Feed restriction strategies, implications on physiology, growth and health of the growing rabbit

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ABSTRACT – This review aims to present the different effects produced by a post-weaning intake limitation strategy on the growing rabbit. If a lower intake level leads to a lower growth, in return an improved feed conversion is obtained, particularly when the rabbits are again fed freely since a compensatory growth occurs. This better feed conversion originates from a better digestion associated to a longer rate of passage, whereas the digestive physiology is slightly modified (morphometry of the intestinal mucosa, fermentation pattern, symbiote). Meat quality and carcass characteristics are not greatly affected by restriction strategy, except a lower dressing out percentage. One of the main interests of limiting post-weaning intake of the rabbit is to reduce the mortality and morbidity rate due to digestive disorders (particularly ERE syndrome). In conclusion, restriction strategies are used by 95% of the French rabbit breeders, because these improve their economic balance. However, this benefit depends of the national market and feed prices, and should be adapted to any specific breeding situation.

Key words: Feed restriction, Digestive health, Growth, Feed conversion.

INTRODUCTION

For the young mammal, the weaning and the post weaning period are particularly important for the growth performances and feed efficiency, including the resistance to digestive pathologies, that are frequent either for the piglet, calve, or for the young rabbit between 5 and 10 weeks of age. For instance, in the rabbit, infectious digestive disorders account for a high incidence during the fattening period (Marlier *et al*., 2003). They may have a multi-factorial origin, with a combination of one or several pathogenic agents (bacteria, coccidia, etc.). Moreover, the European ban on antibiotic growth promoters in animal feeds has even complicated the weaning management. The situation of the young rabbit was most critical, since the first outbreaks in 1997 of the Epizootic Rabbit Enteropathy (ERE) led to high morbidity and mortality rate (up to 70%). Although, preventive medication with antibiotics (given under veterinarian prescription) helps to control the ERE or other previous digestive disease (e.g. enteropathogenic colibacillosis "EPEC") there is an urgent need to find alternative solutions to control the disease, with a reduced used of drugs. Among some solutions, such the improvement of hygiene, the breeding in batch, improvement in the nutritional and feeding strategies has been proposed, for the growing rabbit, in the past ten years.
For instance, new recommendations for fibre requirements and recent reviews were recently published that outlined the minimal needs of the growing rabbit for different fibre fractions to reduce the risk of digestive troubles, either from ERE or EPEC or on specific digestive troubles (De Blas *et al*., 1999, Gidenne, 2003; Carabaño *et al*., 2008; Gidenne *et al*., 2010).

Besides, the control of the feed intake in the young rabbit was subjected to some past studies to analyse the effects on the carcass quality of the rabbit, or its digestive efficiency. But since 2003, several authors deal with the relationship between post-weaning intake level and digestive trouble incidence for the growing rabbit, including either studies with experimental infections (either ERE or EPEC), or large-scale studies in the French network of rabbit experimental units (GEC group).
Presently, strategies of intake limitation after weaning are now largely widespread in French rabbit breeders (95% of the professional breeders), in parallel to the development of new automatic feeding equipments, since positive impact have been obtained on resistance to digestive troubles and on feed efficiency.
Various short-term post-weaning restriction strategies have been studied in the rabbit, according to the duration of the restriction period (1 to 5 weeks), or to the intensity of the intake limitation (90 to 40% of the voluntary intake), or to the method (quantitative feed restriction, water restriction, limited time access to the feeder, etc..). Thus, the present review aims to summarise the results obtained during the past ten years, on digestive functions, health, growth and carcass characteristics, but also on feeding behaviour and welfare, in the growing rabbit submitted to different intake limitation strategies, without changes in feed quality.

FEED INTAKE CONTROL: various techniques for various aims

Before or after weaning, the young rabbit usually has a free access to the feed and water (*ad libitum*, AL). Various techniques have been studied to control the feed (or water) intake, for two main aims: the control of the carcass and meat quality (Perrier and Ouhayoun, 1996) and the improvement of the feed efficiency to reduce the feed costs. Two main classes of restriction techniques are used: a quantitative intake limitation, and a “qualitative” restriction. For the latter, modification of nutrient intake is reached through a modification of the feed composition. For example, energy intake is frequently reduced by using high-fibre diets for young reproducing female. But here, we will detail "quantitative" intake limitation without any change in the diet composition.
A "quantitative" restriction can be applied according to two methods: the time for access to the feeder or the quantity of feed distributed can be reduced (Feugier, 2002; Szendrö *et al*., 2000). In addition, this can be applied for different time periods (e.g. feed restriction applied directly after weaning and ad libitum in the fattening period or vice-versa). For instance, in some periods of the production cycle, namely, during the growing period.
First studies dealing with feed restriction observed *a posteriori* the level of intake, by limiting the access to the water (Lebas and Delaveau, 1975), when rabbits are fed a dry feed, such pelleted feeds. Since, a daily distribution of a ration is time consuming when automatic feedings are not available, and because the feed consumption is directly correlated with the water consumption (Gidenne and Lebas, 2005), hydric restriction has been studied (and used by some French rabbitries) recently to evaluate the impact on digestive health. For instance, the feed intake was reduced by 18% when the access to water was reduced to 2 hours, (Boisot *et al*., 2004), by 22% for 1h30min water access (Verdelhan *et al*., 2004) and by 23% for 1 hour access to water (Boisot *et al*., 2005). But, such a severe hydric restriction is questionable in terms of animal welfare, particularly for hot climatic conditions (Foubert *et al*., 2007; Ben Rayana *et al*., 2008), and the results obtained seems less precise compared to feed restriction in terms of performances and health.

Another easy way to restrict the intake is a time limited access to the feeder, within a day, or among a week. For the latter, it is possible to reach a 80% intake by distributing the feed 5 days a week (no feed during the week end) (Lebas and Laplace, 1982). The same intake level (80% of AL) is obtained with a 8-hour access to the feeder (Szendrö *et al*., 1988; Jerome *et al*., 1998). But, the distribution procedure seems to give different effects on the digestive organs development: for example, the liver weight was higher in rabbits submitted to an intermittent restriction (5 days out 7) compared to those continuously restricted with a ration given daily. In addition, for the same restriction level (70% intake) the digestive tract development vary according to the technique used: the full digestive tract at 67 d of age was 12% heavier (compared to AL) when the feed was given 5 days a week, and 28% heavier when given daily (Lebas and Laplace, 1982). As reported by Jerome *et al*. (1998), giving the feed only during the day (8:00 to 18:00) reduced the feed intake by 20% (121 *vs.* 151 g/d for AL), while a feed access during the night only reduced the intake by 10% and growth by only 5% (*vs.* 12% for day feeding). Feed conversion was improved only for the day-feeding (2.67 *vs.* 2.93 for AL).
Besides, since the feeding behaviour of the growing rabbit corresponds to numerous meals (30 to 40 per day, Prud'hon *et al*., 1975), it is not possible to limit the intake of the growing rabbit only by reducing the access to the pellets, e.g. by reducing the width of the feeder.
In fact, to reach a correct control of the post-weaning intake, the more precise techniques is to give every day a defined quantity of pelleted feed, either manually (such as in experiments) or using automatic feeding equipments (now widespread in French rabbit farms). However, this quantity could be given in one time, or fractionated in several meals. Recent studies showed that giving a ration in 2 meals or even in 13 meals (to simulate the natural feeding behaviour) did not modify the health status, digestion, growth or feed conversion (Gidenne *et al*., 2009b,c; Martignon *et al*., 2009). Thus, the favourable effect of an intake limitation originates from the feed quantity itself and not from the feed distribution technique.
Furthermore, along the fattening period various restriction programs are possible: linear or not, step by step, continuous or alternate restriction periods, etc. The restriction program are thus adapted to the objectives of the farmers: health status improvement, feed costs reduction, reducing the pellets intake to favour the forage consumption (Yakubu *et al*., 2007), etc.

IMPACT OF A POST-WEANING FEED RESTRICTION ON GROWTH, FEED CONVERSION, ORGAN DEVELOPMENT AND CARCASS TRAITS

Weight gain and feed conversion according to the intake level

Obviously, an intake reduction leads to a growth reduction, during the period of intake restriction (Table 1). For instance, according to the results of Gidenne *et al*. (2009) obtained in 2002 on a multi-site study (6 sites and about 2000 rabbits per treatment), a linear reduction of the feed quantity offered to the rabbit, from weaning (35 d) and during three weeks, led to a proportional linear reduction of the growth: i.e. when the intake was reduced by 20% of AL (i.e. intake level=80% of "AL" *ad libitum*) the weight gain was proportionally reduced by 20%. However, this apparently "logic" proportional rule seems not to be generalised for the growing rabbit, since growth reduction obtained in several studies vary substantially, according to several factors, such the feed composition or the health status, etc.

Table 1 – Post weaning quantitative[£] reduction of the feed intake and growth of the rabbit.

Intake level[$]	Restriction // *ad libitum* period	Weight gain, under restriction (R), g/d	Weight gain after restriction (AL), g/d	Whole weight gain	Weight at the end of restriction, g	Weight, end of trial, g	Reference
100		38.1a			2028a		Lebas and Laplace, 1982
70	R: 35-56d	25.2b			1768b		
100	R: 35*-56d	49.6a	42.0a	45.8a	2175a	3059a	Perrier, 1998
70	AL:	28.2b	54.6b	41.6b	1729b	2877b	
50	56-77d	15.3c	62.4c	39.0c	1460c	2772b	
100	R: 28*-49d	42.2a		41.5a	1583a	2443a	Jérome *et al.*, 1998
80	AL: 63-70d	38.3b		37.4b	1505b	2268b	
100	R: 34*-58d	47.8a	38.3a	43.7a	1907a	2519a	Boisot *et al.*, 2003
80	AL:	41.3b	42.5b	41.8b	1772b	2451b	
60	56-70d	32.3c	47.7c	38.7c	1573c	2337c	
100	R: 32*-53d	51.4a	38.6a	46.2a	1908a	2438a	Foubert *et al.*, 2008a
70	AL: 53-67d	36.9b	46.5b	40.3b	1585b	2218b	
100	R: 42-77d	38.5a			2115a		Bergaoui *et al.*, 2008
85		34.6b			1995b		
70		29.4c			1740c		
100	R:	40.7a	46.1a	43.5a	1799a	2468a	Gidenne *et al.*, 2009a
80	35*-54d	32.3b	51.1b	40.8b	1624b	2373bc	
70	AL:	28.4c	54.6c	40.0b	1540c	2340c	
60	54-70d	23.0d	58.4d	38.2c	1431d	2279d	
100	R: 35*-63d	46.4a	39.9a	45.1a	2319a	2612a	Gidenne *et al.*, 2009b
75	AL: 63-70d	38.9b	47.6b	40.6b	2112b	2454b	
100	R: 35*-63d	45.7a	49.2a	46.4a	2352a	2724a	Gidenne *et al.*, 2009c
80	AL: 63-70d	37.8b	73.9b	44.8b	2100b	2650b	
100	R: 28*-53d	53.4a			1349a		Martignon *et al.*, 2010a
75		40.5b			1118b		

£: the limitation of intake is obtained by a daily manual distribution of a defined quantity of pellets.
$: in percent of the voluntary intake (100%= *ad libitum*); R= restriction period; AL = *ad libitum* period
*: age at weaning; a-c: significant difference between AL and R, within the same study.

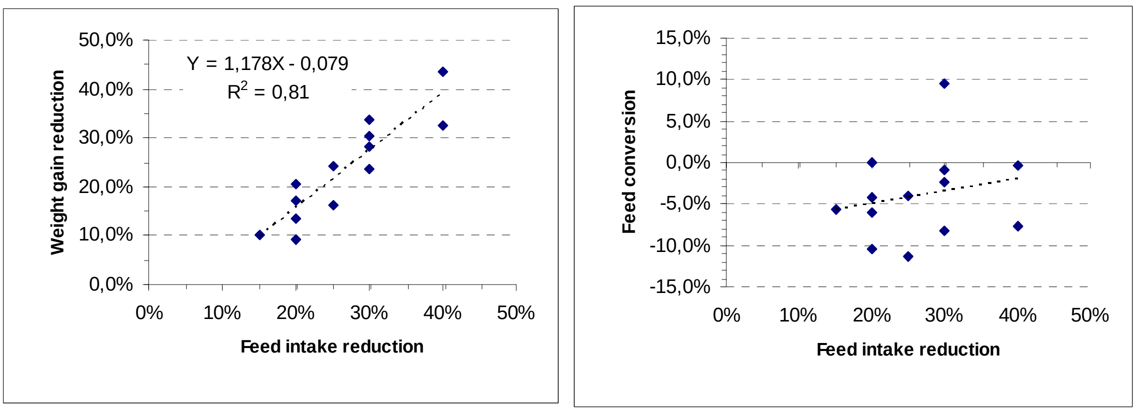
As showed in the figure 1, the growth reduction is globally lower than the intake reduction, during the post-weaning restriction period: for a 20% intake reduction, the growth reduction is meanly of 15.6%. For example, at the end of the restriction period the live-weight is reduced by 7 to 10% for restriction levels of 15 to 25% (Table 1, Boisot *et al*., 2003; Bergaoui *et al*., 2008; Gidenne *et al*., 2009a, b). Additionally, the impact of an intake limitation on weight gain is generally more severe at the beginning of the restriction period (often just after weaning) than after (Martignon *et al*., 2010a; Gidenne *et al*., 2009c). Moreover, the growth reduction seems also higher for a high digestible energy concentration in the feed (Duperray and Guyonvarch, 2009; Gidenne *et al*., 2009c).

Another interesting point is that the intra-cage variability is not affected by the restriction strategy (Tudela and Lebas, 2005). Thus, it shows that, in the same cage, heavy rabbits did not over-eat compared to lighter one (because of the feeding behaviour with numerous meals). This confirms that the growing rabbit adapts very well to intake limitation strategies (see also section following paragraph "Impact of a post-weaning feed restriction on feeding behaviour, welfare and digestive health").

During the restriction period, the feed conversion (FC) is generally slightly reduced (5 to 10%) or similar for R compared to AL rabbits (Figure 1), with a relatively large variations according to studies. In fact, the impact of an intake reduction on the FC is apparently dependant of the diet composition. For instance, for a high DE concentration Gidenne *et al*. (2009c) did not find any effect of the restriction on FC, while for a standard DE content it was reduced by 10% (Table 2).

After restriction, when animals are again fed *ad libitum*, a compensatory growth was always found, and the intensity of this compensatory growth is related to the intensity of the restriction (Table 1). For a 40% restriction the weight gain could 20 to 30% over the weight gain of control (always fed AL), and could reach very high value, such as almost 74 g/d (Table 3; Gidenne *et al*., 2009c). The remarkable ability of the young rabbit for a compensatory growth after a restriction period was already outlined almost 30 years ago (Lebas and Laplace, 1982; Ledin, 1984) and more recently using various restriction techniques (Table 2 and Tumova *et al*., 2002; Matics *et al*., 2008). Nevertheless, even after two weeks of a free intake, the slaughter weight of restricted rabbits remains 5 to 10% lower than control.

But, the most interesting point is that the intake of R rabbits remains generally lower or similar to control. Accordingly, the feed conversion was then highly improved for R animals reaching a reduction of 40% to 50% for a 30 to 40% restriction (Table 2). This FC improvement was observed whatever the diet composition. After a restriction period, contrary to what was expected, no over intake was observed, that is at *"the origin"* of the better FC. Possibly, the rabbits cannot overeat, even after a hard restriction, because its stomacal volume cannot be enlarged quickly, and is more adapted to numerous meals (Gidenne and Lebas, 2006).



Data from table 1, for a usual restriction range of 0 to 40%

Figure 1 – Growth and feed conversion reductions according to the intake reduction, during the post-weaning restriction phase of the growing rabbit.

Therefore over the whole fattening period (R+AL period), and depending of the intake limitation strategy chosen, the final live weight of restricted rabbits is obviously lower compared to control (Table 1). But after returning to a free feeding the growth impairment is lower than expected since a compensatory growth occur without an over consumption. Thus, the overall feed conversion is generally improved by 10 to 20% after the application of a post-weaning strategy of intake restriction (Table 2). Consequently, when an intake limitation strategy is applied, the margin on the feed cost is generally improved by 2 to 10% (Duperray and Guyonvarch, 2009). Nevertheless, in one recent study performed on spanish rabbit breeding system (Romero *et al*., 2010), a sharp impairment of the growth and feed conversion was found after a 2 weeks restriction (35-49d, about 80% of AL), that questioned about the economic pertinence of such a strategy in these conditions.

Table 2 – Post weaning quantitative[£] reduction of the feed intake and feed conversion of the rabbit.

Intake level[$]	**Restriction // *ad libitum* period**	**Feed conversion (R)**	**Feed conversion (AL)**	**Feed conversion, whole period (R+AL)**	**Reference**
100	R:	3.75a			Lebas and
70	35-56d	4.11b			Laplace, 1982
100	R: 35*-56d			3.74a	
70	AL:			3.66ab	Perrier, 1998
50	56-77d			3.56b	
100	R: 28*-49d	2.19a		2.93a	Jérome *et al*.,
80	AL: 63-70d	1.96b		2.73b	1998
100	R: 34*-58d	2.36a	4.37a	3.13a	
80	AL:	2.26ab	3.21b	2.70b	Boisot *et al*., 2003
60	56-70d	2.18b	2.85c	2.57b	
100	R: 32*-53d	2.19	4.04a	2.75a	Foubert *et al*.,
70	AL: 53-67d	2.17	2.89b	2.49b	2008a
100	R: 42-77d	3.93a			
85		3.71ab			Bergaoui *et al*., 2008
70		3.61b			
100	R:	2.49	2.93a	2.69a	
80	35*-54d	2.49	2.43b	2.54b	Gidenne *et al*.,
70	AL:	2.43	2.32bc	2.46bc	2009a
60	54-70d	2.48	2.02c	2.38c	
100	R: 35*-63d	2.99a	4.84a	3.31a	Gidenne *et al*.,
75	AL: 63-70d	2.65b	4.53b	3.04b	2009b
100	R: 35*-63d	2.83a	3.15a	2.85a	Gidenne *et al*.,
80	AL: 63-70d	2.66b	2.30b	2.55b	2009c
100	R: 28*-53d	2.19			Martignon *et al*.,
75		2.10			2010a

£: the limitation of intake is obtained by a daily manual distribution of a defined quantity of pellets.
$: in percent of the voluntary intake (100%= *ad libitum*); R= restriction period; AL = *ad libitum* period
*: age at weaning; a-c: significant difference between AL and R, within the same study.

Organ development, slaughter yield and carcass characteristics

In parallel to a post-weaning growth reduction, a restriction strategy also modifies the body composition. According to the general rule tissues allometry deposition (Cantier *et al*., 1969; Dalle Zotte and Ouhayoun, 1998), the restriction leads to changes in differential growth for the internal organs (liver, digestive tract, etc.) and tissues (muscles, fat, etc.). According to Pálsson (1955), early development tissues (bones, digestive tract) should be more impaired during the restriction comparatively to late ones (muscles and adipose tissue). Thus, the digestive tract development (organ weight) is impaired during the restriction (Schlolaut *et al*., 1978, Perrier et Ouhayoun, 1996). In return, after a restriction period, during the compensatory growth associated to a free intake (AL) the growth of digestive organs is very high (Ledin, 1984). For instance, at slaughter, the stomach and digestive organs (such as the liver) are proportionally heavier comparatively to AL animals (Lebas and Laplace, 1982). However, this increased development of the digestive tract would be dependant of the restriction strategy and of the weight gain (Jérome *et al*., 1998). Finally, the weight of the full digestive tract (organ + digesta) is about 10% higher (Table 3) and participates significantly to the body compensatory growth. But, the increased in digesta content seems the major factor of increase of the full digestive tract. Accordingly, the dressing out (slaughter yield) is reduced by about 2 unit (Table 3), and seemed not closely dependant of the restriction strategy (duration or level of intake). In addition, a minimum length for the restriction period seems necessary, since Tumova *et al*. (2006) did not find any change in dressing percentage for a moderate restriction (70% of AL for 1 or 2 weeks and a re-feeding period of 2 weeks).

Table 3 – Impact of a post weaning quantitative[£] reduction of the feed intake on the slaughter yield and some carcass characteristics of the rabbit.

Intake level[$]	Restriction // *ad libitum* period	Full digestive tract weight (% LW)	Dressing out, %	P+IS[µ] fat (% LW)	Reference
100	R: 28*-49d	17.9	58.3		Jérome *et al*.,
80	AL: 63-70d	18.9	56.9		1998
100	R: 35*-60d		70.2a	1.7a	Bovera *et al*.,
80	AL:60-81d		67.6b	1.3b	2008
100	R: 32*-53d		57.5	2.3a	Foubert *et al*.,
70	AL: 53-67d		56.6	1.6b	2008a
100	R: 42-77d	20.1a	56.4a	1.9	Bergaoui *et al*.,
85		21.1ab	55.3b	1.7	2008
70		23.4b	54.1c	1.3	
100	R:		56.1a		
80	35*-54d		54.6b		Gidenne *et al*.,
70	AL:		55.4b		2009a
60	54-70d		54.8b		
100	R: 35*-63d	16.8a	56.4a	2.3a	Gidenne *et al*.,
75	AL: 63-70d	19.8b	54.5b	1.7b	2009d

£: the limitation of intake is obtained by a daily manual distribution of a defined quantity of pellets.
$: in percent of the voluntary intake (100%= *ad libitum*); R= restriction period; AL = *ad libitum* period
*: age at weaning; a-c: significant difference between AL and R, within the same study.
µ: P+IS= perirenal + interscapular fat
a, b: significant difference between AL and R, within the same study.

Reversely, after re-feeding freely, although the growth increase should profit more to tissues and organs having a late development (such fatty tissues, Ouhayoun, 1998), at slaughter the carcass fattening level remains lower whatever the restriction strategy used: the weight of perirenal and interscapular fat is about 0.5 unit (%) lower, and seemed related negatively to the intake level (Table 3). Besides, Gondret *et al*. (2000) showed that changes in the nutritional status (through a feed restriction) regulate intramuscular lipid deposition, without changing fibre-type composition.
Besides, a restriction strategy seemed not to modify other carcass characteristics or meat quality, such as carcass conformation, meat colour, cooking losses, meat/bone ratio

water holding capacity, pHu, fibre type, (Perrier, 1998; Dalle Zotte *et al.*, 2005; Tumova *et al*., 2006; Gidenne *et al*., 2009a, d).

IMPACT OF A POST-WEANING FEED RESTRICTION ON DIGESTIVE PHYSIOLOGY

Impact of reduced intake on feed digestion and rate of passage.

The improvement of the feed conversion (Table 2) during the restriction and moreover after restriction (during re-feeding freely) should be associated to an improved feed digestion. Effectively, most of the studies reported an improvement of the faecal digestibility, either during restriction (Table 4), or after restriction during re-feeding freely (Table 5).

Table 4 – Impact of a post weaning reduction of the feed intake on the nutrient digestion.

		Digestibility coefficient**: unit deviation from the control (AL= 100)			
Intake level$	**Restriction // *ad libitum* period**	**organic matter**	**crude protein**	**N.D.F**	**Reference**
100	R: 35*-72d	66.8a	77.9a		Ledin, 1984a
50		71.0c	84.0c		
60		68.2b	82.0b		
100	R:about 45d-75d	57.5a	64.6a	27.8	Ledin, 1984b
60		66.8b	74.3b	52.3	
100	R:40-64d	63.7a	70.0a	19.6	Xiccato *et al.*, 1992
75		64.7b	72.5b	20.0	
100	R: 45-60d (digestibility calculated for the 15d period)	76	85	25	Diaz Arca *et al.*, 1999
60		75	87	23	
40		74	86	21	
10		73	85	-0.13	
100	R*35-85d	63.5a	79.8	19.1a	Di Meo *et al.* 2007
90		66.0b	79.9	24.5b	
100	R 42-49d	39.2	68.6a		Tumova *et al.* 2007
≈60		44.2	70.6b		
100	R:35*-54d	71.9	82.1	29.9	Gidenne and Feugier, 2009
80		71.7	82.1	29.3	
70		72.7	83.5	30.1	
60		72.8	83.7	30.1	
100	R: 35*-63d control diet	64.2a	72.0	29.1a	Gidenne *et al.*, 2009c
80		58.1b	71.0	17.0b	
100	R: 35*-63d high DE diet	63.8a	73.7	32.5a	
80		68.9b	80.8	40.9b	
100	R: 35*-63d	60.3a	70.1a	14.5	Gidenne *et al.*, 2009d
75		62.7b	76.2b	17.3	

$: in percent of the voluntary intake (100%= *ad libitum*) ; R= restriction period.
*: age at weaning ; a-c: significant difference between AL and R, within the same study.
**: digestibility measured during the restriction period; µ: digestibility calculated at 77d, with a marker procedure.

However, this improvement is not consistent according to the restriction intensity and its duration, and according to the diet composition. For instance, only 7 days after the application of the restriction strategy, the faecal digestibility coefficient of the organic matter (or energy) was not significantly affected, even for a 40% reduction of the intake level (Gidenne and Feugier, 2009). Without a delay of adaptation, Diaz Arca *et al.*

(1999) failed to detect an effect of the intake level on digestion, even when the intake was reduced to 10% of the voluntary food consumption.

Table 5 – Nutrient digestion of the growing rabbit, previously restricted.

		Digestibility coefficient**: unit deviation from the control (AL= 100)			
Intake level$	**[Restriction] // *ad libitum* period**	**organic matter**	**crude protein**	**N.D.F**	**Reference**
100	[R: 35*-72d]	65.3ab	74.4a		
50	AL: 72-99d	63.9a	73.7a		Ledin, 1984a
60		66.7b	77.3b		
100	[R: 42-56d]	53.9	77.2		Tumova *et al*.,
≈60	AL : 56-63d	61.8	78.7		2007

$: in percent of the voluntary intake (100%= *ad libitum*); R= restriction period; AL = *ad libitum* period
*: age at weaning; a, b: significant difference between AL and R, within the same study.
: digestibility measured **after the restriction period, when rabbits are again fed *ad libitum*.

During intake restriction, an improvement of the growing rabbit digestion seems thus to be reached only after an adaptation delay, of at least 8 to 10 days. An increase in protein digestion was often observed for growing rabbits (Xiccato *et al*., 1992; Gidenne and Feugier, 2009), or for adult rabbits (Lebas, 1979; Xiccato and Cinetto, 1988, Fodor *et al*., 2001). Similarly, in these studies the authors found in restricted animals a better digestive efficiency for energy, but few improvements in lipid or fibre digestion. After restriction, since the feed conversion is sharply improved, we expect logically a sharp increased in digestion efficiency. But, few studies deal with this point (Table 5) and results are not consistent.
Besides, the impact of the restriction seems lower in heavier or adult rabbits: Ledin (1984b) find slight changes in digestibility, while Gidenne (1987) did not find any significant changes in the digestion of high-fibre diets. In return, Lebas (1979) obtained a higher digestibility for restricted pregnant females.
Since the data of literature report large variations for the relationship between digestion and restriction, we can assume that the chemical composition of the feed would play a key role. For instance, a significant interaction have been outlined by Gidenne *et al*. (2009c), between intake level and DE dietary concentration on the faecal digestibility (Table 4), and should be further explained.

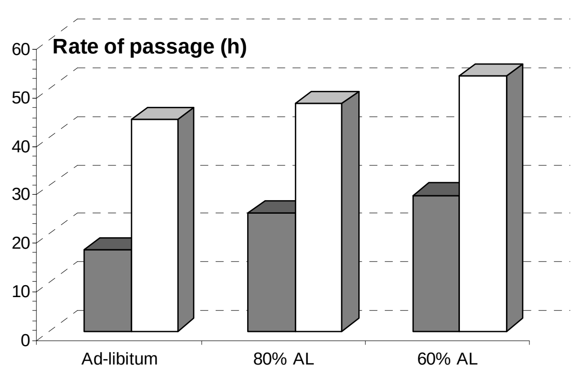


Figure 2 – Rate of passage according to the intake level of the growing rabbit (Gidenne and Feugier, 2009).

Improvement in digestion could originate in physiological changes in the intestine (enzymes secretion, mucosa absorption, etc.), and for instance in a longer retention time of digesta particles in the caeco-colic segment. A 40% reduction of the intake level led to a 65% increase in the retention time of particles (Figure 2). With similar intake levels, a similar increase in digesta retention was observed by Ledin (1984b), while with more fibrous diets Gidenne *et al*. (1987) reported only a 25% increase. Longer retention time in restricted rabbits originated mainly from the first 24 h of marker excretion. However, the impact of the intake level should be more precisely measured, by maintaining a similar delay between marker administration and caecotrophy, that is largely moved in restricted compared to AL rabbits (Laplace and Lebas, 1975; Gidenne and Lapanouse, 1997). Reversely, Fioramonti and Ruckebush (1974) observed no motricity response of the caecum in the rabbit fed *ad libitum*, probably because the caecum is constantly in a repletion status. In return, when adapted to eat in one meal (and thus restricted), there is an increased frequency of caecal contractions before the meal time. Moreover, hungry animals ate a high quantity of food in a short time, and this prolonged the motor activity of the small intestine (Ruckebusch *et al*., 1971). Therefore, applying a restriction strategy to rabbits probably modifies the motor activity in all segments of the tract, and between meals there is a period with a digestive vacuity.

Restriction and digestive physiology

Applying a reduced intake after weaning may impair the maturation of the gut, that evolved quickly in the young rabbit. For instance, the ileal *villus* height and area and crypt depth increased after weaning (Gallois *et al*., 2005), but was not affected by a 25% reduction of the intake from 28 d (weaning) to 53 d of age (Martignon *et al*., 2010a). Also, it is acknowledged that the digestive enzyme secretion is related to substrate availability (i.e. intake level). But, under restriction, ileal maltase activity was not affected (Martignon *et al*., 2010a), and further studies should be realized.

Intake restriction obviously increases the appetite, since the young rabbits eat their ration in 6 to 10 h instead of 24 h (see “Feeding behaviour and welfare” section). Accordingly, the flow of *digesta* in the stomach is rather high just after the feed distribution. Thus, in both stomach parts (antrum and fundus) a higher pH was found for restricted animals compared to control ones (Gidenne and Feugier, 2009; Martignon *et al*., 2010a). This decrease in pH is probably transitory and might be related to a dilution of secreted gastric acidity because of the large meal eaten by restricted animals in a reduced time.

Reversely, in the caecum, lower caecal pH was observed for restricted rabbits and was related to higher VFA concentration (Gidenne and Feugier, 2009). However, since the transit of digesta is about 4 to 6 h from mouth to ileum, a high flow of digesta enter the caecum at 13:00 for restricted animals, thus leading to a "peak" of fermentation (Gidenne and Bellier, 1992). In return, Maertens and Peeters (1988) or Taranto *et al.* (2003) observed a higher pH and a lower VFA concentration in the caecum of young restricted rabbits, since measurements were done in the morning (9-10 h) just after meal distribution and thus before the peak of digestion in the caecum. Therefore, when the caecal sampling occurred within a similar delay from the meal (or the main intake period for AL rabbits), as done by Martignon *et al*. (2010a), the intake limitation seemed not to greatly influence the physico-chemical parameters (pH, VFA) of the caecal biotope, although the redox potential was slightly reduced. Besides, the fibrolytic activity of the caecal bacteria is not affected by the intake level (Gidenne and Feugier, 2009; Martignon *et al*., 2010a). Similarly, the intake level had no significant effect on the number of bacterial 16S rDNA copies per gram of caecum content, and did not influence the bacterial community structure or diversity (Martignon *et al*., 2010a). This lack of effect can be due to both the relatively constant composition of the material

entering the caecum located at the end of the digestive tract and the buffering capacity of the caecal content. However, the bacterial diversity and structure was approached through a CE-SSCP profiles analysis that only took the major bacterial populations into account. More targeted analyses of *Archaea* or of some predominant bacteria species of the caecal microbiota, such as *Firmicutes* or *Bacteroidetes,* could reveal changes that were not addressed by the fingerprint approach, and that may explain the higher resistance of the restricted rabbits to digestive troubles (see “Digestive health of the growing rabbit according to the intake level after weaning” section).
In the same way, the immune status of restricted rabbits was shortly described through some blood characteristics, such as the cell profile. For instance, Tumova *et al*. (2007) reported an increased number of lymphocytes in restricted rabbits. However, the immune status of the growing rabbit is still very scarcely studied.

IMPACT OF A POST-WEANING FEED RESTRICTION ON FEEDING BEHAVIOUR, WELFARE AND DIGESTIVE HEALTH

Feeding behaviour and welfare

As shown in the figure 3, the rabbit adapts very quickly to a restriction strategy, with a very high intake just after the feed distribution, that reached 40% of the daily intake (within two hours) only 8 days after the application of the intake restriction, and decreased to 32% 10 days later (Martignon *et al*., 2009).

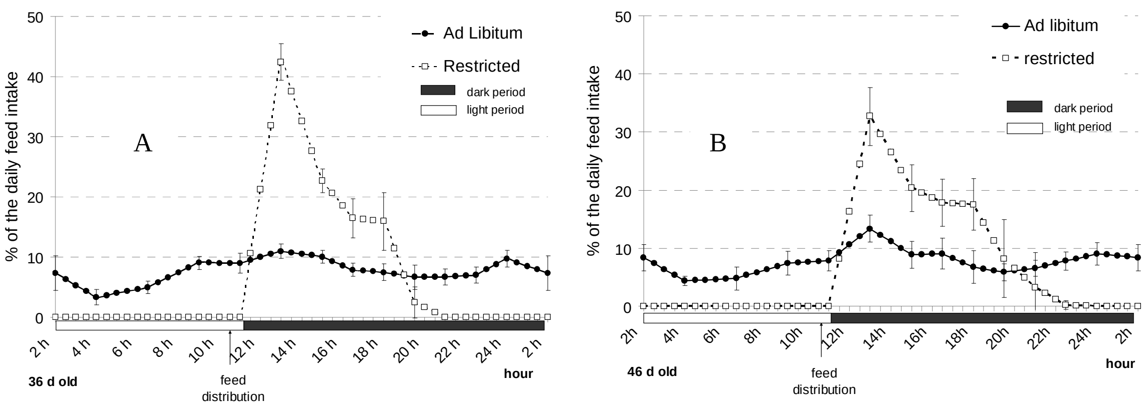


Figure 3 – Feed intake patterns at 36 d (A) and 46 d (B) of age according to the intake level: *ad libitum vs.* restricted (75% of AL) after weaning at 28 d.

In comparison, the rabbit fed freely shows a relatively smooth intake behaviour, with numerous meals, characterised by a maximum of 10% of the daily intake 2 to 4 h after lighting out, and a minimal intake 2-4 h after lighting, that correspond probably to the caecotrophy period. Over the day, the whole meal is totally consumed within 8 hours, for 10 weeks old rabbits restricted at 85% of the AL and having one feeder (1F) in their cage (Figure 4, Tudela and Lebas, 2006), meaning that the rabbit starved for 14 hours a day. Contrary to what was expected, when the rabbit have two feeders (2F), the competition for feeding is reduced and they ate more slowly: the whole meal is consumed within 12h instead of 8h (Tudela and Lebas, 2006). Obviously for higher restriction level, the duration of the starvation increases, but it also depends of the voluntary intake level of the rabbit: for example under a hot climate, Bergaoui *et al*. (2008) reported that the whole meal was consumed within 16 h for a 85% intake level (and within 10 h for a 70% intake level).

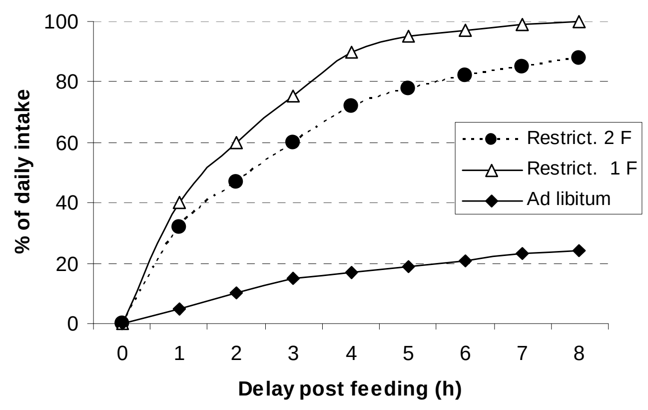


Figure 4 – Intake pattern for restricted (85% of AL) and *ad libitum* rabbits (10 weeks old).

As expected, restricted rabbits showed a strong feeding activity during the first hours following the feed supply, with an average of 4 out of 6 rabbits eating (Martignon, 2010). Conversely, *ad libitum* rabbits had a feeding activity quite balanced along a the day, with two main feeding periods: at the first hour of the dark period (1.7 out of 6 rabbits eating) and 2 hours before the lightening period (2 out of 6 rabbits). Although the feeder was empty, the restricted rabbits continued to visit the feeder until the next feed supply. The number of meals and the total duration spent to eat during a 24 h period were sharply lower for restricted rabbits compared to the AL : n=27 for 2h30min, and n=41 for 3h17min for AL.

Simultaneously the number of drinks is also reduced: n=38 *vs.* 47 for R and AL rabbits (Martignon, 2010). But in fact the quantity of water consumed is higher for restricted rabbits. As reported by Boisot *et al*. (2005), the ratio feed to water is doubled for rabbits restricted to 65% of AL, passing from 1.68 to 3.46 (Figure 5). These authors also reported that a similar 35% reduction of the intake could be obtained with a one hour access to the drinker, and then the ratio water/feed fell to 1.20. Such a water restriction strategy, used for experimentation, is not encouraged in field condition, since it is questionable respect to the welfare of the animal.

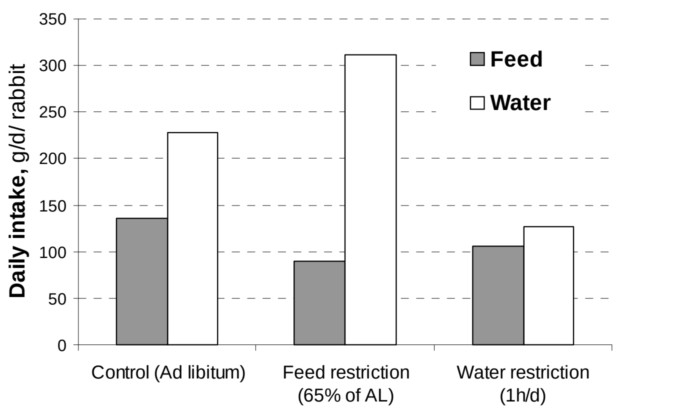


Figure 5 – Water and solid feed intake for restricted growing rabbits, either through a reduced quantity of pellets, or through a reduced time access to drinker.

Once rabbits are fed freely again, their circadian eating and drinking activity was higher compared to control animals (number of meals = 48 for R *vs.*. 38 for AL; total meal duration = 4h17min *vs.*. 2h32min for AL; number of drinks = 40 for R *vs.*. 36 for AL), and it re-adapt very quickly (within two or three days) to a "classical" feeding behaviour, balanced along 24 hours (Martignon, 2010).

Face to these abrupt changes in feeding behaviour, the faecal excretion pattern, including caecotrophy is deeply modified, as shown in figure 6. For restricted rabbits, the faecal excretion peak occurred between 5 to 8 hours after the feed supply, thus about three to four hours later than the eating peak. Accordingly, the caecotrophy period is moved and is located about 8 to 10 h after the feed distribution, as already observed by

Fioramonti and Ruckebusch (1974) on adult rabbits fed one time a day. In return, the ratio soft to hard faces seemed not modified (Martignon, 2010).

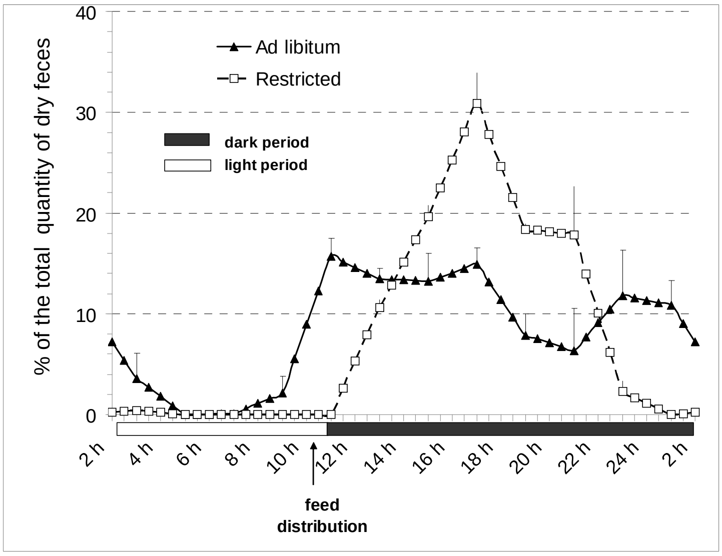


Figure 6 – Fecal excretion pattern (47 d old), according to the intake level: *ad libitum vs.* restricted (75% of AL) after weaning at 28 d.

Since for restricted rabbits the competition to access the feeder is high during the first hour after the feed distribution, we expect some hostile even aggressive behaviour. In fact, Martignon (2010) did not observe any increase of aggressiveness and no more lesions for R rabbits. In consequence, applying a short-term restriction strategy will not completely follow one the 5 rules of the Farm Animal Welfare Council (http://www.fawc.org.uk/freedoms.htm): Freedom from Hunger and Thirst. However, considering a 24h period, the rabbit expressed a transitory hunger (and not thirst, except for a strategy limiting the access to drinker) and its growth is not greatly impaired for a moderate restriction (under 70% of AL). In return, a limited intake strategy will support the third rule "Freedom from Pain, Injury or Disease", since many studies report an improvement in digestive health of the young rabbit (see following section).

Digestive health of the growing rabbit according to the intake level after weaning.
Preliminary to review this point, a brief recall about the method to estimate health status of a group of animals is pertinent respect to the growing rabbit digestive health. A common indicator to evaluate the impact of a disease in breeding is the mortality rate. More recently, morbidity indicator was developed for the growing rabbit to assess more precisely the incidence of the clinical symptoms (Gidenne *et al*., 2010), and it could be combined with mortality to obtain the health risk index ("HRi"= morbidity + mortality rate). This approach allows a more precise assessment of the health status. Thus it means that a large number of animals are required to detect a significant difference between two treatments in mortality. For instance, to detect a 10% deviation among two mortality rates (at a risk level of 5%), more than about 90 rabbits are required in each group (and over 300 rabbits to detect 5% deviation). Similarly, assessing the morbidity level, using clinical symptoms (diarrhoea, caecal impaction, etc.) is relatively easy. In return, when only a reduction of growth rate is detectable, a threshold must be defined to class the animal as morbid or not (such as the average minus 2 × standard deviation), and it needs a large set of rabbits within a group to define the mean and its range of variation. Therefore, except for specific trials implying an experimental inoculation of a pathogen, were hereunder review the results from studies using a minimal number of rabbits to assess correctly the health status according to the intake level.

First large-scale trials dealing with the impact of reducing the intake level on the digestive health were performed in 2002, by a French network of experimental units (n=6, GEC group). First results were published in 2003 (French Rabbit Congress), indicating a half lower mortality and morbidity rate, from spontaneous ERE or non specific enteropathy, when rabbits were submitted to a 60% intake level during three weeks after weaning (Table 6, Gidenne *et al.*, 2009a). In parallel, other trials were performed to assess if a restriction strategy would be efficient against the Epizootic Rabbit Enteropathy (ERE). For instance, Boisot *et al.* (2003) reported that a 65% intake level (or a 1 h drinking access) reduced mortality rate, after an ERE inoculation (Figure 7), and this was confirmed by the study of Foubert *et al.* (2008b). More recently, Martignon *et al.* (2010b) reported that a restriction at 80% of AL had no significant impact for rabbits infected experimentally with an enteropathogenic *E. coli* (0128:C6), and she did not detect a favourable effect of the restriction under a spontaneous colibacillosis (Martignon *et al.*, 2009). Therefore, further studies are necessary to confirm this differential effect of the intake level for this two digestive pathology, and to understand the underlying physiological mechanisms implicated.

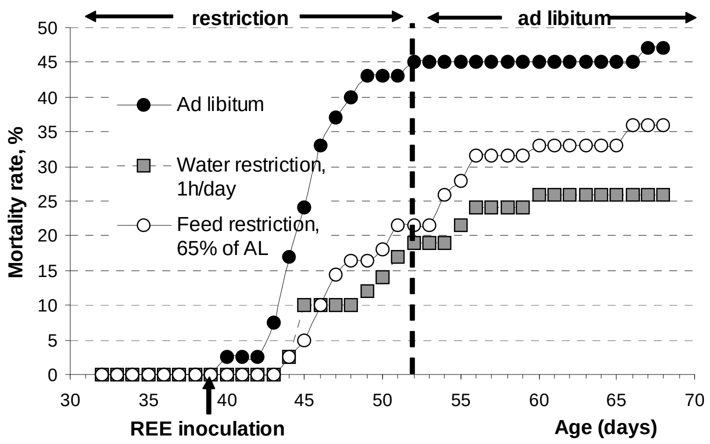


Figure 7 – Mortality rate after ERE inoculation, according to the restriction strategy.

Using large scale experimental design (over 400 rabbits per group on several sites), Gidenne *et al.* (2009a) showed an almost half reduction of the mortality and morbidity for restricted animals (Table 6), for a minimum level of intake reduction of 20%. This effect was confirmed in a further study (Gidenne *et al.*, 2009b), where no effect of distributing the meal in one or two times was detected on health status. Martignon *et al.* (2009) confirmed that the favourable impact of the restriction originated clearly from the quantity of feed distributed and not from the distribution procedure. However, this favourable impact of a reduced intake seems to occur only during the "restriction" period, and is not prolonged when animal return to a free intake (Gidenne *et al.* 2009a; Romero *et al.*, 2010).

Similar results were also obtained by reducing the intake level through a time limited access to drinking water (Boisot *et al.*, 2004; Verdelhan *et al.*, 2004, Elmaghraby, 2011).

Since a lower intake led to growth reduction, Gidenne *et al.* (2009c) compared standard to high-energy feed, for *ad libitum* or restricted growing rabbits, to obtain a favourable impact on health without growth impairment. Unfortunately, first results indicated that restricting rabbits with a high-energy feeds seemed not as efficient as a standard feed to "protect" against digestive troubles. Szendrö *et al.* (2008) reached similar conclusions using two rabbit lines.

Table 6 – Impact of a post weaning reduction of the feed intake on the mortality and morbidity from digestive troubles in the growing rabbit.

		Restriction period		**Whole period (R+AL)**		
Intake level[$]	**Restriction // *ad libitum* period**	**Mortality, %**	**Morbidity, %**	**Mortality, %**	**Morbidity, %**	**Reference**
100	R:35*-54d	12.2a	12.0a	17.6a	11.9a	Gidenne *et al.*, 2009a
80	AL:54-70d	5.5b	11.2a	12.4b	11.2ab	
70	(n=496 rab./ group)	5.4b	5.4b	15.0ab	6.7b	
60		2.8b	6.7b	11.9b	5.6b	
100	R: 35*-63d	19.9a	15.3a	21.6a	18.7a	Gidenne *et al.*, 2009b
75	AL: 63-70d (n=503 rab./ group)	10.7b	10.2b	11.9b	14.0b	
100	R: 35*-63d	30.6a	21.1			Gidenne *et al.*, 2009c
80	(n=170 rab./ group)	25.3b	19.4			
100	R:28*-51d	5.6	13.8			Martignon *et al.*, 2009
80	(n=160 rab./group)	3.8	17.5			
100	R:35*-49d	22.9a	33.3a	25.6a	41.4a	Romero *et al.*, 2010
85	AL: 49-63d (n=96 rab./ group)	4.2b	8.1b	6.3b	12.7b	
100	R:35*-84d	29.5a		12.5		Szendrö *et al.*, 2008
90	(n=40 rab./ group)	28.1a		0		
80		4.8b		3.1		
100	R:35*-63d			12.5		Elmaghraby M. *et al.*, 2011
87	AL: 63-77d			0		
73	(n=32 rab./ group)			3.1		

$: in percent of the voluntary intake (100%= *ad libitum*); R= restriction period; AL = *ad libitum* period
*: age at weaning; a, b: significant difference between AL and R, within the same study.
a, b: significant difference between AL and R, within the same study.

Finally, physiological mechanisms explaining such a favourable effect of reducing the intake level on diarrhoea incidence remained to be elicited. Many metabolic parameters are modified under restriction, as reported for the rabbit by Van Harten and Cardoso (2010). So, an interdisciplinary approach should be pertinent to explore more precisely the response of the young rabbit under restriction or not, and to correlate the inflammatory response, the immune status or the symbiote maturation (stability, diversity) to the intake level.

CONCLUSIONS AND PERSPECTIVES

Since 2003, strategies for limiting the intake after weaning are largely applied in France by rabbit breeders. This is combined with the improvement of materials to control the feed distribution, and particularly automatic feeding system using a chain conveyor for pellets. French private feed companies are improving the strategies to make it easy to control, such a fixed duration of feeding during the night technique (Weissman *et al.*, 2009).

Presently, about 95% of the professional are using a restriction strategy with or without an automatic feeding equipment. But, over the favourable on digestive health (particularly for ERE syndrome), French breeder used a restriction strategy to reduce the feed costs, since the feed conversion of the restricted rabbit is improved. Globally, the margin on the feed cost is estimated to 0.30 € per weaned rabbit. In addition, it is possible to add a reduction of the drug consumption (estimated to about 0.10 to 0.15 €

per rabbit in France). However, an economic balance improvement is also dependant of the price of the feeds, of the national market, and particularly of the slaughter weight. For instance, for light slaughter weights (such in Spain) the economic interest of the restriction strategies may be reduced (Romero *et al*., 2010).
Thus, an intake limitation strategy should be suited to every breeding situation, according to the aims of the farmers: improving health status, reducing feed costs, standardising performances, etc.

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