolium x Trifolium pratense*; multispecies mix	24 ha crops: −13 ha fodder maize −11 ha wheat 37 ha grassland: *Lolium multiflorum*; *Lolium perenne x Trifolium repens*; multispecies mix; permanent	20,5 ha crops: −5 ha triticale −5 ha wheat −10.5 ha fodder maize 28.5 ha grassland: hybrid ryegrass – *Trifolium pratense*; *Lolium multiflorum*; multispecies mix; permanent	21 ha crops: −1 ha grain maize −6.5 ha wheat −2.5 ha barley −11 ha fodder maize 89 ha grassland: alfalfa; multispecies mix; permanent
Grassland area (%)	67	61	58	81
Stocking rate (AU/ha)	1.30	1.45	1.39	1.00
No. of dairy cows	60	50	35	60
No. of heifers	13	19	10	18
Milk yield (kg/cow/year)	4700	7300	7000	6000
Breed	Prim'Holstein	Prim'Holstein	Prim'Holstein	Montbéliarde
Calving period	Distributed all across the year	Autumn	Autumn	Autumn
Concentrates distributed (g/kg milk)	0	185	174	200
% of grazing in animal diet	61	35	20	42