FEED EFFICIENCY IN RABBIT PRODUCTION: NUTRITIONAL, TECHNICO-ECONOMICAL AND ENVIRONMENTAL ASPECTS

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ABSTRACT

Feed accounts for the largest part of the production costs in animal production. Therefore feed efficiency, mostly expressed as feed conversion ratio (FCR), is a key indicator to judge the performance and profitability of a farming system. In intensive rabbit breeding, the global farm FCR (maternity + fattening units) decreased from 3.8 to 3.4 in European farms during the past 15 years. By consequence, nitrogen and phosphorus output were reduced by approximately 10%. This improvement sources from a joint progress in: health control, nutritional factors and strategies, management and genetic progress. In order to optimize farms' FCR both the reproducing stock as the fattening unit have to be considered. This review summarizes the impact of different strategies to optimize FCR under intensive production conditions, in which rabbits are fed exclusively a pelleted diet. High performing reproduction stock results in a reduced FCR in the maternity. The use of diets with nutrient levels to optimize digestive health, together with an appropriate feeding restriction after weaning, leads to minimal losses and has a large impact on the FCR. If the different fibre requirements are met, an increase of the dietary energy level, especially in the finishing stage, reduces the FCR with approximately 0.15 points for an increase of 0.5 MJ DE. In the future, it seems possible to improve further the feed efficiency, and thus to reduce both the inputs and output to reach a global farm FCR of 3.0, similar to that recorded in pig breeding.

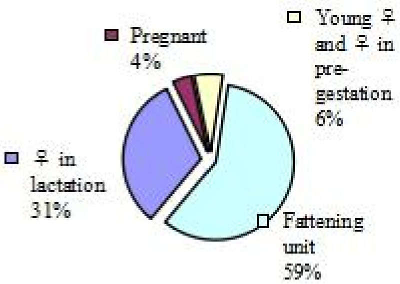
Key words: rabbit farming, feed efficiency, management, environmental release

INTRODUCTION

Feed accounts for the largest part of the production costs in animal production, and could reach up to 70% of total costs according to the investments. Therefore, feed efficiency is a key criterion to improve the sustainability of the farm, both to improve economic balance and to reduce the environmental releases. For example the weight of the feed cost in the economic result (profit) of the farm varies strongly according to the feed conversion ratio (FCR). On average, in 2006 in France, FCR was responsible for 30 % of the variation of the feed cost margin while this was only 9% and 7% for the feed price and the rabbits' sale price, respectively (Jentzer, 2008).

Rabbit production is nearly exclusively executed in closed farms, housing both the does and the fatteners. Artificial insemination and a batch management system are widespread with a 6 weeks reproduction cycle as the most common production system (EFSA, 2005). In such rabbitries, depending of the weaning date and slaughter weight, about 31% of the feed is consumed by the lactating does (Figure 1), 10% by non-lactating and young parent stock and 59% by the growing rabbits (Maertens, 2010).

In French rabbit production systems, feeding costs represented in 2010-2014 between 55 and 60% of the production costs (Coutelet, 2015). Presently, the production costs of meat rabbits are 20-30% higher than in pigs and almost twice those of in poultry (Maertens, 2009). In view of being competitive with these animal productions, a reduction of the feeding costs is of primarily importance. For this reason, this review considers different possibilities for optimizing FCR under intensive production conditions in which rabbits are fed exclusively pelleted diets. In more extensive production systems, when e.g. using local available forages, a different approach has to be used (Oseni and Lukefahr, 2014).



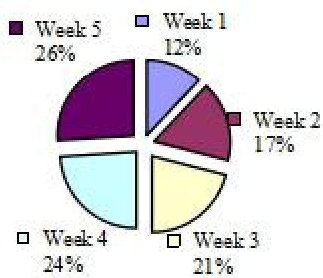


Figure 1. Distribution of the feed consumption in a rabbitry using a 42-day reproduction cycle, weaning at 35 days and a production level of 50 fatteners/doe/year. (a) Closed farm; (b) In the fattening unit (Maertens, 2010).

Table 1. Performances of French rabbit farms between 1999 and 2014 (Adapted from Lebas, 2007 and Coutelet *et al*., 2015).

YEAR	SLAUGHTER WEIGHT	GLOBAL FCR	N° OF WEANED / DELIVERY	N° OF WEANED /FEMALE / Y	NUMBER OF SOLD /♀ / YEAR
1999	2.410	3.83	7.16	55.3	49.0
2000	2.430	3.75	7.84	53.4	47.8
2001	2.410	3.73	7.95	52.0	46.6
2002	2.430	3.70	7.86	51.7	46.2
2003	2.400	3.70	7.75	50.0	44.6
2004	2.420	3.64	7.91	51.8	46.9
2005	2.450	3.57	8.06	54.9	49.4
2006	2.450	3.60	8.04	55.0	50.3
2007	2.470	3.57	8.14	56.0	51.5
2008	2.470	3.53	8.20	56.9	52.5
2009	2.500	3.51	8.17	54.7	50.6
2010	2.470	3.44	8.25	54.0	50.2
2011	2.470	3.40	8.34	54.3	49.9
2012	2.460	3.48	8.43	56.2	51.1
2013	2.470	3.30	8.51	57.7	53.3
2014	2.470	3.31	8.57	57.3	52.3

In practice, the feed conversion ratio "FCR" (see below for definitions) is the essential criterion to monitor the feed efficiency (FE). Data are available for fattening rabbits, but very few for reproductive females and their litters (before weaning).

The global FCR covering the whole farm (reproduction and fattening units) ranged between 3.30 and 3.75 since 2000 for conventional rabbit farming (intensive systems), and is improved regularly along years (Table 1). In order to optimize farms' FCR we must consider both the reproducing unit as the fattening unit. A lot of factors influence the FCR, being the most important factors: breeding management (e.g. efficiency of the reproduction), the genetic potential of the animals, the quality of the feed and the feeding strategy, the loss of animals (mortality and morbidity), and also factors as slaughter age, housing, ...). The effects of these primary factors on FCR will be discussed, as well as the effect of FCR on the environmental impacts of a rabbit farm.

FEED EFFICIENCY: DEFINITIONS AND GENERAL RECALLS

Definitions

The literature provides mainly two ways of calculating feed efficiency: the FCR ratio and the FE. The FCR or feed to gain ratio, is the ratio between the amount of feed consumed (kg) for the corresponding amount of live weight produced in the same period (kg of rabbit). The FCR is the most extensively used parameter to express the efficiency to convert the feed to live weight gain. It is generally used both to judge the conversion on farm level as in nutrition experiments. Feed and gain are expressed in kg as such, however when fresh roughages or a combination of a compound feed and roughages are fed, a correction for the DM content of the roughages is recommended.

The feed efficiency index (FE) is the inverse of the FCR. From a scientific viewpoint this inversed ratio, namely kg of weight gain/kg of feed consumed, shows a figure between 0 and 1 (or in %) which expresses better the efficiency and is therefore suggested for experimental purposes. Although it best expresses the concept of feed efficiency, it is rarely used in the literature or by professionals.

During fattening, the feed efficiency is classically calculated as the ratio between the amount of feed consumed (kg) and the weight gain (kg) between weaning and slaughter (finishing weight minus weaning weight). If in this FCR the feed consumption of lost (dead or morbid) or unmarketable rabbits is considered, which is correct from an economical viewpoint, than the FCR is defined as **the economical FCR**. For the reproduction unit, we can also calculate an economical FCR by dividing the amount of feed consumed by the weight of the young rabbits at weaning (adding also, the weight of females sold).

Regardless of the mortality during fattening, we can also compute a **true or technical FCR**, which corresponds to the feed efficiency respect to the nutrient processing for tissues synthesis (muscle, bone, etc.). If mortality is not one of the target variables in experiments, the effect of mortality is eliminated by extracting the estimated quantity consumed of those rabbits. In this method, only the feed consumed by rabbits reaching the end of the experimental period is taken into account. As a consequence, the true FCR is lower than the economical FCR. If animals are housed collectively, we can calculate the true FCR, making a correction for dead rabbits and considering they have not eaten for 2 days preceding death (Gidenne, 1995).

Global feed conversion ratio

When speaking about FCR, in practice the most extensively used parameter for estimating FE in intensive rabbit production units is the **overall (global) farm FCR** This global FCR is defined for a closed unit (maternity including young female parent stock and eventually the males and fattening unit) as the ratio between the kg of feed consumed (purchased) and kg of rabbits produced (sold). Consequently, it is a very valuable parameter from a practical and economical viewpoint, whatever the farming system because it measures the overall technical level of the farm and its efficiency.

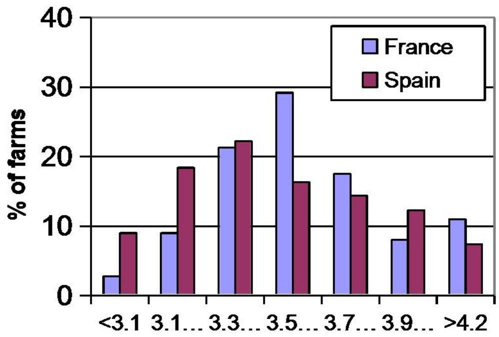


Figure 2. Global farm FCR (adapted from Jentzer,2008; Rosell and González, 2007).

Table 2. Farm FCR for different slaughter weights and No of rabbits produced/doe/year (Maertens *et al.*, 2005).

No rabbits produced/doe/year	40	45	50	55
Slaughter weight, kg	Global feed conversion ratio			
2.00	3.64	3.39	3.21	3.07
2.25	3.79	3.53	3.34	3.19
2.50	4.03	3.75	3.55	3.39

In Europe, under intensive production conditions data of farm FCR ranges around 3.60, 3.82 and 3.63 in France, Italy and Spain, respectively (Lebas, 2007, Xiccato *et al.*, 2007; Rosell and González, 2007). Differences among these 3 countries can mainly be explained by differences in age at slaughter being much higher in Italy than in Spain (Table 2). All these studies stressed the big differences between farms: from < 3.0 till > 4.5 (Figure 2). Nevertheless, a clear trend can be observed, being a strong improvement as observed over the last 15 years in France (Table 1). Actually average farm FCR's of 3.30 are obtained while e.g. in 1999 this amounted still 3.83. For memory, the global FCR was 4.3 in 1984 (Lebas, 2007).

Because rabbit farms are nearly exclusively closed farms, both the FCR in the maternity as fattening unit has to be considered separately in view of optimizing the farm FCR.

IMPACT OF BREEDING MANAGEMENT AND HEALTH STATUS ON THE FEED EFFICIENCY

FCR in the reproduction unit

The farm FCR is largely dependent of the reproduction efficiency and slaughter weight (age). Fertility rate, litter size and pre-weaning mortality have a very large impact on the number of rabbits weaned per doe and, as a consequence, on the FCR of the reproducing unit. The farm FCR exceeds 4 when the production level is lower than 40 produced rabbits/doe/year. However, at a production level of 55 rabbits it decreases till 3.39 (Table 2).

Table 3. FCR in **the fattening unit**, according according to mortality rate and age (Maertens *et al.*, 2005).

	Mortality rate (%)				
	0	5	10	15	20
5 wks	2.72	2.74	2.76	2.78	2.81
7 wks	2.72	2.78	2.85	2.92	3.00
9 wks	2.72	2.86	3.02	3.20	3.43

Table 4. Variation of the FCR in the **maternity** to the post-weaning mortality and production level.

	No of weaned /♀ / year		
Losses in the fattening unit (%)	62	57	52
0	2.79	3.03	3.31
5	2.93	3.27	3.59
10	3.09	3.45	3.79
15	3.27	3.66	4.01

Data concerning the FCR in the reproduction unit are very scarce in the literature. Therefore, a theoretical calculation is presented for a unit with weaning at 35 days, based on recent feed intake data obtained at the ILVO Institute (Maertens and Van Gaver, 2010; Maertens *et al.*, 2013) (Table 5). During the entire lactation period, productive does and their young consume on average 18.5 kg of feed. Furthermore, their feed consumption outside the lactation period has to be considered (110 days/year) and also the feed consumption of the young females and females in pre-gestation cages (together 45 ọ/100 ọ).

For the calculation of FCR in a productive maternity, we have assumed an average of 7.3 litters/ọ/year and 8.5 weaned young per litter. The weight of the sold females have to be taken into account to calculate the FCR in the maternity, in addition to the weight of the weaned rabbits. The FCR obtained in such a productive maternity unit with 62 rabbits weaned/doe/year is only 2.79, but it increases to 3.31 if the production level decreases till 52 weaned young/doe/year (Table 4).

Table 5. Calculation of the FCR in a productive reproduction unit with 100 does.

Feed consumption	Kg for 100 ♀	**Rabbits produced**	Kg LW (for 100 ♀)
1) Lactation: 18.5kg/litter x 7.3 litters/♀/year:	13 505	1) 8.50 weaned/litter x 7.3 litters or 62 weaned/♀/year with a weaning weight 1.0 kg	6 200
2) ♀only pregnant: 110d x 160g/d :	1 760	2) Sold females: 50 with an economical weight of 3 kg :	150
3) Young ♀and ♀in wait cages : 45 ♀ x 365d x 150g/d:	2 464		
Total	**17 729**	**Total**	**6 350**
	Global "maternity" FCR = 2.79		

Another way to judge the feed efficiency of females is to exclude effects of renewal and mortality. This is of interest in experimental rabbit farms. For instance, in a multi-site trial, the FCR was only 1.90 for lactating females, under a 42d cycle (weaning 35d, litters equalized to 10 and a pre-weaning mortality of 3.6% for the kits) and fed a control diet, and 2.05 if fed a high-fibre diet (Fortun-Lamothe *et al.*, 2006). This demonstrates the high production efficiency of the female rabbit. In parallel, the kits consumed 4.17 kg of feed from 18 to 35d (weaning), or 34% of the exclusively female consumption (12.2 kg from parturition to weaning). After weaning, the FCR of the growing rabbits was 3.20 from 35 to 70d (excluding mortality) or a total consumption of 35.8 kg for a litter of 10 rabbits. Thus, in this study and regardless of mortality or renewal, the global FCR was estimated to be only 2.57. This indicates the large potential which exists to improve the actual farm FCR.

Females which are not immediately pregnant have to be restricted fed because overfattening impairs their further reproductive career and leads to reduced performances in the subsequent lactation (Pascual *et al.*, 2003). Based on the data of Table 5, an over-consumption of 10g/day increases the FCR by 2 to 3% in the maternity.

Feed conversion ratio of the growing rabbit

The FCR of growing rabbits increases gradually with age (Figure 3). Obviously, young and fast-growing animals have a far more favourable FCR in the early fattening stage than when near slaughter weight. Above a weight of 2 kg (9 wks), the FCR increases quickly due to tissue deposition allometry (fat versus protein and water) that becomes strong for adipose tissue and whose energy cost of synthesis is high. Moreover, the maintenance requirements become high and are also responsible for the quick increase in FCR above 2.0 kg LW (FCR >3.25). Then, between 11 and 14 weeks of age, the growth rate is strongly reduced (30 to 15 g/d) while the feed intake remained quite stable (≈180 g/d), resulting in a sharp increase of the FCR (week by week): from 5 to 12 (Figure. 3).

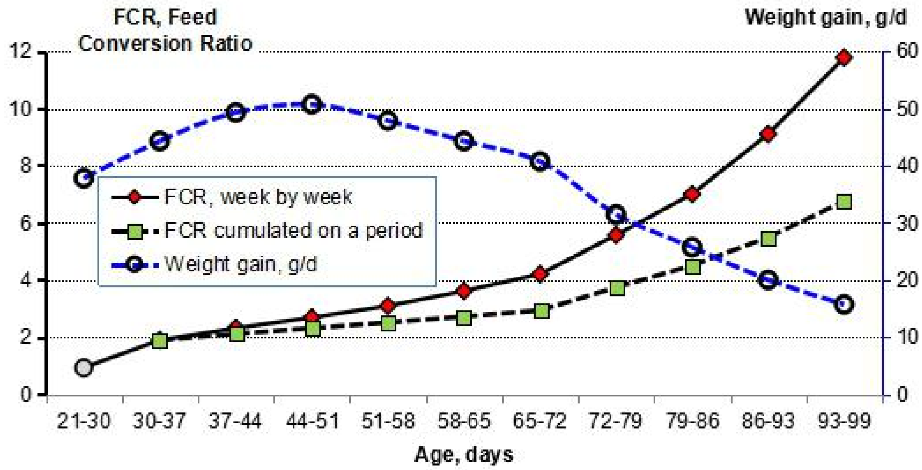


Figure 3. Evolution of FCR in growing rabbits, of quickly growing rabbits (* between 21 and 30d, the young also consumes maternal milk, adapted from Maertens, 2010).

In rabbits, differences in FCR between males and females are not significant before the usual slaughter age or weight is reached (60-70% of adult weight) (Trocino *et al.*, 2015). Only at a later stage, because of a higher adipose tissue deposition, females have a worse FCR.

To better assess the nutritional quality of a feed, we can calculate the energy conversion ratio (MJ DE / kg weight gain), which corresponds to the amount of digestible energy (MJ DE) consumed divided by the weight gain between weaning and slaughter (Perez *et al.*, 2000; Gidenne *et al.*, 2005). For example, in the post weaning period (30-49d) where true FCR ranges between 2.1 and 2.3, the energy conversion ranges between 22 and 26 MJ DE/kg gain. In the finishing fattening period (50-72d), these values are 3.6 to 3.9, and from 42 to 46 MJ DE/kg for energy conversion. The best FCR observed in the post-weaning period corresponds also to the better digestive efficacy (digestibility) observed at this age for whole nutrients (or organic matter): 75-80% (between 5 and 6 weeks of age) against 65-70% between 7 and 8 weeks of age (Gidenne and Fortun-Lamothe, 2002).

Impact of mortality or morbidity

The health status of the herd (maternity and fattening) has an obvious impact on the global FCR, either by mortality (animals who consumed feed without producing) or morbidity (low performance animals), the later being more difficult to estimate.

Losses in the fattening unit have consequences on the FCR in the reproduction unit. Effectively, fatteners which die have also consumed feed before weaning. The feed consumption before weaning of these rabbits is lost and the FCR worsens in the maternity unit. Moreover, as a consequence of the lower number of young the relative impact of the feed consumption of the doe increases when less young can be sold.

In Table 4, the effect of post-weaning losses on FCR in the maternity unit is presented for different production levels (Maertens, 2010). When 10% losses are considered, the FCR already increases till 3.45 at a production level of 57 young/doe/year. An increase with 5 young/doe/year leads to a decrease of the FCR till 3.09 or 11%. The simultaneous impact of an increase of 5 weaned youngs and a decrease of 5% of post-weaning mortality results in an 18% reduction of the FCR (e.g. from 3.45 to 2.93).

Moreover, the impact of mortality on the FCR is logically proportional to the age at which it occurs. Maertens (2010) estimated the impact of mortality on the FCR, according to age and mortality rate obtained in nutrition experiments (Table 3). Both the effect of increasing mortality (from 0 to 20%) and when the mortality occurred (week 1, week 2-3 or during the last week, respectively) is presented. If mortality occurs in early fattening stage, by consequence the economical FCR increases only slightly. However, if the losses (mortality and culled rabbits) are concentrated at the end of the fattening period the FCR will be 11% and 26% higher for a mortality rate of 10% and 20%, respectively (Table 3).

DIETARY AND NUTRIONAL FACTORS IMPACTING THE FEED EFFICIENCY

Nutritional quality of the feed

Effects of dietary energy and fibre concentrations
As all monogastrics, the FE of the growing rabbit improves with the dietary energy concentration. If fed *ad libitum*, rabbits try to regulate their feed intake to adjust the intake of digestible energy (DE) as already been shown 40 years ago (Lebas, 1975). This regulation is however only possible as the dietary energy concentration ranges between 9.00 and 11.50 MJ DE/kg, and without dietary addition of lipids (Xiccato and Trocino, 2010). In monogastric animals the glycaemia plays a key role in food intake regulation, while in ruminants the levels of volatile fatty acids in blood have a major role. Since rabbit is a monogastric herbivore, it is not clear which is the main blood component regulating feed intake, but it is likely to be the blood glucose level (Gidenne and Lebas, 2005). However, because of the close relationship between dietary fibre and DE content, daily feed intake (and by consequence FCR) is even more correlated with the less digestible fibre than with the DE content (Gidenne and Lebas, 2006). In the range of 10 - 25% lignocellulose (ADF), the rabbit can properly express its growth potential. Generally, the FCR decreases linearly with increasing DE or decreasing ADF concentration.

However, if rapidly fermentable fibres replace a portion of the starch, a small FCR impairment is observed (+0.10 to +0.15 pt, Perez *et al.*, 2000; Gidenne *et al.*, 2004). Conversely, the supply of lignins (ADL) or cellulose (ADF-ADL), which are very poorly digestible fibre fractions, results in a strong deterioration of the FCR (+ 0.17pt per % ADL; + 0.09pt per % cellulose) in parallel with a decrease in digestibility (Gidenne, 2015). Beyond 25% dietary ADF, the rabbit cannot ingest enough DE to maintain an optimal growth rate. Its FCR will be impaired by 20 to 40% for dietary ADF levels over 30%.

Reversely, when the fibre level is too low (<18% ADF), rabbits are exposed to a higher risk of digestive pathology, although growth and FCR are maintained. Below 13% ADF, also the risk of diarrhoea increases, the growth of the healthy rabbit is often reduced from 10 to 20%, while the FCR is maintained or improved (+5 to +10%, Gidenne *et al.*, 2000; Bennegadi *et al.*, 2001).

The fibre intake affects also the FCR in the reproduction unit. According to De Blas *et al.* (1995) an optimal feed conversion ratio is obtained at a dietary concentration of 16 to 17% ADF (31 to 33% NDF) (Figure 5). However, recently Read *et al.* (2015) demonstrated that a diet with a high fat content but also with levels of the different fibre types to maximize digestive health resulted both in a favourable FCR as in a low mortality rate.

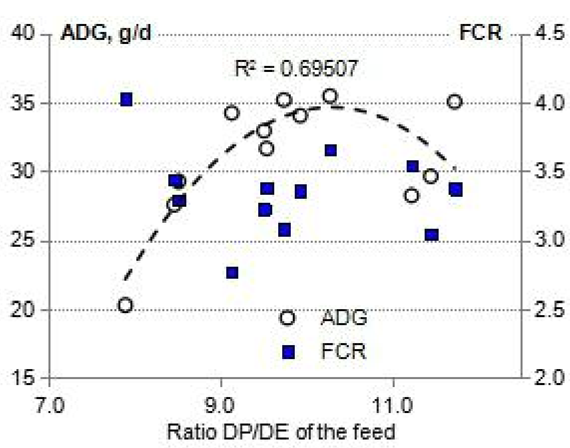


Figure 4. FCR variations and growth rate (ADG) according to the dietary DP/DE ratio (Adapted from De Blas *et al.*, 1981)

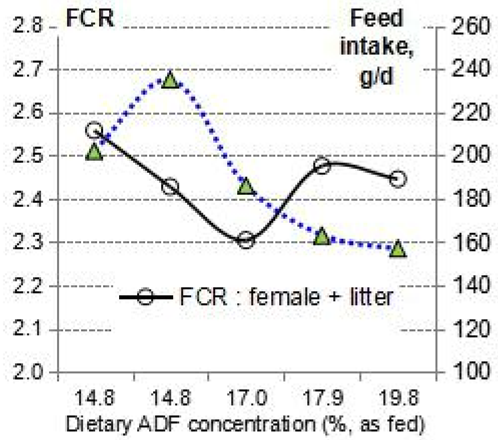


Figure 5. FCR in the reproduction unit according to the dietary lignocellulose (ADF) (Adapted from De Blas *et al.*, 1995)

Effects of dietary lipid incorporation

Based on the relationship between dietary DE content and intake, improved FCR ratio can be obtained with energy dense diets. However, due to the dietary fibre requirements of rabbits and the low digestibility of different fibre classes (Gidenne, 2015), rabbit diets have a low energy content (DE or ME) compared to poultry and pig diets. If the dietary fibres recommendations (Gidenne, 2015) are respected, it is possible to increase to some extend the energy density of a feed by replacing starch with fat. However, the incorporation of lipids is often limited between 2 and 4% if we want to maintain the technological quality of the pellets (degradation of hardness and durability).

The DE content of fats (or oil) is nearly 2.5 to 2.7 times as high as that of cereals (Maertens *et al.*, 2002). When replacing 2% of cereals by 2% fat (oil) an increase of 418 to 460 kJ DE / kg of feed (100 to 110 kcal) is obtained. An increase of 418 kJ (100 kcal) DE will improve the feed efficiency in fatteners, which according to different authors ranges between -0.08 and -0,15pt FCR (Fernandez-Carmona *et al.*, 2000; Corrent *et al.*, 2007; Gidenne *et al.*, 2009a; Maertens, 2010, Read *et al.*, 2015).

Recently, this effect was shown again with a large multi-site study (GEC) by Knudsen *et al.* (2014), where an increase of 1.01 MJ of DE corresponded to a FCR reduction of 0.39 pt. Thus, in most cases where lipids replace starch in the feed, and without changing the fibre content, rabbits do not reduce their feed intake but increase their DE intake. Growth rate and FE are higher if the feed is adjusted for the other essential nutrients such as amino acids (Read *et al.,* 2015).
The use of such high energy feeds seems particularly interesting during the finishing phase (Corrent *et al.*, 2007), since the risk of digestive disorders is lower and also because about 2/3rd of the feed is consumed during the last 3 weeks of fattening (age 49-70 days) (Figure 1). Moreover, after weaning, priority is often given to reduce the risk of digestive diseases rather through a high dietary fibre content or a feeding restriction (Gidenne, 2015).

Moderate dietary fat addition for reproductive females is frequently used for intensive rabbit breeding systems, because of its favourable impact on milk production (Pascual *et al.*, 2003). However, the effects on weight at weaning of the litter are not very marked. Also, since there are negative effects on the energy balance of the doe (lower body fatness) during lactation, a diet rich in DE with a significant addition of fat is not recommended (Xiccato and Trocino, 2010). Moreover, according to Lebas (2004), a decrease of the FCR with very high-energy diets (> 11.09 MJ or 2650 kcal DE/kg) remains to be shown.

Effect of protein supply and additives

De Blas *et al.* (1981) defined an optimum ratio digestible protein (PD) / DE, between 9.5 and 11.0 g

DP/MJ DE for optimal growth rate (Figure 4). The FCR is not correlated with the ratio DP/DE, even if we observed an inverse relationship between growth rate and FCR. If we meet the recommended intake of essential amino acids (lysine, sulphur amino acids, etc.), protein intake has little direct impact on the FCR during fattening. It is thus possible to reduce the intake of protein during the finishing period, up to 10 g DP/kg feed, without impact on the growth rate or FCR (Maertens *et al.*, 1997, 1998; Xiccato and Trocino, 2010). Conversely, a high dietary protein level, leading to a high DP/DE, improves slightly the growth rate, but would impair the FCR (Kjaer and Jensen, 1997). Moreover, a surplus of (undigested) protein has been linked with a higher incidence of diarrhoea or increased mortality (De Blas *et al.*, 1980; Gidenne *et al.*, 2001; Garcia-Ruiz *et al.*, 2006; Chamorro *et al.*, 2007).

Therefore, since 65-70% of the feed is consumed during the last 3 weeks of the fattening period (7-10 weeks of age), one of the current feeding strategies is to use a finishing diet having a higher DE level and a moderate DP content, to reduce the nitrogen release (Maertens *et al.*, 2005) while promoting an optimal FCR and growth rate (Knudsen *et al.*, 2014).

In the reproduction unit, to optimize the intake and the milk production and thus the FCR at the lactation peak, it is recommended to have a concentration of 4.4 g of digestible threonine per kg feed. Higher or lower concentrations degrade both the number of weaned rabbits and FCR (De Blas *et al.*, 1998).

The direct impact of various additives (enzymes, phytase, probiotics, etc.) to improve the FCR is often not consistent (Falcao-e-Cunha *et al.*, 2007). However, if these additives (*e.g.* coccidiostats) reduce mortality, indirectly the FCR is improved. In early weaned kits (at 25 days), Garcia-Palomares *et al.* (2006) and Garcia-Ruiz *et al.* (2006) showed that a supplementation with a cocktail of enzymes (beta-glucanase, beta-xylanase, alpha-amylase and pectinase) improved digestion, growth rate and FCR, while reducing the mortality. However, both the impact on FCR as the effects in later fattening stage remain to be confirmed.

Feeding strategy and feed efficiency of the growing rabbit

An appropriate strategy of feed restriction after weaning improves the feed efficiency

For almost 15 years, in French professional rabbit farms a feed restriction strategy for the growing rabbits, sometimes from weaning until slaughter, is common practice. The first weeks after weaning a strong restriction is executed (during 2 to 3 weeks) followed by a period of weak restriction or free intake (AL: *ad libitum*). In the French conventional system 42d cycle + slaughter at 10-11 weeks), such a strategy offers two main advantages: firstly the risk of post-weaning digestive disorders is strongly reduced (Gidenne et al., 2009c; Romero *et al.*, 2009; Gidenne *et al.*, 2012), and secondly the FCR is improved (Gidenne et al., 2009c; Romero *et al.,* 2010). Thus, under restriction and for a regular restriction range (15 to 35% less than AL), the growth rate is globally reduced proportionally to the intake (i.e. -20% intake = -20% growth rate). In parallel, we observed a 5 to 10% FCR reduction according to the studies (Figure 6).

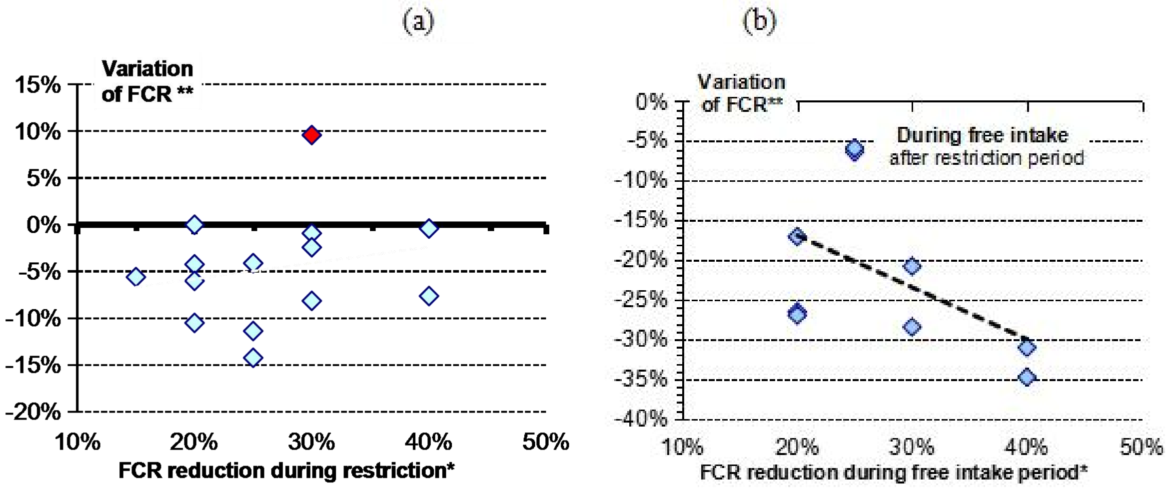


Figure 6. FCR variations according to level of the feed intake reduction (a) during the restriction period and (b) applied for the period of free feed intake (Data from a meta-analysis (Gidenne *et al.*, 2012) : one point = one study; *: expressed in % of *ad-libitum* intake of contemporary animals; **expressed in % of FCR for contemporary animals).

When restricted rabbits are fed freely afterwards, they have a compensatory growth even stronger than the executed restriction. In parallel, we observed an overconsumption of feed that is moderate, and thus the FCR is significantly improved from 15 to 30% (Figure 6). On the whole fattening period (weaning-slaughter), using a feed restriction strategy, such 3wks restriction +2wks *ad-libitum*, leads to a moderate decrease in the growth rate, due to compensatory growth (-5 to -10%). In parallel, the FCR improved by 10 to 15% (Figure 7), but with a wide variability which may depend on the nutrient composition of the feed (Gidenne *et al.,* 2012).

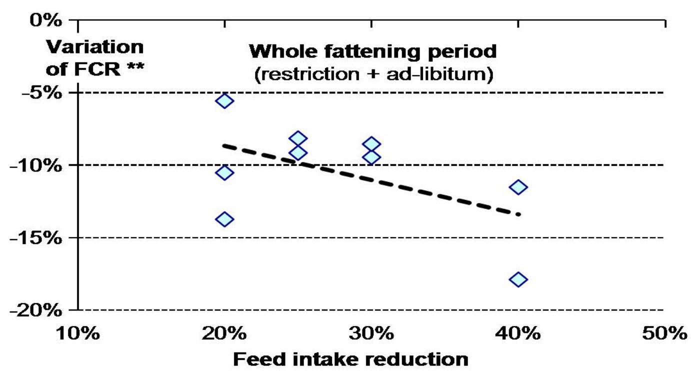


Figure 7. FCR variations according to level of the feed intake reduction over the whole fattening period (Data from a meta-analysis, Gidenne *et al.,* 2012).

Accordingly, the application of a restriction strategy improves the FCR and therefore the feed costs margin by +2% to + 10% (Duperray and Guyonvarch, 2009; Knudsen *et al*., 2014). However, rabbits have to be hold about 2 to 3 days extra to reach the same slaughter weight, which slightly reduces the economic benefit.

Effect of the feed distribution mode.

The distribution of a restricted amount of feed (-25%) in 13 meals spread over 24h (to simulate the natural feeding behaviour) would slightly improve the FCR, without impact on growth (Martignon *et al*., 2009); while a distribution (restricted or not) in one or two times does not impact the FCR or growth (Gidenne *et al.*, 2009b). The feed distribution at night (16h to 23h) rather than during the day, would improve the FCR of nearly 10% during the first 3 weeks of fattening (3.09 *vs* 2.79), without impact on growth or health (Weissman *et al.*, 2009). However, this effect has not been found by Salaun *et al.* (2011).

Physical factors: quality of the pellets.

In general, it is recommended to use pelleted feed with a diameter between 3 and 5 mm, for a length of

6 to 13 mm. If the length is longer, the rabbit can waste feed simply because when the rabbit bites the pellets, parts of it may fall down and passes through the grid floor. The pellet durability and hardness must be optimized. Hardness and durability will reduce losses as fine particles, but too hard pellets reduce the feed intake, particularly for the young rabbit between 3 and 6 weeks, and this may lead to lower FCR (Gidenne and Lebas, 2005).

Feed wastage due to the feeder design can also have a significant impact on the FCR. Pregnant females can waste large amounts of feed by scratching it out of unmodified feeders. Another important wastage results because rabbits do not like fines. Any mash present between the pellets or formed in the feeding system worsens FCR. Farm data indicate that this loss can approach 1.5–2% of the total amount of feed (Maertens, 2010).

It is possible to feed rabbits with mash or even flour, but in this case we should expect an increase in FCR from 5 to 25% due to the strong reduction in feed intake (Maertens, 2010).

GENETIC FACTORS AFFECTING THE RABBIT FEED EFFICIENCY

Improving feed efficiency was first made by the use of heavy strains crossed with maternal lines. Overall, strains with a high growth rate improve the FCR of meat rabbits (Larzul and De Rochambeau, 2004, 2005; Orengo *et al.*, 2009). Selection for growth rate has indirectly improved the FCR via an early age at slaughter with a constant live weight. Since feed efficiency increases with the age of the animals, a 12 days earlier slaughter age, from a selection on weight, improves the FCR by 0.5 unit (Larzul *et al.*, 2005). Feed efficiency can also be accessed through other criteria such as the residual feed intake (RFI) or the residual maintenance energy, residual gain or residual intake and gain (Willems *et al.* 2013).

Piles *et al*. (2004) confirmed that heritabilities of growth rate and FCR are moderate in rabbits (± 0.30), which predicts successful selection of these traits. However, the genetic correlation (± -0.48) between both traits is not very high. Therefore, both traits should be preferentially used in an index in order to improve the response to selection in FCR (Piles *et al.,* 2004).

In fact, there are two main selection strategies to obtain a reduction of the FCR ratio, as studied in other species (cattle, pig, ...). Or to increase the weight gain (for same amount of feed consumed) or to reduce the amount of feed consumed (for the same weight gain). The first strategy is among the animals ingesting the same amount of feed, to select those which express the greatest capacity for growth. This requires to restrict animals to ensure that all the animals ingest the same amount of feed (e.g. 80% of *ad libitum*) and therefore the difference in growth is due to the difference in feed efficiency.

The second strategy is to select animals on their RFI when fed *ad libitum*. The RFI corresponds to the fraction of the total feed intake which is not explained by maintenance or growth needs. The RFI is calculated as the residual of the multiple linear regression of total feed consumption on average metabolic LW (e.g. average LW between 30 and 63d to the power 0.75) to account for maintenance requirements and ADG between 30 and 63 d of age to account for production requirements. These two strategies were applied for 9 generations of rabbits and compared recently for the growing rabbit, at the INRA Toulouse.

The two selected lines had a FCR reduced by 0.2 point compared with the G0 line (no selection). Selection on ADG would lead to heavier animals with no significant reduction of feed costs, whereas selection on RFI leads to lower feed costs and no increase of animal BW under ad *libitum* feeding (Drouilhet *et al*., 2016).

Besides, the intestinal microbial communities from efficient rabbits differed from their unselected counterparts in terms of fermentation end products and microbial phylotypes, suggesting a central role of the digestive microbiota in the improvement of the feed efficiency. In view of reducing the feed costs and output in the environment, the selection on RFI should be applied. However, presently the private hybrid selection companies still select nearly exclusively rabbits only for growth rate. The determination of the FCR is more laborious and difficult especially for group housed rabbits.

ADDITIONAL EFFECTS AFFECTING THE FEED CONVERSION RATIO

Heat stress has a detrimental impact on feed intake and by consequence on the FCR (Marai *et al.*, 2002). The impact of environmental parameters (temperature, housing) strongly influences growth performances and therefore it's FCR. This include for example the impairment of the FCR of fatteners at a constant temperature of *e.g.* 30°C compared to a temperature of 18 °C, 4.84 *vs.*4.22, respectively (Eberhart, 1980).

During the summer, under natural conditions, a better FCR is obtained than during the winter despite the lower growth rate. Higher growth rates but worse FCRs are observed at low temperatures (under Spanish winter conditions) compared to fattening under moderate heat stress (Ramon *et al.*, 1996).

If fattening is conducted in individual cages, the FCR is improved by 5 to 10% compared to cages containing 6 to 8 growing rabbits (Garcia-Palomares *et al.*, 2006). Moreover, in the case of fattening in large pens, on straw or on the ground, one should expect a deterioration of the FCR (Maertens and Van Oeckel, 2001; Dal Bosco *et al.*, 2002, Szendrö and Dalle Zotte, 2011; Xiccato *et al.*, 2013).

HOW HIGH FEED EFFICIENCY REDUCES THE ENVIRONMENTAL IMPACTS

Agricultural recycling of manure is the best way of managing them. Therefore a good knowledge of these releases is essential to optimize their agricultural recovery and minimize negative impacts on the environment. Mean values for nitrogen and phosphorus outputs from rabbit farms are available in some countries in Europe (CORPEN, 1999; Maertens *et al.*, 2005; Xiccato *et al.*, 2007) and constitute official references, used presently for sizing manure, spreading plans or for controls. CORPEN estimated in 1999, the releases in rabbit production (for a breeding and fattening farm) for nitrogen (N): 66 g/rabbit or 3.24 kg/female; and for phosphorus (P): 40 g/rabbit or 1.94 kg/female (for phosphorus "P_2O_5"= 91 g/rabbit or 4.44 kg/female). However, these references were mainly based on an old technical database. More recently Maertens *et al.* (2005) calculated the N and P and both for a closed farm as for an individual fattener. Expressed per doe, the N and P excretion amounted 7.42 and 2.08 kg.

Recently, these data have been recalculated by Gidenne *et al.*, 2013 including the progress in rabbit performances (Table 1). Moreover a reduced dietary protein concentration (16.8 vs. 16.0%), as well as a lower dietary P level (0.6 vs. 0.5%) was taken into account. Furthermore, the protein level of rabbit carcass was assessed to 18.7% and 0.5% for P in agreement with Maertens *et al.*, (2005).

For N volatilization losses, the ratio of 60% compared to the excreted N was retained (losses inside the units and during storage of manure). Under these conditions, nitrogen rejection per rabbit produced (or sold) reduces over the period (1999-2012), from 66.1g to 58.9g which corresponds to a decrease of 11%. In parallel, the phosphorus output passes from 39.6 g to 35.5 g (resp. 90.6 and 81.3g of P_2O_5) corresponding to a 10% decrease.

The total excretion of N and P from a rabbit farm (breeding and fattening) expressed per female per year, based on the production performance of 2012, was respectively 7.53 kg and 1.82 kg. These values should be compared to those of Maertens *et al.* (2005): 7.42 and 2.08 kg; and to those of Meda *et al.* (2014): 7.55 and 2.17 kg. Expressed by rabbit produced, those values are 147 g of N and 35 g of P (Maertens: 165 and 46 g; Meda: 140 and 40 g). These differences in estimates are mainly related to differences in the level of animal performance (51.1 rabbits products/female/year vs 49 for Maertens and 54 for Meda) or the assumed dietary P level.

The improvement of animal performance and changes in feed composition (lower protein and especially phosphorus levels) results in a sharp reduction of the releases. In France, when comparing the year 1999 to 2012, nitrogen output was reduced by 19% and that of phosphorus (P_2O_5) by 28%. This should help the public services to correct the references for environmental releases, and to re-calculate the spreading plans, thus optimising the spreading surfaces, especially when they are referenced on P output.

CONCLUSIONS

The feed efficiency is a key indicator to assess the performance of a farming system. The rabbit can reach high production efficiencies, since in controlled conditions (experimentation) the global FCR (maternity + fattening) is about 2.6, for an intensive rabbit breeding system. Therefore, in field conditions, the optimization of health management and diet combined with the use of animals with better genetic potential should lead to a global FCR close to 3, which is similar to that obtained in pig farming.

Different strategies have to be followed: high performing reproduction stock resulting in a reduced FCR in the maternity. The use of diets with nutrient levels to optimize digestive health together with an appropriate feeding restriction after weaning lead to minimal losses and has a large impact on the FCR. If the different fibre requirements are met, an increase of the dietary energy level, especially in the finishing stage, reduces the FCR with approximately 0.15 points for an increase of 0.5 MJ DE.

In the field, e.g. in French rabbit farming, a steady improvement of the global FCR is observed over the last 15 years, to reach an average of 3.3 in 2014. Thus, rabbit production still shows large potential to improve the feed efficiency, and to reduce both the inputs and the releases through the environment.

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