How can farms with beef cattle systems based on permanent pasture cope with extreme climatic years? Results of a study using the whole-farm simulator SEBIEN

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***Abstract:** The farm-scale simulation of grassland production and use allows the farm system to be evaluated for feed self-sufficiency under different management strategies and in different climatic years. We investigated the impact of the frequency of years unfavourable to grassland production, such as the year 2003 that was characterized by a severe spring drought and by heat stress. We used the whole-farm simulation model SEBIEN, which reproduces the steady-state functioning of grassland-based beef suckler systems. The model is based on the interface of animal, vegetation and management sub-models, and was calibrated for suckler farms in the upland areas of the Auvergne region in France. We ran the model with a recent climatic series (1994-2005) and with artificial climatic series consisting of increasing frequencies of unfavourable years (e.g. 2003) or 'normal' years (e.g. 2000) for grassland production. Simulation results indicated that without changing the management rules, in 2003 the total amount of herbage harvested was reduced by 54% compared to 2000. The grass quality was also markedly reduced in 2003, leading to a dramatic decrease in farm feed self-sufficiency. The frequency of unfavourable climatic years did not affect the average results for 2003 and 2000. Adaptations of the forage system, aimed to cope with frequent climatic incidents as drought and heat stress were tested with the simulation model. Increasing farm area with productive grassland or increasing the productivity of the grassland for the same farm area were found to be efficient to improve feed self-sufficiency. Changing the harvesting system from field-dried hay to earlier cut forage conserved as barn-dried hay or big bale silage, was found to be the most efficient and minimised the loss of harvested herbage to 34% while maintaining grass quality. However, these adaptations have an economic cost and environmental impacts that need to be taken into account. This study highlights the importance of adapting the management rules of the forage system, either tactically or strategically, to cope with extreme climatic events.*

***Keywords:** forage system, beef cattle, permanent pasture, drought, climate change, adaptation, simulation*

Introduction

Climate change will probably produce increased frequency of adverse climatic events. A recent example occurred in 2003, when drought and heat stress caused a dramatic decrease in crop and forage yields and, consequently, livestock performance. The impact of such events might be beyond that caused by the normal variability of climatic conditions (Easterling *et al.*, 2007).

Beef suckler systems that rely exclusively on permanent pastures such as those found in upland areas of Europe (e.g. Massif Central, France), might be very sensitive to extreme climatic events such as those which occurred in the spring and summer of 2003. The sustainability of such systems depends mainly on their feed self-sufficiency (Lherm and Benoit, 2003). Given the constraints of a continental climate, the production of herbage is concentrated in spring and summer. Thus, the animal production cycle and the forage system are managed to exploit herbage growth for grazing and also for the harvest of hay (Figure 1). During the long (5 to 6 months) winter period, the herd is housed and fed with conserved forage. The amount and quality of the hay harvested should be sufficient to feed the cows during late pregnancy and early lactation, which usually occur in winter. A drought in summer and spring is very harmful to these systems, where farmers depend on high yields for the first hay cut and are not used to sparing standing forage for grazing in summer.

We investigated the impact of climatic events on feed self-sufficiency in a beef suckler system typical of the Massif Central. We used the whole-farm simulation model SEBIEN (Jouven and Baumont, 2008) which reproduces the steady-state functioning of grassland-based suckler systems. We simulated the response of a virtual farm (based on a real case) to different frequencies of unfavourable climatic years such as 2003, with unchanged management rules, and then we tested different scenarios including changes in the management of the forage system.

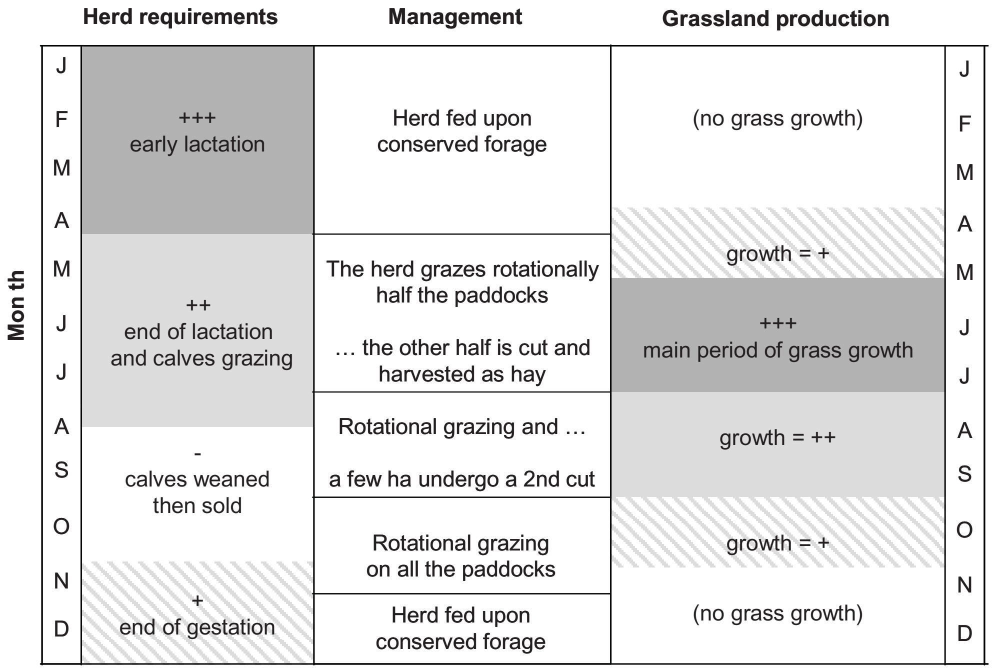

Figure 1. Organization of the feeding system at farm-scale for a typical beef suckler system based on permanent pasture (Massif Central, 800-1000m above sea level). The signs + or – indicate the seasonal variations of the herd requirements and of the grassland production.

Materials and methods

The whole-farm simulator SEBIEN

SEBIEN predicts the steady-state functioning of the farm using a daily time-scale, with simulation runs lasting 1 to 15 years (with longer time scales, the grassland is expected to change under the pressure of utilization, but this was not modelled). Paddocks, animal groups and animal categories within groups are the management units. The model is made of three sub-models which interact at multiple time scales. The grassland resource sub-model (Jouven *et al.*, 2006) predicts grass growth and quality at the paddock level, from soil quality, vegetation functional traits and climatic data. The animal sub-model (Jouven *et al.*, 2007a) calculates selective intake at pasture from the biomass and digestibility of plant parts. It also predicts weight gain and milk production from energy intake, for each animal type within each group. The management sub-model (Jouven and Baumont, 2008) comprises a strategic component (management plan) and a tactical component (management rules). Herd management works mainly on a pre-planned schedule. Use of paddocks is also planned, but can be revised at fixed dates depending on the amount of herbage available to graze. Fertilization practices are not modelled but they are taken into account with the types of grassland defined according their productivity. Management rules adjust feed availability for the herd, through grazing rotations, hay harvests, and supplementation with forage and concentrate to achieve production objectives (calf weight at sale, cow body condition score at calving). Consistent with farmer behaviour, the animal production objectives are always achieved through concentrate supplementation if needed, and grazing takes priority over forage harvests when grass is scarce.

The inputs to SEBIEN (Figure 2) include farm structure (description of herd and grassland resources), management plan (animal production objectives and grassland utilization), thresholds for management rules and weather data which introduces variability between seasons and years. The outputs of SEBIEN (Figure 2) include the daily operation of the forage system, the dynamics of intake and performance for the average animal of the herd, and the dynamics of grassland production and use on each paddock. To evaluate the performance of the farming system with a focus on feed self-sufficiency, we considered the following outputs of the model: i) the amount and quality of the forage harvested, ii) the hay and concentrate purchased, iii) the forage grazed and the number of days where the herd is fed hay outdoors, iv) the forage balance and v) the live weight increase of cows during the grazing season.

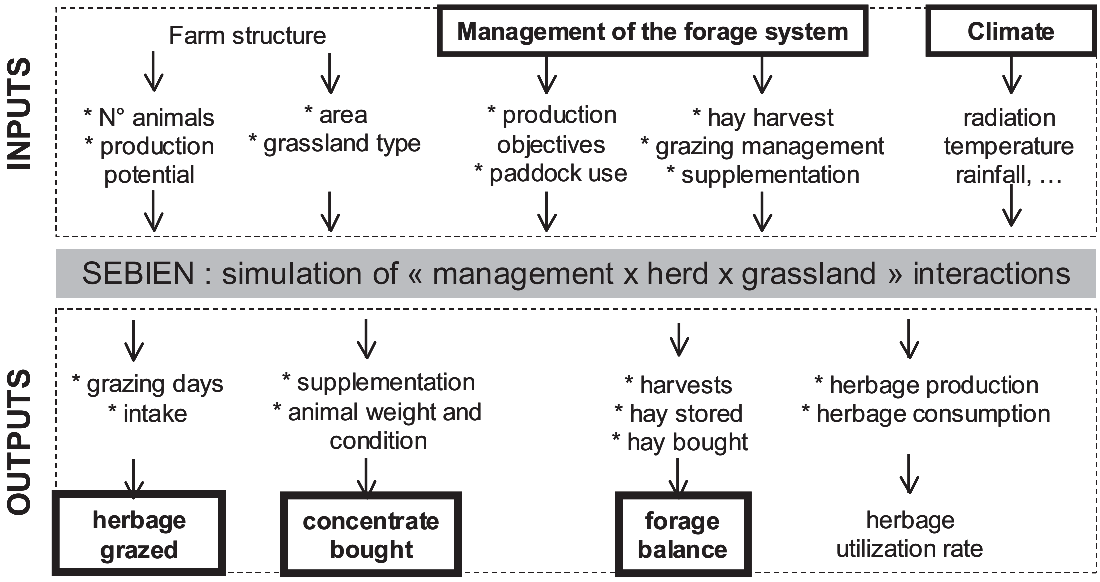

Figure 2. Inputs and outputs of the whole-farm simulation model SEBIEN.

The simulated beef-suckler farming system

For the simulations, we defined the farm structure and the management of the forage system in order to match a real farm considered to be typical of beef-suckler systems. For simplification, the simulated farm was half the size of the real one, but with the same stocking rate of 1.1 LSU per ha. We designed a virtual grassland farm of 30ha comprising 3 types of grassland (Jouven et al., 2007b): 6ha of high productivity that can be cut and grazed, 18ha of medium productivity that can be cut and grazed, and 6ha of low productivity that can only be grazed. The farm area is divided into 15 paddocks of 2ha, used to feed a group of 26 Salers cows calving on 15 January with their calves sold at 9 months and 325 kg, and a group of 10 heifers (1 to 3 years old).

Almost half the grassland (including the most productive paddocks) was scheduled to be cut for hay in June or July (depending on climatic conditions and harvestable biomass), and the most productive grasslands were scheduled to be cut a second time in August or September (depending on harvestable biomass). The area available for grazing was highest in autumn, where no cut was scheduled. As a rule, the group of cows had priority access to the most productive grassland, while the group of heifers was kept on low to medium productive grassland. For each group, grazing rotations took place when the amount of green herbage on the paddock was under a threshold height, or when a maximum residence time was reached.

The climatic series

To assess the impact of climatic incidents on feed self-sufficiency, we ran the model for series of 12 years based on climatic data from the INRA research station of Marcenat. This station is located in the upland area at an altitude of 1100m. Average annual rainfall reaches 1150mm per year, and mean daily temperature is 6.9°C.

First we ran the model on the actual climatic series that was recorded between 1994 and 2005. The series was characterized by a succession of years favourable to grassland production until 2002 followed by three unfavourable years, in particular 2003 and to a lesser extent 2005. The year 2003, was characterized by a 53% reduction in rainfall between April and June and by a 3°C increase in average temperature between May and June compared to the average values of the last forty years.

Secondly, we built artificial climatic series that associated the year 2003 and the year 2000 with various frequencies. The year 2000 was characterized by the absence of climatic incidents and by a good system performance in terms of feed self-sufficiency. It was thus considered as 'normal' year while 2003 was representative of a 'dry' year. The characteristics of these two climatic years are given in details in Figure 3. We built four artificial climatic series, so that the year 2003 occurred every 2, 3, 4 or 6 years.

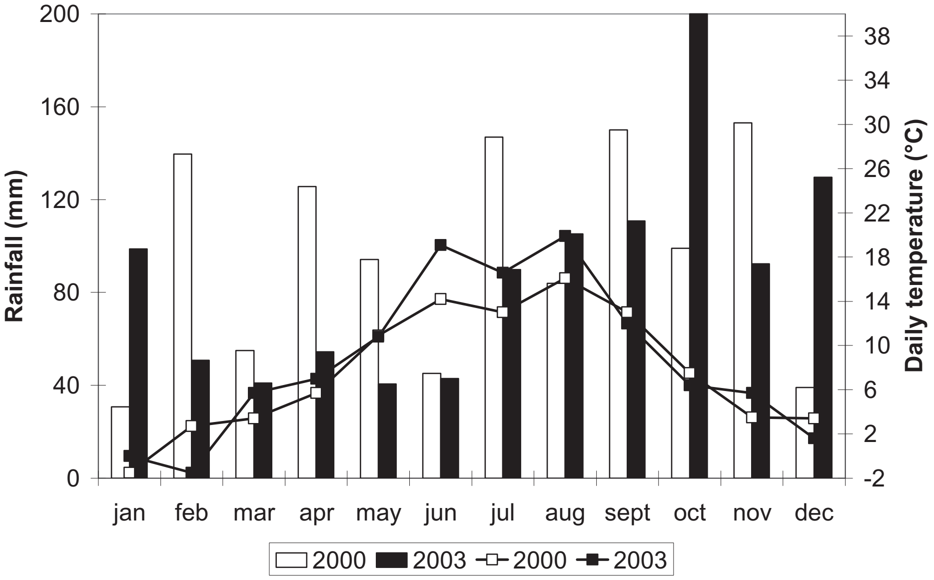

Figure 3. Diagram of monthly rainfall (bars) and mean temperature (lines) recorded in 2000 and 2003 at the INRA research station of Marcenat (France, 1100m above sea level.)

The simulations and the scenarios tested

In a first step, we analyzed the performance of the farming system for the actual climatic series. In a second step we investigated the impact of increasing the frequency of the climatic incident of 2003 with the artificial climatic series. These two steps were performed running the model without any change in management rules.

In a third step, we used the climatic series in which the events of 2003 occurred every two years, and the following three management scenarios designed to investigate the possible improvements of forage self-sufficiency:

1) Increasing the grassland resources by extending the farm area either with 2ha of highly productive grassland (can be cut and grazed) or with 6 ha of low productive grassland (can be grazed only), which represented about the same amount of additional herbage produced. This scenario implies that the farmer has access to new land. A similar alternative could be to decrease the stocking rate at farm scale, by reducing the number of cows and heifers.
2) Increasing the grassland resources for the same farm area by switching 4ha of medium grassland into 4ha of highly productive grassland. This simulates an increase in fertilization of the medium productive grassland which is cut. This scenario implies that the total amount of fertilization per ha remains lower than the thresholds imposed to obtain agro-environmental subsidies, which determine the viability of beef suckler systems.

3) Changing the harvesting system: i) harvesting the 1st cut earlier in the season (beginning of heading instead of during heading), to have a longer period of grass re-growth, and if possible make 3 cuts; ii) harvesting barn-dried hay or big-bale silage, which reduces the numbers of dry days needed for harvesting to 3 (4 days needed for hay); and iii) decreasing the biomass threshold for cutting to 1.5 t $DM.ha^{-1}$ for first- and of 1 t $DM.ha^{-1}$ for second-cut harvests instead of 1.7 t $DM.ha^{-1}$ for both cuts.

Our scenarios did not include changes of the grazing rules. In fact, in the model, grazing is the priority over hay harvest. Despite the thresholds for paddock change, if there is no grass to graze elsewhere, the animals are kept on a paddock. They are supplemented with conserved forage only if herbage height falls below 4 cm, and the re-allocation of paddocks to grazing is also done independently of thresholds for paddock change. Thus, the type of accident observed in 2003 will affect mainly predicted forage harvests.

Results and discussion

The performance of the farm using actual climatic series

With the actual climatic series, the feed self-sufficiency of the simulated farm was almost fully achieved between 1994 and 2002. As the forage balance was close to zero, very little hay was bought, and only 45kg of concentrate per LSU were used, mainly for the calves (see Figure 4 and Table 1). During this period, the variability between years was more pronounced for the amount of forage harvested than for the amount of forage grazed (Figure 4). First, the variation between years in the amount of forage harvested is related to the variation in 1st cut yields, with a minimum of 2.7 t DM/ha in 1999 and a maximum of 4.8 t DM/ha in 1997. Secondly, the management rules applied in the model secure the use of the paddocks for grazing. Indeed, in a less favourable year for grass production the second cut of hay that normally happens at the beginning of August, is suppressed to provide enough grass for grazing. This happened in 1999, a year characterised by a rainfall deficit in June and July.

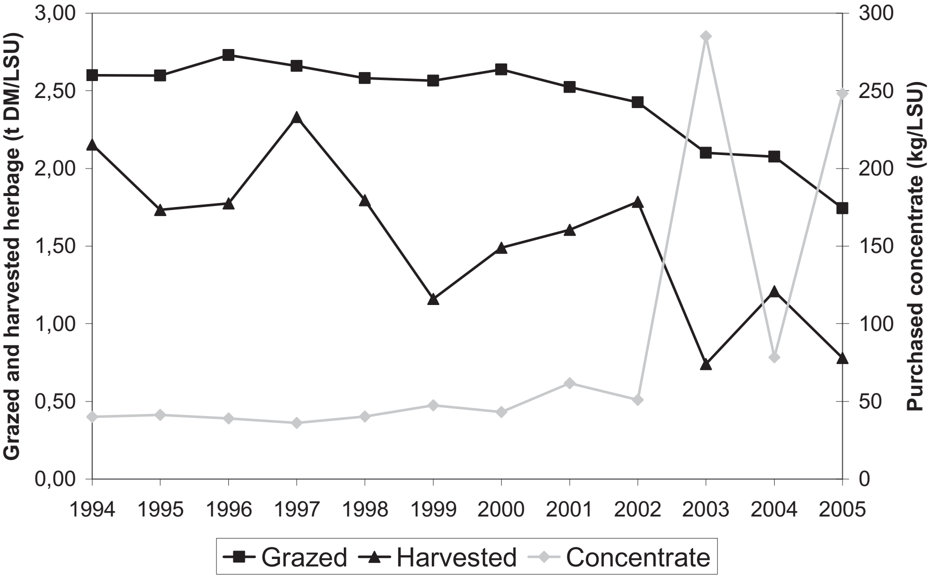

Figure 4. The dynamic of grass production and of the concentrate purchased in the simulated farm between 1994 and 2005

Extreme climatic conditions in 2003 were disastrous for the grass production as simulated by the model. The drought led to reduced growth, earlier maturation of herbage and increased losses of biomass trough senescence in relation to heat stress. Thus, the amount of herbage harvested decreased dramatically (-54%). First cut yields were reduced to only 1.8 t DM/ha, and the quality of the hay harvested was also markedly reduced (predicted digestibility reduced from 0.64 to 0.54). In contrast to previous years, the amount of herbage grazed could not be maintained and decreased by

20% (see Figure 4 and Table 1). Thus the animals needed to receive hay at pasture during 32 of the 180 days in the grazing season. As a consequence, to compensate for the herbage deficit in quantity and in quality, the amount of concentrate purchased increased from less than 50 to more than 200 kg/LSU. Similar conditions occurred again during the year 2005 characterized by low rainfall from June to August.

Table 1. Evaluation of the performance of the farming system for the actual climatic series (average +/- s.d. between years) and for the artificial climatic series.

	Actual climatic years		Artificial climatic series		
	1994 - 2002	1994 - 2005	'Dry' years (2003)	'Normal' years (2000)	½ Dry ½ Normal
Forage balance (t DM / LSU)	-0.03 ± 0.36	- 0.41 ± 0.79	-1.73	-0.23	-0.98
Harvested herbage (t DM / LSU)	1.76 ± 0.35	1.55 ± 0.50	0.78	1.54	1.16
Grazed herbage (t DM / LSU)	2.59 ± 0.08	2.44 ± 0.30	2.06	2.63	2.34
Digestibility of 1st cut hay (g/g)	0.64 ± 0.02	0.63 ± 0.05	0.56	0.64	0.60
Grazing season					
Number of days with hay feeding	0.8 ± 1.9	8.2 ± 15.1	32	0	16
Cow weight gain (kg)	51 ± 4	49 ± 5	45	55	50
Feeds purchased					
Hay (t DM / LSU)	0.07 ± 0.11	0.44 ± 0.72	1.73	0.23	0.98
Concentrate (kg / LSU)	44 ± 9	84 ± 86	177	41	109

The impact of an increased frequency of extreme climatic years

The impact of increasing the frequency of the year 2003 in the climatic series, from once every six years to once every two years, on the production of herbage and on the consumption of concentrate at the farm level is shown on figure 5. Detailed results for the series in which 2003 occurred every two years are reported in table 1.

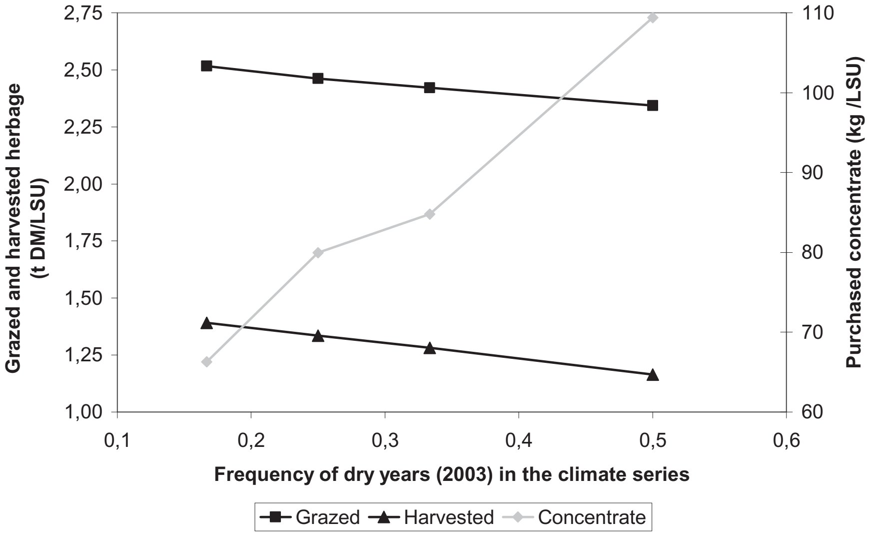

Figure 5. The impact of an increase in the frequency of dry years on the herbage production and the concentrate purchased in the simulated farm

A linear decrease in the herbage harvested and grazed and an almost linear increase of subsequent concentrate consumption is predicted by the model when increasing the frequency of the year 2003. The linear behaviour of the model can be explained by the particular feature of the climatic series we built and by the characteristics of the vegetation model included in the whole farm simulator. The 'normal' year 2000 is favourable for grazing but not very favourable for the production of harvested forages as shown by the slightly negative forage balance predicted for this year (Table 1). Thus, at the beginning of each simulated 2003 ‘dry’ year, there is no forage stored in the barn that could smooth the impact of herbage deficit of the ‘dry’ year. Furthermore the linear behaviour of the model indicates that there was no residual effect of the dry climatic year on herbage growth during the subsequent simulated year. In the particular case of 2003, this could be explained by the favourable weather conditions for grassland production in autumn, and more generally by the fact that the vegetation model (Jouven et al., 2006) does not simulate the possible cumulative effects of a series of unfavourable years on grassland productivity by decreasing plant reserves and by changing botanical composition (Stampfli and Zeiter, 2004).

Scenarios to improve farm feed self-sufficiency

In this part of the study we explored different ways to improve feed self-sufficiency, either by modifying farm structure (increasing the area), or by modifying the strategic management component (increasing the productivity of grassland scheduled for cutting through fertilization) or the tactical management component (changing the harvesting system).

Increasing the farm area

Increasing the farm area implies that the farmer can have access to new land. We compared the simulated impacts of two contrasting options on farm feed self-sufficiency: i) an increase of highly productive meadows by 2ha, and ii) an increase poor pasture that can only be grazed by 6ha (Table 2). Increasing the farm area with 2ha of highly productive meadows increased the amount of harvested forage per livestock unit by 17% in ‘dry’ years and by 21 % in ‘normal’ years. Because management rules for harvesting were not modified, the hay quality did not change. Increasing farm area with 2ha of highly productive meadow had positive consequences on grazing for the ‘dry’ years’. The number of days during which hay feeding was necessary at pasture was reduced from 32 to 26 and the weight gain of cows during the grazing season increased by 9%. Finally, farm feed self-sufficiency is increased on ‘dry’ years as well as on ‘normal’ years, and the amounts of purchased hay and concentrate are reduced by 30%.

Table 2. Evaluation of the performance of the farming system when the farm area is increased either with 2ha of rich meadows, or with 6ha of poor pastures.

	With 2ha rich meadows for cutting			With 6ha poor pasture		
	Dry years (2003)	‘Normal’ years (2000)	½ Dry ½ Normal	Dry years (2003)	‘Normal’ years (2000)	½ Dry ½ Normal
Forage balance (t DM / LSU)	-1.53	0.14	-0.69	-1.78	-0.22	-1.00
Harvested herbage (t DM / LSU)	0.91	1.87	1.39	0.80	1.55	1.18
Grazed herbage (t DM / LSU)	2.11	2.63	2.37	2.03	2.64	2.34
Digestibility of 1st cut hay (g/g)	0.55	0.63	0.59	0.55	0.63	0.59
Grazing season						
Number of days with hay feeding	26	0	13	37	0	19
Cow weight gain (kg)	49	56	52	46	50	48
Feeds purchased						
Hay (t DM / LSU)	1.31	0.05	0.68	1.78	0.22	1.00
Concentrate (kg / LSU)	118	33	76	216	55	136

In contrast, increasing the farm area with 6ha of poor pasture did not increase farm feed self-sufficiency. In ‘normal’ years, the additional herbage produced on these paddocks could not be correctly exploited because grassland production on grazed pastures is globally higher than herd requirements. As this additional area cannot be harvested, herbage biomass is thus lost. In ‘dry’ years, these poor pastures were not helpful in management of the grazing season as at the beginning of the season before the drought the herbage was under-exploited by grazing, and when dry conditions at the end of spring occurred the re-growth is stopped.

Increasing the productivity of the paddocks scheduled for cutting

In this scenario we changed 4ha of medium productive grassland into 4ha of highly productive grassland. This implies increased fertilisation and increased intensity of utilisation of this area to progressively change the botanical composition of the meadow into more productive species, such as

Lolium perenne (ryegrass) or *Dactylis glomerata* (cocksfoot) instead of *Festuca rubra*. This scenario needs several years to be achieved and the model can only simulate the final stage when botanical composition is stabilized.

Without other changes in forage system management, increasing the productivity of 4ha of grassland increased the amount of harvested forage by 14% on ‘dry’ years and by 11% on ‘normal’ years (Table 3). In 'dry' years, system performance was also improved during the grazing season with a reduction of 32 to 26 days required for feeding hay at pasture, and an increase of 9% in the cow weight gain during the grazing season.

Finally, increasing the productivity of 4ha grassland improved feed self-sufficiency both on ‘dry’ and on ‘normal’ years. For the climatic series with half of the years being ‘dry’ and half being ‘normal’, the purchase of hay was reduced by 22% and the purchase of concentrate by 25%. The improvement was slightly lower than with an increase of the farm area by 2ha of productive grassland.

Table 3. Evaluation of the performance of the farming system when either the productivity of 4ha of cut meadows in improved, or when changes in the harvesting system are applied (earlier first cut in big-bale silage or barn-dried hay instead of later cut field-dried hay).

	Increased productivity of paddocks scheduled for cutting			Changing the harvesting system		
	Dry years (2003)	‘Normal’ years (2000)	½ Dry ½ Normal	Dry years (2003)	‘Normal’ years (2000)	½ Dry ½ Normal
Forage balance (t DM / LSU)	-1.52	0.00	-0.76	-1.11	-0.27	-0.69
Harvested herbage (t DM / LSU)	0.89	1.71	1.30	1.13	1.38	1.25
Grazed herbage (t DM / LSU)	2.13	2.64	2.39	2.15	2.63	2.39
Digestibility of 1st cut hay (g/g)	0.56	0.65	0.60	0.64	0.69	0.67
Grazing season						
Number of days with hay feeding	26	0	13	24	0	12
Cow weight gain (kg)	49	60	54	44	53	48
Feeds purchased						
Hay (t DM / LSU)	1.48	0.05	0.76	1.11	0.27	0.69
Concentrate (kg / LSU)	131	31	81	74	33	53

Changing the harvesting system

We simulated a change in the harvesting system from the traditional field-dried hay harvested at heading or flowering stages to big-bale silage or barn-dried hay, which can be harvested earlier at the beginning of heading.

In ‘dry’ years, changing the harvesting system increased the yields by 45% (Table 3). The first cut was made before the losses of biomass trough senescence were too important, and even a small amount of the farm area could be cut a second time (in early September) after the dry period. However, in ‘normal’ years, earlier cutting decreased the amount of forage harvested by 10% as cutting happened before the peak of biomass production was reached. The second consequence of earlier cutting was to increase the forage quality by 14% on ‘dry’ years and by 8% on ‘normal’ years. Earlier cutting improved also slightly the performance of the system during the grazing season, as a larger area was available for grazing earlier in the season.

Finally, changing the harvesting system was the best option among the different scenarios we tested to improve the farm feed self-sufficiency in a context of highly frequent ‘dry’ years. The need to purchase hay decreases by 30% and the need to purchase concentrate decreases by 50% compared with the performance of the system without any adaptation. However, this option has an economic cost, as it requires specific equipment, machinery and building for making big-bale silage or barn-dried hay.

Ingrand et al. (2007) defined the flexibility of a farming system as the capacity of the livestock system to adjust quickly to a wide range of economic, technical, marketing and climatic constraints, whilst allowing the livestock farmer to cope with his production plan in the medium term, or even the long term. The results we obtained in this study indicate that the mode of conservation of forages and the harvesting dates are important issues on which the farmer can act to adapt and secure the forage system. The diversity of winter forages and food management was also identified as important technical variables for flexibility of suckler cattle farms (Ingrand et al, 2007). However, in this study we only investigated adaptations of the forage system to cope with frequent climatic accidents. A more thorough revision of the production system could be tested. For example, if the forage production in spring becomes more uncertain, and the forage production in autumn more abundant, it might be interesting to dissociate the period of forage harvests from that of high energy requirements of the herd, and manage the herd with the calving period in autumn or with two calving periods, one in autumn and one in spring as proposed by Pottier et al. (2007).

Conclusions

From this study, it appears that the farm structure and the management of the forage system we integrated in the simulation model matches closely the real case of the 'typical' farm and is appropriate for 'normal' climatic years as feed self-sufficiency is high in absence of extreme climatic events. In a context of climate change, this study highlights the interest of taking into account extreme climatic years rather than average ones to design a farm structure and set management rules. Moreover different types of climatic incidents need to be considered. Consequences of drought and heat stress are not the same when they occur in spring during the main period of grass production or during summer. Dry years can be followed by very wet years as observed in northern Europe in 2007.

SEBIEN, the model we used is this study, is suited to investigate different bio-technical options to cope with different types of constraints imposed by the farm structure, the management rules or the climate. The model aimed at evaluating the performance of the system in terms of feed self-sufficiency and its impact on the grassland utilisation. Obviously farm sustainability includes other aspects. The adaptations we tested all have an economic cost (buying or renting new area, fertilisation, making big-bale silage…). They also have environmental impacts and consequences on the labour organisation of the farm. Thus, for a more complete assessment of adaptations aimed to cope with climate change it should be necessary to use complementary simulation tools which focus on economical assessment (Veysset et al., 2005) or on labour (Dedieu et al., 1997).

Climatic events such as the drought and heat stress in spring and summer that occurred in 2003, have a dramatic impact on the feed self-sufficiency of beef suckler systems based on permanent pasture. Following the results of our simulations at short to medium time scales (<12 years), the impact is almost proportional to the frequency of unfavourable years. In the real world, the impact could increase on the long term, if the plants do not have the opportunity to replenish their reserves, or if the seed banks run out leaving areas of bare soil. The analysis of our selected scenarios of management adaptation to climate change suggest that beef suckler systems based on permanent pasture can limit the negative impact of climatic accidents, by adapting their forage management system. However, to cope with frequent climatic accidents, the production systems might also need a more thorough revision of their herd management. Finally, this study highlights a simulation approach to investigate the ability of farming systems to cope with climate changes and the results provide a basis for further analysis with farmers and extension services.

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