European Journal of Agronomy 94 (2018) 89–97

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Vulnerability to climatic and economic variability is mainly driven by farmers' practices on French organic dairy farms

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ARTICLE INFO

Keywords:
Organic agriculture
Dairy farming
Farm management
Resilience
Robustness

ABSTRACT

The climatic and economic context of agricultural production is increasingly unpredictable and volatile. These issues raise questions about the vulnerability of agricultural systems, *i.e.* their ability to cope with, adapt to, or recover from the effects of a range of hazards. Applied to organic dairy farming, vulnerability relates to farm productivity and economic efficiency that remain controversial. Our objective was to show whether and how organic dairy farm vulnerability can be reduced by adapting agricultural diversity as well as land-use and herd-management intensities of farm configurations over time, along with contextual changes (both climatic and economic). We analyzed data from 51 organic dairy farms surveyed for 5–14 years in the northwest lowland plains and central mountains of France. Our method considered farm vulnerability as a function of the mean level of, trend in, and variability in productivity and economic efficiency and related these vulnerability variables to explanatory variables that illustrate farm exposure to climatic and economic variability and farm configurations over time using partial least square (PLS) regressions. The animal stocking rate in both regions was positively related to mean farm productivity, whereas concentrate (nutrient-rich feedstuffs *e.g.* soybean meal) distribution was negatively related to mean and trend of economic efficiency. On average, farm productivity responded positively to land-use intensification, but increasing farm economic efficiency required thrifty management and self-sufficiency with regard to animal feeding. Overall, it appeared that tradeoffs among vulnerability variables were driven by farmers' practices rather than by interannual variability in rainfall amounts and energy or milk prices. This reveals that the extent to which farms must adapt to changes in the production context remains large and partly unexplored by most organic dairy farmers.

1. Introduction

The climatic and economic context of agricultural production is increasingly unpredictable and volatile (IPCC, 2013; Wright, 2011). Moreover, the occurrence and impacts of these contextual changes are increasingly variable between farms within a single region (Reidsma et al., 2007). Over time, these issues raise questions about the vulnerability of agricultural systems, *i.e.* their ability to cope with, adapt to, or recover from the effects of a range of hazards (Smit and Wandel, 2006). Vulnerability depends on (i) the exposure of agricultural systems to these hazards, *i.e.* their degree, duration and extent; (ii) the sensitivity of agricultural systems to these hazards, *i.e.* the degree to which they are affected; and (ii) their capacity to cope with, adapt or recover from these hazards. Farm vulnerability is assessed through productivity and profitability by measuring changes in yield or income over several years (Dong et al., 2015; Reidsma et al., 2010).

While the ecological performance of organic farming is now undisputed in research (Schader et al., 2012; Tuomisto et al., 2012), its productivity and economic efficiency remain controversial. The difference in yields between conventional and organic production has been repeatedly reported (de Ponti et al., 2012; Seufert et al., 2012). Restrictions on agricultural practices in organic crop and livestock production may decrease stability of farm productivity over time (Niggli et al., 2015), and this trend is expected to grow along with climate change (IPCC, 2013). Organic farming has also been criticized for having viability problems related to insufficient technical and economic efficiency, as reported for dairy sheep farms in Spain (Toro-Mujica et al., 2011) and dairy cow farms in Finland (Kumbhakar et al., 2009).

Diversification of agricultural systems consists of an increase in the variety *i.e.* how many different crops, pastures, animals, *etc.*, balance *i.e.* how many of each element, and disparity *i.e.* how different the elements are from one another (Biggs et al., 2012). It has frequently been shown to reduce their vulnerability by promoting increased and more stable productivity (Liu et al., 2016; Martin and Magne, 2015;

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https://doi.org/10.1016/j.eja.2018.01.013
Received 13 June 2017; Received in revised form 12 January 2018; Accepted 18 January 2018
Available online 07 February 2018

Ponisio et al., 2014). In some cases, it could also lead to improved technical and economic efficiency (Martin and Magne, 2015). Diversification practices increase yields in organic agriculture (Liu et al., 2016), *e.g.* by 8% for crop rotations (Ponisio et al., 2014). They also tend to stabilize yields under variable climate conditions (Isbell et al., 2015). Diversification practices promote greater internal nutrient recycling. For example, plant associations with root systems that explore soil horizons might reduce fertilizer rates without influencing yields (Zhang and Li, 2003). This kind of benefit could improve technical efficiency and in turn positively influences economic efficiency (Martin and Magne, 2015). Yet diversification could also lead to reduce economies of scale within farms and accordingly farm overall economic performance.

Diversification practices alone do not provide solutions to reduce farm vulnerability. Organic fertilizers are expensive. The main sources of nutrient inputs on organic farms are nitrogen fixation *via* legume crops and the purchase of animal feed in the form of forage and concentrates from livestock farms (Barataud et al., 2015). Internal nutrient recycling is a key issue to achieve productivity and technical and economic efficiency to decrease vulnerability (Bonaudo et al., 2013). Recycling of carbon (C), nitrogen (N) and phosphorus (P) depends strongly on land-use and herd-management intensities. Beyond a site-dependent threshold of land-use intensification, C, N and P cycles become decoupled and associated with losses to the environment (Lemaire et al., 2014; Soussana and Lemaire, 2014). For example, Ledgard et al. (2009) described a doubling of nitrate leaching from 30 to 60 kg $N.ha^{-1}.yr^{-1}$ by increasing milk yields per ha from 13,200 to 15,500 kg $milk.ha^{-1}.yr^{-1}$.

Our objective was to show whether and how organic dairy farm vulnerability can be reduced by adapting agricultural diversity and land-use and herd-management intensities (*e.g.* stocking rate, percentage of cropping area, concentrate distribution) of farm configurations over time, along with contextual changes (both climatic and economic). Examining organic dairy farms in France, we analyzed relations between agricultural diversity, land-use and herd-management intensities and vulnerability in two regions: the northwest lowland plains and the central mountains.

2. Materials and methods

2.1. Case study farms

We performed this study in France. At this country scale, exposure to economic hazards is considered equal among dairy farms but variable over time. In contrast, exposure to climate hazards varies among farms and over time. We analyzed farms in two large French regions, corresponding to two of the main dairy production areas in France (Fig. 1): the northwest lowland plains (West) and the central mountains (Mountains). These two regions have contrasting climates (oceanic vs. mountainous, respectively), ranges of elevation (0–416 vs. 139–4807 m above see level, respectively), types of production systems (high vs. low opportunities for cropping, respectively), and presence of product-quality schemes besides organic specifications (few vs. many Protected Designation of Origin cheeses, respectively).

In France, in the framework of the Réseaux d'élevage program (Inosys, 2016), 261 organic dairy cattle farms in a network were surveyed annually from 2000 to 2013. The number of years surveyed ranged from 1 to 14 years, depending on the farm. Data were collected about key aspects of livestock systems: geographic location, land use, crop and pasture yields, herd structure and management (feeding, reproduction), animal production, and economic revenues and costs. Of the 261 farms, only 79 were surveyed at least 5 years. We assumed it was the minimum time necessary to consider variability in farm productivity and technical and economic efficiency. As we had selected two French regions *i.e.* the West and the mountains, we further restricted analysis to the 51 farms located in these regions, 36 in the West

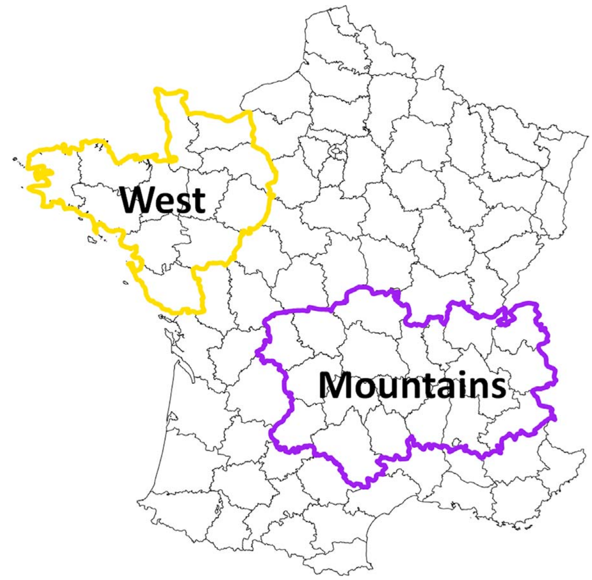

Fig. 1. Locations of the two regions analyzed.

(5 of which were surveyed more than 10 years) and 15 in the mountains (4 of which were surveyed more than 10 years). These farms represented a diversity of climate conditions and production systems since they differed in water deficit, farm size (land area, herd size), land-use intensity (stocking rate, milk production per ha, maize cropping percentage) and herd-management intensity (concentrate distribution, milk production per cow) within and between regions (Table 1).

Both climatic and economic variability occurred during the survey period. The national price index for energy (IDELE, 2017) varied from a minimum of 77 in 2002 to a maximum of 160 in 2012 (index = 100 in 2005), indicating an increasing trend, especially from 2010 to 2011, when the index increased by 22.7. These variations tended to increase farm energy costs but likely those of other inputs (*e.g.* feed, organic fertilizers) as well. Mean milk price also varied considerably during the period, ranging from 284 to 479 €/t in the West and 285–487 €/t in the Mountains. Variability in milk price among farms was also high, with coefficients of variation of 11% in both regions related to differences in milk quality among farms. During the period, milk prices showed an increasing trend. The daily mean difference between rainfall and evaporation tended to decrease in spring and summer during the period, but with high variability among years, ranging for example in the West from −1.68 to 0.7 mm/day in spring and from −2.28 to 0.46 mm/day in summer.

Table 1
Key features of the sample farms in the two study regions.

Feature	West	Mountains
Daily mean water balance in spring (mm)	−0.3 ± 0.7	0.2 ± 1.1
Daily mean water balance in summer (mm)	−1.0 ± 1.0	−0.7 ± 1.5
Farm area (ha)	100.4 ± 51.9	67.6 ± 22.0
Farm area used to feed livestock (ha)	84.6 ± 39.8	59.4 ± 21.1
Number of dairy cows	65.1 ± 26.1	38.1 ± 10.9
Stocking rate (livestock units/ha)	1.26 ± 0.26	0.98 ± 0.22
Maize area (% of farm area)	6.9 ± 6.8	0.9 ± 2.5
Concentrates distributed (kg/livestock unit/year)	604.3 ± 307.3	751.7 ± 245.4
Milk production per ha (kg milk/ha/year)	4317 ± 1366	3420 ± 832
Milk production per cow (kg milk/cow/year)	5312 ± 990	5150 ± 829