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A simple model to assess the sensitivity of grassland dairy systems to scenarios of seasonal biomass production variability

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ABSTRACT

In recent decades, dairy herds of the peri-Mediterranean area have coped with high climatic variability, which has contributed to weakening their economic equilibrium. Survey studies highlighted that climatic impact depends on the strategies of farmers, related to forage autonomy. To explain this observation precisely and assess the opportunity of changing forage strategy as an adaptation to cope with climatic variability over the long term, a simulator was developed to explore the impact of several biomass production variability scenarios on forage purchases. This approach was applied on dairy cattle farms in a mountain area in the South of France (Ardèche), with forage systems based on grass (hay and pasture), using several levels of forage autonomy. A computer application was developed through a partnership project between our research team and officers of an extension board. We then validated the ability of the simulator to account for the operation of special cases of farms after calibration and studied the model sensitivity to key parameter variations. Then we explored (i) how the simulator can be used to assess the sensitivity of six dairy farms to biomass production variability and (ii) the value of an adaptation strategy with advance forage stockpiling. The sensitivity analysis highlights that the purchase of forage was highly sensitive to production variation during March, April and May. The farms which used grazing the most, exhibited a lower standard deviation than the other farms. Variation obtained for the standard deviation of forage bought was not only explained by the forage autonomy but might depend on other characteristics such as time of turnout and surface allocation. The succession of disadvantageous years was tested. The decrease in the stock differed according to the forage autonomy of farms. Whereas farms which were only just autonomous bought forage as of the first disadvantageous year, farms with forage autonomy of 120% can resist repeated biomass production variability for 8 years with the constitution of remaining stocks of forage. The simulator developed here is simple enough both to explore the sensitivity of a dairy system and promote the debate on the results with farmers and advisers.

1. Introduction

Since the 90s, studies have predicted extensive impact of climate changes in both agricultural sector (Tol, 2002) and food production (Parry et al., 2004). Adapting agriculture to climate change is a major concern due to the strong trends which have already been observed and the likely occurrence of further changes (IPCC, 2001; GIEC, 2007). As climate change often results in high climatic variability (Howden et al., 2007), the ability to manage this type of risk is one of the main components in the adaptation strategy (Cooper et al., 2008). The issues related to the decrease of sensitivity to climatic variability are more pronounced in areas at the interface of climate zones, such as that encountered in the south of France, between the temperate and the Mediterranean climates (Lelièvre et al., 2010). Exposure to drought risk is increased for farms with grazing livestock, where forage production comes mainly from grassland or where forage crops are not irrigated. Faced with this variability, livestock farms are more or less sensitive. According to Gallopin (2006), "sensitivity is the degree to which the system is modified or affected by an internal or external disturbance". Livestock farms therefore exhibit various response capabilities in order to cope with climatic variability. The structure and the functioning of livestock farming systems determine their attributes of sensitivity. To design more sustainable systems, it is important to evaluate this attribute to compare the interest of various structures of the system or different farming practices to be implemented in response to climatic variability. For this, we need to explore the behaviour of different systems, including new systems, in a range of different climatic situations.

Simulation can offer concrete solutions for carrying out an evaluation of the sensitivity of a system to climate variability. This

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approach assesses the impact of climate observed in recent years on the different systems concerned or the impact of new climate series reporting on possible climate variability (Boone and Wang, 2007; Mosnier et al., 2009). Unlike observed data, computer simulation is used to apply the same risk exposure for different farms. The sensitivity of farms can then be assessed in several ways. The sensitivity can be measured by the deformation undergone by the system for a given value of a shock (Gallopin, 2006). It can also be assessed by the variability of the system behaviour in response to environmental or climatic variability. The simulation makes it possible to repeat a series of similar climate variability (same exposure) for different systems and thus to measure the variability of the response of systems: systems with more variable behaviour are considered as more sensitive. A system can endure a shock for 1 year, but can be sensitive to repeated shocks. The simulation can therefore appreciate the time it takes for the system to become distorted.

Nevertheless, the use of a whole farm model built by a research team is relatively limited in supporting farmers in the design of new strategies (Matthews et al., 2008; Le Gal et al., 2011). The complexity of models, which aims at depicting biophysical process and management rules, generally leads to limited use by farmers or advisers (McCown et al., 2009; Martin et al., 2011). Our goal is therefore to develop a simulator of the flow management of forage in a dairy farm, reporting, in a simple but sufficiently realistic way, the behaviour of the system coping with seasonal climate variability. As we want this simulator to be used by advisers, they were involved in several validation steps during the creation of the model. We validated the ability of the simulator to account for the operation of special cases of farms after calibration and studied the sensitivity of the model to key parameter variations. Then we explored (i) how the simulator can be used to assess the sensitivity of dairy farms to climate variability and (ii) the value of an adaptation strategy with advance forage stockpiling.

2. Materials and methods

Two requirements have guided the development of the simulator. Firstly, the model must be simple enough to be used in joint work sessions between researchers and advisers, and the outputs can be used in information meetings with farmers. Secondly, the simulator must be used with on-farm data typically available to advisers during a working session of half-day maximum with a farmer and without implementing costly measures.

2.1. Dairy production in a montane area in France coping with climatic variability

We worked in the area of Ardèche, in the southeast of the Massif Central in France, in a temperate climate to date. The montane areas (altitude of 500–1200 m) are valued by livestock farms, particularly by dairy farms. In the higher or rugged areas, the herd feeds almost exclusively on grass, grazed from spring to autumn and stored in the spring (as hay or silage) to feed the herd the following winter in the cowshed. In these systems, the breeding period is generally spread throughout the year (Jaquot et al., 2010). Grass production is based on permanent or temporary grassland. In the best cases, annual fodder crops, such as maize which can possibly be irrigated, may complement and secure the production of fodder. The climate of the area tends to move towards a Mediterranean climate (Lelièvre et al., 2010), with summer droughts becoming more pronounced. Farmers are thus more likely to buy fodder (DM: dry matter; LU: Livestock unit; 490 ± 670 kg DM/LU in 2006, 130 ± 150 kg DM/LU in 2007 in a sample of 13 farms, Moulin et al., 2009) to supplement the diet of the herd during bad years. An adaptation strategy is stockpiling in advance, with stored forage carried over from 1 year to another. Although this strategy is costly and its interest was being discussed by advisers, Moulin et al. (2009) highlighted a diversity of strategies leading to several levels of forage autonomy.

2.2. Design of a simulator depicting storage of forage and biomass flow management in a dairy farm

The model is developed with Scilab (http://www.scilab.org/fr), software for numerical computation. It is a mechanistic dynamics model that runs at a daily time step and at the farm level. This daily time step is the basic unit to represent the biomass production on pasture and then the amount of forage cut or grazed. From the simulation of the production of biomass, the stocks of forage are calculated for a year.

2.2.1. Model inputs

The inputs of the model are sets of parameters (Table 1A) that define: (i) the cattle herd characteristics, (ii) the pasture schedule calendar and (iii) the animal feed calendar (see Table 2 for details). The model user registers all data in the file in spreadsheet format.

2.2.2. Biomass flow dynamics

We defined a pasture as a group of paddocks with the same plant cover and similarly managed throughout a year. The biomass production is updated each day for each pasture. The daily production is based on data from the STICS model detailed in Lelièvre et al. (2010) which was successfully applied on grassland (Gateau et al., 2006) and adapted to Mediterranean conditions (Ruget et al., 2009). The STICS model evaluates the maximum production of biomass under irrigated conditions. From the soil characteristics of each farm paddock, an estimate of biomass production in different climatic conditions can be achieved through this model. We therefore chose to use a yield curve model, with a possible modulation (p) of the potential maximum according to the pasture (i) considered. Here, a calibration process can limit the number of input parameters to be observed; however, it requires the development of a specific set of parameters for each farm concerning the pasture yields. So it is useful to have a tool with a generic architecture to quickly calibrate the model parameters for each farm studied. The calibration process used for the model is then based on the consistency of other outputs based on observed data (bought forage or cutted biomass). If needed, the user can reduce or increase this yield according to field data. Characterization of pasture types depends on plant cover. Four types of plant cover are distinguished, from the typology of grasslands proposed by Cruz et al. (2002). These types are defined by their growth characteristics (early or late) and the quality of plant concerned.

The production biomass is calculated daily using the amount of biomass available from the last time step, the daily production multiplied by the modulation ratio (noted p_i with i the pasture

Table 1A
Description of the parameters used in the simulation model.

Notation	Description	Value
p_i	Dry/irrigated ratio for a pasture of type i	From x to y
r_L	Rate of loss due to handling and transport of forage to the hay loft	15%
r_H	Herbage rejection rate	5%
t_P	Intake threshold on pasture	60%
r_F	Foddering ratio when lack of grazed biomass	50%
n_T	Theoretical DM needed by LU (livestock unit) per year	13.7 kg