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ABSTRACT

Increasing input self-sufficiency is often viewed as a target to improve sustainability of dairy farms. However, few studies have specifically analysed input self-sufficiency, by including several technical inputs and without only focussing on animal feeding, in order to explore its impact on farm sustainability. To address this gap, our work has three objectives as follows: (1) identifying the structural characteristics required by specialised dairy farms located in the grassland area to be self-sufficient; (2) analysing the relationships between input self-sufficiency, environmental and economic sustainability; and (3) studying how the farms react to a decrease in milk price according to their self-sufficiency degree. Based on farm accounting databases, we categorised 335 Walloon specialised conventional dairy farms into four classes according to their level of input self-sufficiency. To this end, we used as proxy the indicator of economic autonomy – that is, the ratio between co...

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Role of input self-sufficiency in the economic and environmental sustainability of specialised dairy farms

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Increasing input self-sufficiency is often viewed as a target to improve sustainability of dairy farms. However, few studies have specifically analysed input self-sufficiency, by including several technical inputs and without only focussing on animal feeding, in order to explore its impact on farm sustainability. To address this gap, our work has three objectives as follows: (1) identifying the structural characteristics required by specialised dairy farms located in the grassland area to be self-sufficient; (2) analysing the relationships between input self-sufficiency, environmental and economic sustainability; and (3) studying how the farms react to a decrease in milk price according to their self-sufficiency degree. Based on farm accounting databases, we categorised 335 Walloon specialised conventional dairy farms into four classes according to their level of input self-sufficiency. To this end, we used as proxy the indicator of economic autonomy – that is, the ratio between costs of inputs related to animal production, crop production and energy use and the total gross product. Classes were then compared using multiple comparison tests and canonical discriminant analysis. A total of 30 organic farms – among which 63% had a high level of economic autonomy – were considered separately and compared with the most autonomous class. We showed that a high degree of economic autonomy is associated, in conventional farms, with a high proportion of permanent grassland in the agricultural area. The most autonomous farms used less input – especially animal feeding – for a same output level, and therefore combined good environmental and economic performances. Our results also underlined that, in a situation of decrease in milk price, the least autonomous farms had more latitude to decrease their input-related costs without decreasing milk production. Their incomes per work unit were, therefore, less impacted by falling prices, but remained lower than those of more autonomous farms. In such a situation, organic farms kept stable incomes, because of a slighter decrease in organic milk price. Our results pave the way to study the role of increasing input self-sufficiency in the transition of dairy farming systems towards sustainability. Further research is required to study a wide range of systems and agro-ecological contexts, as well as to consider the evolution of farm sustainability in the long term.

Keywords: input self-sufficiency, dairy farming, economic sustainability, environmental sustainability

Implications

Dairy farming systems are facing major changes and uncertainty related to price volatility, socio-cultural values and political aspects. At the same time, they are considered as exerting pressure on the environment and animal welfare. Consequently, there is a social demand for developing alternative farming systems. Increasing input self-sufficiency constitutes a possible pathway to design systems that are more sustainable and able to operate in this changing context. In this perspective, it is crucial to understand the role of input self-sufficiency in the sustainability of dairy farms, using an indicator based on several technical inputs – for example, animal feeding, fertilisers and energy.

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Introduction

In recent decades, the development of intensive and specialised livestock farming systems has been called into question due to detrimental effects on animal welfare and the environment (Ten Napel *et al.*, 2011). Moreover, farmers now have to operate in a context characterised by unprecedented change and high uncertainty, such as volatility in agricultural product prices, increases in production costs, changes in agricultural policies and socio-cultural values (Astigarraga and Ingrand, 2011; Dumont *et al.*, 2013). As a consequence, there is currently lively scientific and public debate about the future evolution of livestock production (Bernués *et al.*, 2011) and the development of alternative systems (Dumont *et al.*, 2013).

Several authors agree that increasing self-sufficiency provides one way to develop more sustainable agricultural systems in such an uncertain context (López-Ridaura *et al*., 2002; Vilain, 2008; Bernués *et al*., 2011). Broadly defined, self-sufficiency is '*the capacity of the system to regulate and control its interaction with the environment*' (Bernués *et al*., 2011). Farm self-sufficiency can be considered at three levels as follows (Ruiz *et al*., 2011): (1) decision-making; (2) financial – that is, related to subsidies and debts; and (3) technical – that is, related to the use of external inputs. Our paper specifically focusses on this last level – input self-sufficiency – that Vilain (2008) defined as '*the capacity of a farm to produce goods and services from its own resources, i.e., with a minimal amount of external inputs*'.

Input self-sufficiency is known to have economic, environmental and societal assets. First, in the coming years, the agricultural sector will probably be confronted with an increase in input and energy prices, because of competition for various land uses (*feed, food, fuel*) and depletion of oil resources (Bernués *et al*., 2011). In this context, the most self-sufficient systems will keep lower production costs, giving them a comparative economic advantage. Indeed, systems that are less dependent on inputs are less affected by resource scarcity and price volatility (Bernués *et al*., 2011). Second, because of a lower consumption of inputs such as mineral fertilisers, pesticides and animal feed, self-sufficient systems also have a lower impact on the environment (Vilain, 2008; Raveau, 2011). Finally, from a societal point of view, input self-sufficiency, especially regarding animal feeding, improves the traceability of the products (Paccard *et al*., 2003).

In the literature, input self-sufficiency has often been used as an attribute of sustainability in livestock farming system analyses (e.g. López-Ridaura *et al*., 2002; Ripoll-Bosch *et al*., 2012). It has also been considered as a key principle of agro-ecology for animal systems (Dumont *et al*., 2013), as well as a strategy to improve their resilience (Darnhofer, 2010). However, few studies have focussed on input self-sufficiency of dairy farms, although dairy production usually depends on many inputs (Thomassen *et al*., 2009). Moreover, existing studies have analysed feed self-sufficiency without including other inputs such as mineral fertilisers or veterinary products (see, for instance, Paccard *et al*., 2003). Therefore, some issues related to input self-sufficiency of dairy farming systems need to be assessed in an objective and reproducible way – for example, what are the relationships between input self-sufficiency and economic, environmental and social farm performances? Does input self-sufficiency involve specific structural characteristics? How do self-sufficient farms react to external changes – for example, changes in milk price?

To address these issues, this work has the following three objectives: (1) to identify structural characteristics required by specialised dairy farms located in the grassland area to be self-sufficient; (2) to analyse the relationships between input self-sufficiency, economic and environmental sustainability, as well as to explore whether self-sufficiency allows the farms to conciliate these two sustainability dimensions; and (3) to study the economic impact of a decrease in milk price according to input self-sufficiency. In this article, we address these three objectives through the analysis of the input self-sufficiency of 365 specialised dairy farms located in the grassland area of Wallonia, the southern part of Belgium.

Material and methods

Farm sample

To analyse the relationships between input self-sufficiency, structure, economic and environmental sustainability, we used data derived from two regional farm accounting databases (that is, Agricultural Economic Analysis Department and Walloon Breeders Association). These databases mainly included socio-economic and inputs-related data such as amounts of animal feed or mineral fertilisers.

From these databases, we first selected a sample of 478 specialised dairy farms. Farms were considered as specialised according to the definition of the European typology: in these farms, at least 66% of the total standard gross margin was originated from dairy cattle (European Commission, 2012). On the basis of a diversity analysis, 80 farms were excluded from this set because they were less specialised in milk production (e.g. they had secondary cash crop or meat production activities) or they highly differed from the main farm groups identified (Lebacq *et al*., unpublished results). In order to avoid confusing the effect of input self-sufficiency with that of organic production method, we considered separately conventional and organic dairy farms: 335 conventional dairy farms were used in the core of this study; 30 organic dairy farms were managed independently and characterised at the end of the result section; and 33 farms for which the information – organic or conventional – was not known were excluded from the analysis.

Data were available for 2008 and 2009. The year 2008 was considered as the reference year, and 2009 was used to follow the evolution of economic results in a situation where the milk price drops sharply. Indeed, 2009 was characterised in Europe by an average decrease in the milk price of 24%, compared with 2008 (European Commission, 2014).

Selection of an indicator of input self-sufficiency

Various indicators could be used as proxy to assess input self-sufficiency of dairy farms at farm scale – that is, to assess the extent to which the farms use small or large amounts of off-farm inputs. We considered the following two selection criteria: (1) the indicator should be measurable from the data available in our two databases; and (2) the indicator should not focus only on one input, such as concentrate feed, but include several ones. In addition, indicators expressed per 1000 l of milk were not suitable for our farm sample. Indeed, even if the farms were specialised in dairy production, some of them also had minor secondary activities such as beef, pork, poultry or crop production. Available data did not allow the inputs to be correctly allocated between these different activities. Therefore, indicators expressed per unit of product were not used. From these criteria, we first selected the indicator of economic dependence, which was calculated as follows: the sum of the variable costs of animal (e.g. feed, veterinary products) and crop (e.g. seeds, fertilisers, pesticides) production – excluding contract working – and the fixed costs of electricity and energy (i.e. fuel, lubricants and other energy sources) use, divided by the total gross product excluding subsidies (Raveau, 2011). In order to facilitate the interpretation of the indicator, we calculated an indicator of *economic autonomy* (EA) – that is, 1 – economic dependence. The higher this indicator value, the lesser the farm uses inputs and the more the farm is self-sufficient regarding these inputs.

EA classes and comparison among classes

In 2008, the 335 conventional farms had an average EA of 62 ± 8%[1]. In order to compare farm structure (i.e. land use, scale and intensity of production), economic and environmental performances according to their EA, these farms were categorised into four classes. The classes were defined from the following quartiles of EA in our conventional sample: 57% (quartile 0.25), 62% (median) and 68% (quartile 0.75). The classes were called *Auto*−− (with the lowest degree of EA), *Auto*−, *Auto*+ and *Auto*++ (with the highest degree of EA).

First, these classes were characterised and compared for several structural indicators, using the Kruskal–Wallis and multiple comparison tests. Owing to the characteristics of the farm sample, this characterisation was performed regardless of productive and pedoclimatic constraints: our farm sample only included specialised dairy farms, and 93% of them were located in two agro-ecological regions specialised in dairy production (*Région herbagère liégeois*e and *Haute-Ardenne*), in which the agricultural area (AA) is mainly covered by permanent grassland and forage crops.

In order to compare the sustainability of EA classes, we used the canonical discriminant analysis. This method allows the differences among groups of individuals (here, the EA classes) to be characterised through simultaneously considering several quantitative variables measured on these individuals (here, the sustainability indicators) (Cruz-Castillo *et al*., 1994). To perform this analysis, we used a set of sustainability indicators (Supplementary Table S1) selected according to the process described by Lebacq *et al.* (2013). In order to identify differences among classes according to sustainability performance, we excluded from this set all indicators linked to farm structure, such as stocking rate, permanent grassland area and economic specialisation. As a result, 10 environmental indicators and nine economic indicators were introduced as variables in the discriminant analysis (Supplementary Table S1).

Third, we studied how the farms reacted to the decrease in milk price of 2009, according to their level of EA. We centred this analysis on the farm income per work unit, because it represents a key aspect for maintaining farms in the agricultural landscape. Farm income is the difference between the gross operating surplus – that is, the total gross product (including subsidies) minus variable costs, fixed costs, salary and farm renting – and the financing costs and depreciation. As financing costs and depreciation were not computed in the same way in our two databases, we used the gross operating surplus per familial work unit as proxy for the farm income per work unit. In order to study the evolution of this indicator between 2008 and 2009, we calculated the variation of gross operating surplus per familial work unit between 2008 and 2009 and compared this variation among classes through the Kruskal–Wallis and multiple comparison tests. To help understand how the farmers dealt with this crisis, we also calculated and compared among classes average variations of variable costs, gross product, milk production and input use.

Characterisation of organic farms

As organic farms are part of the agricultural landscape, we aimed to explore the relationship between organic farming and EA. Organic farms had an average EA of 69 ± 9%, similar to the average of *Auto*++ ($P = 0.5$). Moreover, 63% of organic dairy farms had an EA >68% – that is, the border value defining the class *Auto*++. Therefore, we compared the organic farms with the class *Auto*++ for various structural, environmental and economic (including the variation of gross operating surplus per familial work unit between 2008 and 2009) indicators through the Kruskal–Wallis tests.

Results

Characterisation of EA classes

Structural features of each class are shown in Table 1[2]. All classes were similar in terms of workforce, AA, herd size, share of heifers and total milk production. Regarding production intensity, *Auto*++ had lower milk production per hectare and stocking rate than *Auto*−, and lower milk production per cow compared with *Auto*− and *Auto*−−. All classes were forage based, with identical proportions of forage area in the AA. However, the proportions of grassland and maize differed among classes: *Auto*++ had a higher proportion of permanent grassland in the AA, compared with *Auto*− and *Auto*−−, and a lower proportion of maize, compared with *Auto*−−.

From an economic point of view, the four classes had similar gross product, despite a slight increase in the price for the milk delivered to the dairy according to the EA level. *Auto*++ had costs related to electricity use, animal and crop production significantly lower than *Auto*− and *Auto*−−, whereas *Auto*+ showed intermediate average values. The difference between extreme classes *Auto*++ and *Auto*−− was particularly large for costs of animal production (44%). Indeed, *Auto*++ used significantly less dairy cow concentrates. This class also bought less forage than *Auto*−−[3]. Variations of crop production costs among

[1] Mean ± standard deviation.

[2] Residual standard errors are provided in Supplementary Tables S2, S3 and S4.

[3] This result should be interpreted with caution due to the presence of zero values in each class. *Auto*++ included the highest proportion of zero values: 30% against 23%, 10% and 14% for classes *Auto*+, *Auto*− and *Auto*−−, respectively.

Table 1 *Mean structural characteristics of organic and conventional dairy farms according to their degree of economic autonomy (2008)*

	Unit	*Auto*−−[1] ($n = 78$)	*Auto*− ($n = 80$)	*Auto*+ ($n = 96$)	*Auto*++ ($n = 81$)	Organic ($n = 30$)
Workforce	Annual work unit[2]	1.6[a]	1.6[a]	1.5[a]	1.6[a]	1.6
Farm scale and intensity						
Agricultural area	Ha	59[a]	61[a]	57[a]	58[a]	68*
Herd size	Dairy cows	71[a]	80[a]	71[a]	72[a]	56*
Stocking rate	LU/ha[3] forage area	2.7[a,b]	2.9[b]	2.7[a,b]	2.6[a]	1.8*
Share of heifers	% of cows	32[a]	32[a]	30[a]	31[a]	28
Total milk production	l	477 115[a]	539 629[a]	462 599[a]	454 547[a]	305 249*
Milk yield per cow	l/cow	6693[b]	6666[b]	6479[a,b]	6218[a]	5473*
Milk yield per hectare	l/ha agricultural area	8201[a,b]	8890[b]	8230[a,b]	7832[a]	4592*
Land use						
Forage area	% of agricultural area	98[a]	98[a]	98[a]	99[a]	95*
Permanent grasslands	% of agricultural area	86[a]	86[a]	89[a,b]	93[b]	87
Maize	% of agricultural area	10[b]	9[a,b]	8[a,b]	6[a]	1*
Milk price	€/l	0.31[a]	0.32[a,b]	0.33[b]	0.34[c]	0.42*
Gross product (without subsidies)	€	177 165[a]	204 199[a]	179 431[a]	185 930[a]	151 155
Costs included in EA						
Animal production	€	65 362[c]	61 725[c]	46 891[b]	36 349[a]	33 948
Crop production	€	11 372[b]	11 097[b]	9090[a,b]	8620[a]	5295*
Electricity	€	4565[b]	4594[b]	3726[a,b]	3579[a]	3211
Other energy sources	€	4686[a,b]	4567[b]	3785[a,b]	3620[a]	4704*
Input use						
Dairy cow concentrates	kg/1000 l milk	248[c]	221[b,c]	209[b]	171[a]	166
Concentrate autonomy[4]	%	2[a]	4[a]	2[a]	2[a]	13*
Forage purchase	kg dry matter/LU	3918[a]	1012[a]	3133[a,b]	1913[b]	1978
Mineral fertilisers	kg N/ha agricultural area	96[a]	94[a]	86[a]	87[a]	16*
Use of contract work	€/ha agricultural area	202[a,b]	200[b]	174[a,b]	156[a]	119

LU=bovine livestock units; EA=economic autonomy.
[a,b,c]Mean values within a row with different superscripts differ significantly at $P<0.05$.
[1]*Auto*−−: dairy farms with an EA <57%; *Auto*−: between 57% and 62%; *Auto*+: between 62% and 68%; and *Auto*++: >68%.
[2]Annual work units include familial and salaried work units. For familial workforce, 1 work unit is a farmer (or the spouse) who works full time on the farm. For salaried workforce, the value of one work unit corresponds to 1800 h/year.
[3]Livestock units were calculated from regional coefficients based on animal dietary needs.
[4]Proportion of livestock concentrates (in kg) produced on the farm.
*Significant differences between the mean values of organic farms and *Auto*++ farms at $P<0.05$.

classes were not associated with significant differences in terms of nitrogen fertiliser use. *Auto*++ had energy costs smaller than *Auto*−, but did not compensate it by a greater use of contract workers.

Canonical discriminant analysis

The canonical discriminant analysis identified three canonical variables. All were significant – that is, the canonical correlation coefficients were significantly different from 0. The first canonical variable had an eigen value >1 and explained 95.7% of the total between-class variance, against only 2.3% and 2.0% for the second and third variables, respectively (details of the analysis are provided in Supplementary Table S5). It means that the differences among the four classes were important mainly in one direction. Consequently, we did not consider the second and third canonical variables in the description of the results.

The first canonical variable was interpreted from the correlations with the initial variables – that is, environmental and economic indicators (Table 2). The first canonical variable was positively correlated mainly with the financial dependence (i.e. the ratio annuities/gross operating surplus), veterinary costs, energy consumption per hectare and nitrogen surplus per hectare (for details on the indicators, see Supplementary Table S1). On the other hand, the first canonical variable was negatively correlated mainly with the economic efficiency (i.e. the ratio gross operating surplus/gross product including subsidies), capital efficiency (i.e. the ratio value added/total capital excluding land), gross margin per hectare and gross operating surplus per familial work unit. In other words, this variable represented the environmental and economic performances of the farms: low values of the first canonical variable corresponded to farms with low environmental impact and good economic results.

Conventional farms and means of EA classes were plotted on the first two canonical variables (Figure 1). As expected, the differences among classes occurred mainly along the first axis. Figure 1 highlights a gradient of EA along the first canonical variable: classes with higher EA degree had significantly lower values on this variable. On the basis of the

Table 2 *Total canonical structure: correlations between the economic and environmental indicators, and the three canonical variables*

Sustainability indicators[1]	Can1	Can2	Can3
Economic			
Gross operating surplus per familial work unit	– 0.45	– 0.43	0.19
Gross margin per hectare	– 0.48	– 0.26	0.19
Capital efficiency	– 0.61	– 0.17	– 0.20
Economic efficiency	– 0.87	– 0.06	– 0.17
Importance of subsidies	0.20	0.13	– 0.44
Financial dependence	0.43	0.21	0.29
Capital per familial work unit	0.09	– 0.33	0.35
Concentrate feed autonomy	– 0.01	– 0.27	0.21
Direct sale of milk	– 0.08	0.26	– 0.14
Environmental			
Pesticide costs per hectare	0.22	– 0.35	– 0.03
Soil link rate	0.12	– 0.44	0.30
Sprayed area	0.02	– 0.18	– 0.18
Phosphorus fertilisation per hectare	0.09	0.04	0.20
Potassium fertilisation per hectare	0.09	– 0.31	– 0.37
Area without mineral nitrogen	0.08	0.11	– 0.24
Energy consumption per hectare	0.35	– 0.33	0.24
Nitrogen surplus per hectare	0.33	– 0.26	0.22
Nitrogen efficiency	– 0.28	0.29	– 0.07
Veterinary costs per cow	0.43	0.07	– 0.22

[1]For definitions of indicators, please refer to Supplementary Table S1.

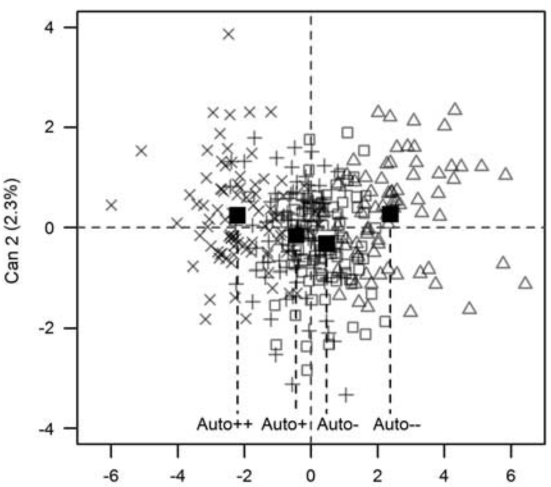

Figure 1 Plotting of conventional dairy farms and means of economic autonomy classes on the first two canonical variables. ■ Means of economic autonomy classes. × Farms belonging to the class *Auto+ +*; + *Auto+*; □ *Auto–*; Δ *Auto– –*.

interpretation of the first canonical variable, more autonomous classes were, therefore, characterised by better environmental performance – that is, lower nitrogen surplus per hectare, energy consumption per hectare, veterinary costs and higher nitrogen efficiency – and higher economic performance – that is, higher economic efficiency, capital efficiency, gross operating surplus per familial work unit, gross margin per hectare and lower financial dependence. These observations were globally confirmed by comparing the mean values among classes (Table 3).

Economic impact of the sharp decrease in milk price of 2009
In average, the milk price decreased by 19 ± 9% in our conventional farm sample between 2008 and 2009. As a consequence, the farm income per familial work unit decreased by 9 ± 29%, with a considerable variability among farms. This variability was also found within EA classes. Nevertheless, the average income variation significantly differed between the class *Auto– –* and the other three classes. The income of *Auto– –* was favourably impacted with a slight average increase, whereas the other classes experienced an average income decrease. This may be partly explained by the following two aspects: the variation of variable costs and the variation of the gross product (Table 4). First, the average variable costs decreased more sharply for *Auto– –*. This variation was mainly related to the variation of animal production costs, as reflected by the high correlation between both indicators (0.99, Pearson test $P < 0.001$). The variation of concentrate use and concentrate autonomy was identical across classes. However, performing *t* tests[4] for each class showed that *Auto– –* significantly decreased the use of dairy cow concentrates ($P < 0.001$), whereas the average variation of concentrate use was not significantly different from zero in the other classes. Second, the decrease in the average gross product of *Auto– –* was less marked than for other classes due to a lower average decrease in the milk price. Despite these two characteristics, the class *Auto– –* had, in 2009, the lowest average farm income per familial work unit (Table 4).

Comparison between organic and Auto++ *conventional dairy farms*
Compared with the class *Auto++*, organic farms employed similar workforce for a smaller dairy herd and lower total production. They were more extensive systems with lower milk yield and stocking rate. They had a wider AA, characterised by a low proportion of maize. They obtained a significantly higher milk price, allowing them to achieve a similar gross product from smaller milk volumes. Organic farms used similar amounts of dairy cow concentrates but produced a larger proportion of the concentrates on the farm. They also used no mineral fertilisers[5] (Table 1). Regarding sustainability performance, organic farms had economic results similar to those of *Auto++* – that is, income per work unit and economic efficiency – but a lower environmental impact – that is, energy consumption and nitrogen surplus per hectare (Table 3). In 2009, the organic milk price was less affected by the crisis than the conventional price. As a result, the average income per familial work

[4]Normality assumption was tested using a quantile–quantile plot. When the plot was close to linear, the distribution of the indicator was considered as close to normal (MathWorks, 2014).
[5]The mean value is positive because the sample includes farms in transition towards organic farming. In 2010, these farms were recorded as organic.

Table 3 *Mean economic and environmental results of organic and conventional dairy farms according to their degree of economic autonomy (2008)*

Indicators[1]	Unit	*Auto− −*[2] (*n* = 78)	*Auto−* (*n* = 80)	*Auto+* (*n* = 96)	*Auto+ +* (*n* = 81)	Organic (*n* = 30)
Economic						
Gross operating surplus	€/familial work unit[3]	48 999[a]	71 313[b]	72 072[b]	82 028[b]	72 650
Gross margin	€/ha of agricultural area	1676[a]	2084[b]	2128[b,c]	2381[c]	1651*
Capital efficiency	%	43[a]	57[b]	65[b,c]	73[c]	66*
Economic efficiency	%	43[a]	53[b]	60[c]	68[d]	71
Financial dependence	%	65[b]	49[b]	37[a]	31[a]	31
Environment						
Energy consumption	MJ/ha of agricultural area	27 478[c]	26 564[b,c]	23 144[a,b]	19 934[a]	10 172*
Nitrogen surplus	kg N/ha of agricultural area	152[c]	144[b,c]	122[a,b]	102[a]	27*
Nitrogen efficiency	%	31[a]	32[a,b]	35[b,c]	40[c]	71*
Veterinary costs	€/cow	115[c]	92[b]	89[b]	69[a]	80

[a,b,c,d]Mean values within a row with different superscripts differ significantly at $P < 0.05$.
[1]For detailed definitions, please refer to Supplementary Table S1.
[2]*Auto− −*: dairy farms with an economic autonomy <57%; *Auto−*: between 57% and 62%; *Auto+*: between 62% and 68%; and *Auto+ +*: >68%.
[3]One familial work unit is a farmer (or the spouse) who works full time on the farm.
*Significant differences between the mean values of organic farms and *Auto+ +* farms at $P < 0.05$.

Table 4 *Average economic impact of the milk price crisis of 2009 on organic and conventional dairy farms according to their degree of economic autonomy*

	Unit	*Auto− −*[1] (*n* = 78)	*Auto−* (*n* = 80)	*Auto+* (*n* = 96)	*Auto+ +* (*n* = 81)	Organic (*n* = 30)
Variation between 2008 and 2009[2]						
Gross operating surplus per FWU[3]	%	9[a]	− 14[b]	− 14[b]	− 16[b]	− 2*
Gross product per FWU	%	− 3[b]	− 10[a,b]	− 9[a,b]	− 11[a]	− 2*
Milk price	%	− 17[a]	− 18[a]	− 20[a,b]	− 22[b]	− 15*
Milk production (l)	%	7[a]	6[a]	6[a]	8[a]	9
Variable costs per FWU	%	− 14[b]	− 11[a,b]	− 8[a]	− 5[a]	−1
Animal production	%	− 12[b]	− 10[a,b]	− 7[a,b]	− 4[a]	−2
Crop production	%	− 17[b]	− 11[a,b]	− 1[a,b]	− 2[a]	38
Dairy cow concentrates	%	− 8[a]	− 4[a]	− 1[a]	− 2[a]	−12
Concentrate autonomy[4]	%	2[a]	− 1[a]	2[a]	− 1[a]	2
Mineral fertilisers	kg N/ha agricultural area	1[a]	11[a]	9[a]	16[a]	−1
Gross operating surplus per FWU in 2009	€/familial work unit	49 789[a]	60 407[b]	61 594[b]	68 098[b]	67 753

FWU = familial work unit.
[a,b]Mean values within a row with different superscripts differ significantly at $P < 0.05$.
[1]*Auto− −*: dairy farms with an economic autonomy <57%; *Auto −*: between 57% and 62%; *Auto+*: between 62% and 68%; and *Auto+ +*: >68%.
[2]Variation was calculated as follows: 100 × ((Value of 2009 − Value of 2008)/Value of 2008), except for the concentrate autonomy and mineral fertilisers for which the variation was calculated as: (Value of 2009 − Value of 2008), because of the presence of 0 values.
[3]One FWU is a farmer (or the spouse) who works full time on the farm.
[4]Proportion of livestock concentrates (in kg) produced on the farm.
*Significant differences between the mean values of organic farms and *Auto+ +* farms at $P < 0.05$.

unit of organic farms decreased less sharply compared with *Auto++* (Table 4).

Discussion and perspectives

Specialised and intensive livestock farming systems were developed from an industrial paradigm focussing on practice simplification and standardisation, as well as intensive use of inputs (Kirschenmann, 2007). As such systems have been called into question, increasing input self-sufficiency may constitute a key principle to improve sustainability of livestock farming systems (Dumont *et al.*, 2013). In this study, we used the indicator of EA as proxy to assess input self-sufficiency of dairy farms. Comparison among EA classes shows inefficiencies of some farms in the use of technical inputs, and therefore underlines the possibility of reducing input use, especially animal feeding, without decreasing the total milk production.

Efficient use of inputs, structural characteristics and sustainability performance

In our case study, reducing input use is achieved by class *Auto++* without involving a larger production of concentrates on the farm. As found by Guerci *et al.* (2013), it is associated with higher proportion of permanent grassland and less maize in the AA. Indeed, permanent grasslands require less mineral fertilisers and crop protection products than crops (Raveau, 2011). However, this result differs from other studies underlining the benefit of combining crop and livestock production to reduce input use (Ryschawy *et al*., 2012). We assume that this is related to pedoclimatic characteristics of the study area that are poorly suited to crop production. As a result, the AA is covered mainly by permanent grassland that constitutes the main resource for livestock (through grazing or mowing). Growing maize in this area is often associated with the quest for high production levels involving an intensive use of inputs and explaining the higher costs of livestock production.

Concerning the environmental and economic sustainability, our results show that increasing the EA level allows the farms to have better environmental and economic results. From an environmental point of view, several studies have reported that farms using fewer concentrates and mineral fertilisers have lower nitrogen surplus and energy consumption (Hansen *et al*., 2001; Paccard *et al*., 2003; Meul *et al*., 2012). In our case study, this relationship was established whatever the unit in which the indicators were expressed: per hectare or per unit of product. We found, for a subsample of 205 farms fully specialised in dairy production, a gradual decrease in the average energy consumption per 1000 l when the EA level increased (data not shown). The higher use of inputs of *Auto−* and *Auto−−* does not involve a similar increase in milk production, and therefore results in lower nitrogen efficiency and higher energy consumption per 1000 l.

From an economic point of view, the good economic results of farms with a high EA degree can be explained by three aspects. First, using fewer inputs for an equivalent level of milk production allows the farms to reduce their variable costs without affecting the gross product, and therefore have a positive effect on their income. Second, in our case study, *Auto++* farms received in 2008 a milk price slightly higher than other farms. Higher prices could be explained by the production of higher quality milk – for instance, in terms of protein content or number of somatic cells, or by the delivery of milk to a specific dairy paying higher price. Third, the use of EA as indicator to categorise the farms into four classes plays a role in these economic results. Indeed, EA is also an indicator of economic efficiency. It explains the strong correlation between economic efficiency, capital efficiency and the first canonical variable. Nevertheless, we observed that the first canonical variable was also correlated with other economic indicators such as gross operating surplus per familial work unit and financial dependence.

Inefficiencies in input use observed in our farm sample, especially in terms of animal feeding, could be related to path dependency on past agricultural policies and evolution trajectories. Since the Second World War, agricultural subsidies have been based on the output level, which pushed the farmers to consider the gross yield as their main production objective (Vanloqueren and Baret, 2008). In addition, the increase in labour productivity and the process of practice standardisation have encouraged farmers to simplify their management practices and distribute concentrate all year round to enable high and steady production, without taking the quality of the forage available into account (Veysset *et al*., 2014). Including higher proportions of forage in the diet constitutes a possible path to reduce the use of concentrates without decreasing the output level. It could be achieved through the optimisation of forage and grassland management, and by avoiding losses during grazing, harvesting, preservation and feeding (Meul *et al*., 2012). Havet *et al.* (2014) mentioned as an example the use of grassland calendars with a visual assessment of the grass height to optimise the management of grass quality during rotational grazing. They also refer to research on leader and follower grazing systems aiming to decrease the grazing of refusals by dairy cows and assign them to animals with low dietary requirements. However, despite better performance of more autonomous farms, breaking away from existing routines needs specific management skills and requires social influences (e.g. objectives of extension services and organisation of the dairy industry) to be overcome (Meul *et al*., 2012; Veysset *et al*., 2014).

Evolution in a changing context

Input self-sufficiency has often been considered as interesting to promote farm sustainability, faced with an increase in energy and input costs (López-Ridaura *et al*., 2002; Bernués *et al*., 2011; Ripoll-Bosch *et al*., 2012). In addition, Raveau (2011) found that when product prices increased, as in 2007, autonomous farms had more latitude for increasing their production, through increasing the use of inputs. They could, therefore, benefit more from these increased prices. As far as we know, no paper dealt with the role of input self-sufficiency in a context of decrease in milk price, as observed between 2008 and 2009. Our results underline that *Auto−−* farms are less affected by the decrease in milk price. First, they have greater leeway for reducing the variable costs by decreasing the use of concentrates without decreasing strongly the milk production. A strategy of input substitution – that is, the use of less expensive input – may also have been implemented simultaneously; however, we did not have the appropriate data to test this assumption. However, according to a perception survey, farmers and consultants would rather envisage rationalising concentrate purchase and optimising forage and grass production to decrease feed costs (Association Wallonne de l'Elevage, 2012). Second, the milk crisis involved a levelling out of prices among classes in 2009, explaining the sharper price decrease for *Auto++*. Despite these evolutions, the farms having little autonomy kept in average lower gross operating surplus per familial work unit in 2009.

Organic farming and EA

It was already stated that input self-sufficiency is a crucial aspect to guarantee the economic viability of organic farming systems due to the high price of organic inputs, especially concentrates (Lherm and Benoit, 2003). As established in our study, input self-sufficiency in organic farms is achieved through the greater use of on-farm resources and the non use of mineral fertilisers and pesticides, thereby leading to a low environmental impact per hectare (Hansen *et al.*, 2001; Paccard *et al.*, 2003). Our brief comparison between organic and conventional *Auto++* farms shows that organic farming provides economic benefits in a situation of milk price decrease. In 2009, organic farms kept a stable income per work unit because of a smaller milk price decrease. However, although high EA levels in conventional farms do not involve strong structural adaptations, the organic production method is associated with extensive practices – that is, low yields and stocking rate.

Limitations and perspectives

Our results provide new insights about the benefit of increasing input self-sufficiency in the context of a transition towards more sustainable farming systems. In this respect, however, our work shows several limitations and should be broadened in several respects. First, the EA indicator has two main drawbacks with respect to its ability to assess input self-sufficiency. On the one hand, this indicator is based on economic values and therefore varies according to input and milk prices. These variations may skew the estimation of relative amounts of inputs used by the farms. However, input prices could be considered to be homogeneous among conventional farms, as they have access to the same economic market and resources. In addition, the impact of milk price variations on the EA indicator was found to be negligible for conventional farms (data not shown). On the other hand, EA constitutes an indicator of economic efficiency. Consequently, the use of this indicator could lead to consider economically efficient farms as those that are input self-sufficient whereas they use a lot of inputs, and vice-versa (Raveau, 2011). However, we found that, for a subsample of 205 farms fully specialised in dairy production, EA was highly correlated with the variable costs per 1000 l (−0.77, Pearson test $P < 0.001$). Therefore, farms with a higher EA degree used fewer inputs for the same milk production and similar input prices.

Second, we performed an analysis based on the comparison among farms for a specific case study. Focussing on specialised farms did not allow us to study the interest in diversifying farming activities to increase input self-sufficiency. In fact, input self-sufficiency is usually associated with the diversification of farm activities in order to perform synergies and exchanges (Vilain, 2008). For instance, a mixed farm could increase its self-sufficiency by using manure for the crops or by producing animal feedstuff on the farm (Bonny, 2010; Bell and Moore, 2012). On the other hand, although this work highlighted interesting findings in the scope of farm sustainability, it provides information about one type of production within a specific agro-ecological context. Our results cannot be directly applied to other contexts. This analysis should consequently be broadened to explore other types of production – for example, more diversified farming systems – within various agro-ecological contexts. It would provide reference values of EA to the farmers to compare their farm with farms having similar structural constraints and opportunities. In such a benchmarking process, it is crucial to identify practical ways to improve EA in a specific context.

We assessed input self-sufficiency using a farm-level proxy. The farm scale is the main management level and economic unit, at which decisions, strategic choices and technical actions are performed by the farmer to produce goods and services (Lebacq *et al.*, 2013; Botreau *et al.*, 2014). At this level, such actions could allow the farmer to improve the economic and environmental sustainability of the farm. Like other sustainability attributes, input self-sufficiency could, however, be assessed at higher levels – for example, local, regional or national. Such assessments would consider synergies and exchanges between farms located in the same territory, such as the transfer of forage or manure between crop and livestock enterprises (Bell and Moore, 2012).

This study constitutes a first approach to analyse the impact of input self-sufficiency on the evolution of farm sustainability. The use of 2-year data did not allow us to take the inter-annual variability of data into account. Moreover, the use of farm accounting data involves possible overlaps of processes – for example, variation of prices and volumes – and contextual changes – for example, decrease in milk price, increase in input price and impact of climate events. Consequently, to further investigate this dynamic approach, long-term studies should be performed through farm network monitoring over a long period. In this context, more detailed data should be collected to enable fine-grained analyses in terms of processes and contextual changes, and to take social aspects – for example, labour, into account. Such long-term studies could explore the extent to which input self-sufficiency supports farm development and constitutes the core for long-term action (Havet *et al.*, 2014).

Conclusion

Input self-sufficiency is usually considered as a key aspect to promote sustainable farming systems. In this study, we used the EA indicator to assess input self-sufficiency of specialised dairy farms located in the grassland area. We showed that high EA degrees in conventional farms could be favoured by high proportions of permanent grassland in the AA. Owing to an efficient input use (especially in terms of animal feeding), the most autonomous farms combine a low environmental impact with good economic results. In the context of milk price decrease, the least autonomous conventional farms have greater leeway for reducing input use, without decreasing milk production, and thereby maintaining a stable income level. Despite this latitude, these farms have a lower income compared with more autonomous ones. In this context, organic farms have a stable income because of a slighter decrease in the organic milk price. This dynamic approach should be further investigated through long-term studies in order to consider inter-annual variability and various types of contextual changes.

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Supplementary material

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