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PERFORMANCE AND SUSTAINABILITY OF TWO ALTERNATIVE RABBIT BREEDING SYSTEMS

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Abstract: The aim of this study was to evaluate 2 alternative breeding systems that differ from the current system in terms of reproduction rhythm, age of females at first insemination and the age of kits at weaning and at slaughter. We measured the performance of 332 females and their offspring over 4 consecutive cycles, as well as the sustainability of the systems. We compared an intensive (group I: reproduction rhythm [RR]=35 d; first insemination [AI_1]=20.6 wk of age; weaning age [WA]=32 d; slaughter age [WS]=63 d) an extensive (group E: RR=49 d; AI_1=16.6 wk; WA=30 d; WS=70 d) and a semi-intensive system (group S: RR=42 d; AI_1=19.6 wk; WA=35 d; WS=70 d) considered as the control system. Sustainability was evaluated using a multicriteria assessment method that takes 14 economic, environmental and social criteria into account, for which 3 to 5 indicators were expressed as the relative score [–1; –0.5; 0; +0.5; +1] for alternative systems compared to the control system. The productivity measured at 28 d (3.5, 4.2 and 4.6 kg/AI, for groups I, S and E, respectively), at 63 d *post-partum* (30, 38 and 42 kg/female for 4 cycles, respectively), and the total body energy measured 3 d after the 1st and at the 4th insemination (45.4, 46.8 and 49.5 MJ, respectively), were significantly increased when the reproductive rhythm decreased (P<0.001). Before and after weaning, kit mortality decreased when the reproduction rhythm decreased (11.4, 7.3, and 1.9% and 18.3, 15.3 and 10.6% for groups I, S and E, respectively, P<0.05). Carcass quality (weight and dressing percentage) was lower in I than in the S and E groups (P<0.001). On this basis, the yearly productivity per doe at weaning could be estimated at 79, 83, and 78 kg for groups I, S and E, respectively. Consequently, the productivity per reproductive cycle increases with the extensification of the breeding system. Nevertheless, compared with the current French system (S), simultaneous changes in several breeding practices could lead to new coherent and functional systems capable of improving various aspects of sustainability.

Key Words: rabbit, breeding system, productivity, body composition, growth, sustainability.

INTRODUCTION

In an uncertain economy and in view of increasingly urgent societal demands, breeding sectors should be capable of proposing new productive models that are sustainable, i.e. economically viable, socially acceptable and ecologically sound. New systems can be designed incrementally, starting from existing systems.

In France today, the dominant rabbit breeding system is characterised by the use of artificial insemination (AI) of the females every 42 d, a single batch management, a sanitary break between each fattening group, ending when the fatteners are 70-77 d old, and a renewal of reproductive does by adoption of 1-d-old females (Coutelet, 2015). This technical management allows for highly efficient organisation of the work on the farm until removal of animals for slaughter, while improving sanitary management. However, the use of a 42-d reproductive rhythm (RR) means that females are simultaneously pregnant and lactating for more than half of the reproductive cycle, leading to high nutritional needs that are difficult to meet and which can explain the moderate and/or irregular fertility rate, as well as

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the reduced reproductive lifespan (Coutelet, 2015). Indeed, a negative energy balance is unfavourable to fertility and leads to a depletion of body reserves (Fortun-Lamothe *et al.,* 1999; Fortun-Lamothe, 2006).

Two solutions are proposed to improve this situation. The first is based on an extensification of the RR (>42 d) that would be more respectful of the female's reproductive abilities while reducing work pressure (social incentive), and the other is based on an intensification of the RR (<42 d) to improve system productivity and efficiency (economic and environmental incentive). However, husbandry practices generally form a coherent package that meets the constraints of the animal's biology and of the different segments of the supply chain (breeders, farmers, slaughterers, sellers, etc.). Therefore, to improve livestock production systems, it might be necessary to propose several concomitant changes in breeding practices to maintain this consistency.

The objective of this study was to compare 3 breeding systems that differed in terms of RR, age of females at first AI, and age of kits at weaning and at slaughter on rabbit doe productivity and body composition, as well as on kit growth and viability recorded over four successive reproductive cycles, in addition to the quality of the carcasses and meat. However, a new production system must not only be technically feasible and efficient, but its interest and limits in terms of economic, social and environmental criteria should also be evaluated. We therefore assessed the effects of the changes in practices on sustainability using a multicriteria assessment method.

MATERIALS AND METHODS

All procedures were conducted in accordance with the guidelines for the Care and Use of Animals in Agricultural Research and Teaching (French Agricultural Agency and Scientific Research Agency).

Animals, experimental design and reproduction management

The experiment was performed at the ITAVI experimental farm (Rambouillet, France) using 332 Hyplus rabbit does (Hypharm, Roussay, France). Females were randomly housed in 3 independent rooms according to their weight at 13 wk and subjected to one of the 3 systems (I, S and E systems) described in Table 1. The S system corresponds to the actual dominant rearing practice in France: the females were inseminated for the first time at 19.6 wk and then every 42 d; suckling rabbits were weaned at 35 d of age and slaughtered at 70-77 d of age. In the 2 alternative systems, the RR was modified: it was lower in the I system (35 d) and higher in the E system (49 d). However, the single group management of the reproduction combined with the renewal of reproductive does by adoption of 1-d-old females forced the age at first insemination of young females to be synchronised with the rest of the herd. Concretely, in the E system where AI occurred every 49 d, the future reproductive females, that are adopted at 1-d of age, could be inseminated for the first time at 16.6 or 23.6 wk of age if the herd is managed as a single group. A first AI at 23.6 wk of age increases the lifetime that is not productive and the number of fatty females, therefore, in the E system, the age at first AI was 16.6 wk. In the I system, AI occurred every 35 d and the future reproductive females, that are adopted at 1-d of age, could be inseminated for the first time at 15.6 or 20.6 wk of age if the herd is managed as a single group. Females did not reached puberty at 15.6 wk of age, therefore, in the I system, the age at first AI was 20.6 wk. In the I system, the growing rabbits were weaned at 32 d and slaughtered at 63 d to maintain a sanitary break of at least 3 d between 2 fattening batches. In the E system, rabbits were weaned at 30 d to limit the overlap between pregnancy and lactation.

In the 3 systems, the does were placed under a constant 8 h light/d (between 8 a.m. and 4 p.m.), except for 7 d before each artificial insemination (AI), when a light stimulation was applied (sudden change from 8 h light:16 h dark to 16 h light:8 h dark, light extinction at 24 h). The return to the initial illumination (8 h) occurred gradually over

Table 1: Husbandry practices in the three breeding systems.

	Females		Kits	
Breeding system	Reproduction rhythm (d)	Age at 1st AI (wk)	Age at weaning (d)	Slaughter age (d)
Intensive	35	20.6	32	63
Semi-intensive	42	19.6	35	70
Extensive	49	16.6	30	70

4 d from the day of AI. This lighting schedule is intended to maximise fertility (Theau-Clément *et al.,* 1990; Theau-Clément, 2007), as no hormonal treatment was used to induce sexual receptivity. Females were fed *ad libitum,* except nulliparous females and unfertilised ones that were fed 150-160 g/d and fed *ad libitum* for 6 d before AI. Does were only culled for sanitary reasons.

Inseminations were performed using heterospermic pools of bucks from a commercial breed (PS40, Hypharm, Roussay, France). Three days after birth (day 0), litters were standardised to 8 kits for nulliparous, 9 for primiparous and 10 for multiparous does, after removing non-viable (low weight) or surplus kits. Fostering was performed within the room and free nursing was allowed.

Females were weighed at each AI. Litter size was recorded at birth (total born, born alive, stillborn), after fostering at day 21 and day 28, and at weaning. The litters were weighed at birth, day 21, day 28 and weaning. Growing rabbits were individually weighed at day 63. Productivity per cycle or per year (weight of kits/AI, kg) was calculated from these data.

Feeding strategy

Four commercial diets (INZO, Chateau-Thierry, France, except the diet for finishing rabbits: Sanders Nutrition Animale, Pontivy, France) were used during the experiment. Their composition is reported in Table 2. After insemination, does in groups S and E were fed the P diet, which meets the nutritional requirements of pregnant does (digestible energy [DE]: 2580 kcal/kg; crude protein [CP]: 17.3%). During pregnancy and from day 0 to 25, does in group I were fed

Table 2: Ingredients and chemical composition of diets.

Item	Diets			
	P	L	Y	F
Ingredients (g/kg)				
Wheat	33	101	0	15
Barley	150	90	42	95
Bran and straw	250	245	271	242
Oilseed meal and whole grains	319	336	240	188
Molasses	25	30	25	40
Grape pulp	22	0	39	17
Beet pulp	95	87	200	105
Alfalfa	80	80	158	280
Rapeseed oil	0	5	0	5
Minerals	16	17	5	6
Amino acids	4	4	0	2
Additives	6	6	20	5
Chemical composition[1]				
Crude protein (g/kg)	173	175	152	155
Ash (g/kg)	74	75	82	77
Starch (g/kg)	164	173	92	124
Fat (g/kg)	30	33	27	32
Acid detergent fibre (g/kg)	186	179	234	209
Neutral detergent fibre (g/kg)	327	312	386	345
Acid detergent lignin (g/kg)	51	46	60	5.3
Lysine (g/kg)	8.7	8.1	6.3	6.8
Methionine + Cysteine (g/kg)	6.8	6.9	5.3	5.5
Digestible energy (kcal/kg)[2]	2580	2650	2300	2445

[1]Calculated according to the tables of ingredients (Sauvant *et al.,* 2004), unless digestible energy.

[2]Calculated according to Maertens *et al.* (2002).

P (pregnant): diet formulated to meet the needs of pregnant does. L (lactating): diet formulated to meet the needs of lactating does. Y (young): diet formulated to meet the needs of young rabbits. F (fattening): diet formulated to meet the needs of fattening rabbits.

the L diet formulated to meet the nutritional needs of lactating does (DE: 2650 kcal/kg; CP: 17.5%). Indeed, the nutritional needs of females in the I system are very high due to intensive RR, which leads to a long period of overlap between pregnancy and lactation. In the 3 groups, all the does from day 25 of lactation to weaning (day 32, 35 or 30 in groups I, S and E, respectively; Table 1) and the kits from day 25 to 49 of age were fed the Y diet formulated to meet the nutritional needs of young rabbits (DE: 2300 kcal/kg; CP: 15.2%). From day 49 to slaughter, rabbits in the 3 groups were fed the F diet formulated to meet the nutritional needs of finishing rabbits (DE: 2445 kcal/kg; CP: 15.5%). Kits were fed *ad libitum* except if digestive problems occurred in a cage (2 dead rabbits). In this case, they were restricted to 80% of *ad libitum* feed intake. No antibiotics were used during the experiment.

Body composition and meat quality

The evolution of the total body energy (MJ/animal) between 17.6 wk and the 4th AI was measured on a sample of females fertile at each previous cycle (n=63 and n=73, respectively), applying the method of Nicodemus *et al.* (2009) using a quantum II device (Model BIA-101, RJL Systems, Detroit, MI USA). Briefly, the body of rabbits is traversed by a low intensity alternating current (frequency: 50 kHz, intensity: 425 µA) using 2 electrodes, one at 4 cm from the base of the ear and the other at 4 cm from the base of the tail, to measure an impedance value.

Age at weaning and at slaughter differed between systems, thus making it necessary to control the consequences of changes in breeding practices on the quality of carcasses and meat. Meat quality measurements were taken in kits from the 3rd reproductive cycle of the does. In each group, 100 rabbits were slaughtered at day 63 (I group) or day 70 (S and E groups). Rabbits were weighed and sexed before slaughtering. After 24 h of chilling, carcasses were weighed and the dressing percentages were calculated. Perirenal fat was weighed and the carcasses were then divided into fore parts and hind parts (between the last thoracic and the first lumbar vertebra; Blasco and Ouhayoun, 1993) to calculate the hind part/fore part ratio. Meat pH was measured 24 h *post mortem* in the lumbar region (*Longissimus dorsi lumborum,* LM) and in the right hind legs (*Biceps femoris*, BF) with a glass penetrating electrode (Mettler Toledo). Meat colour was assessed on the surface of fresh cut LM (first lumbar vertebra) and on the surface of the BF on the basis of L* (lightness), a* (redness) and b* (yellowness) scales using a Minolta Chroma Meter (CR 300, Minolta, Osaka, Japan).

Sustainability assessment

The conceptual framework to evaluate the sustainability of the breeding system was adapted from the work of Fortun-Lamothe *et al.* (2012). These authors have developed a conceptual framework to evaluate the sustainability of commercial rabbit rearing units. However, some sustainability criteria are difficult to assess in experimental conditions. Indeed, in research conditions, the cost or time of labour (specific work-related experiments) and financial constraints (amortisation) are not representative of the field conditions. Thus, the alternative systems were evaluated in terms of 14 sustainability criteria (Table 3): 5 based on economic criteria (economic viability, labour efficiency, efficiency of the production process, control of added-value, transmissibility), four on the basis of environmental criteria (production of renewable resources, energy use, biomass use, land link, biodiversity) and 5 based on social criteria (working conditions, work hardship, product quality, living conditions and animal welfare, breeding practices and animal welfare). The methodological framework was adapted from Coudurier *et al.* (2015). Briefly, each criterion was evaluated on the basis of 3 to 5 indicators measured or assessed during the reproductive period and/or the fattening period in the 3 systems (I, S and E). Most of the indicators corresponded to zootechnical performances described above (mortality, productivity, growth, meat quality, etc.). Some other indicators are specific to the sustainability evaluation. For example, the feed costs (€) or feed conversion ratio were estimated taking feed intake measured globally into account (reproduction and fattening) per breeding room (kg), per cycle and feed price (€), or per weight of fatteners at slaughter age (kg), respectively. Efficiency of work was evaluated by combining productivity and working time (h) measured globally per cycle for feeding, cleaning and other breeding activities. Transmissibility concerned the need for specific investment (material or building) and flexibility. Energy use (kWh) was evaluated on the basis of lighting, ventilation and cleaning time (h) per breeding room. Biomass use was assessed on the basis of feed intake (kg) and litter use (kg). Working conditions referred to batch or sanitary break duration, number or duration of breeding activities. Work hardship was evaluated on the basis of work posture for feeding and other breeding activities, as well as the atmosphere in the breeding room. As for animal welfare, indicators of growth and

Table 3: Indicators used to evaluate sustainability and scores obtained by the 2 alternative systems.

Sustainability objectives	Sustainability objectives	Score of the Intensive system	Score of the Extensive system
Economic dimension			
Economic viability	Production (kg of rabbit weaned rabbit/yr)	–0.5	–0.5
	Feed cost (€/kg)	+1	+0.5
	Fossil energy use (lighting, ventilation and cleaning time, h)	0	0
Labour efficiency	Productivity (kg of rabbit sold/yr)	–0.5	–0.5
	Working time for feeding (h/batch)	0	0
	Working time for breeding activity other than feeding (h/batch)	0	0
	Number of batches/yr	+1	–1
Process efficiency	Feed conversion ratio	0	+0.5
	Mortality (%)	–1	+0.25
	Productivity (No. rabbit/IA)	–1	+1
	Weight of rabbits at weaning and slaughter age (kg)	–1	+1
	Fossil energy use (lighting, ventilation and cleaning time, h)	0	0
Control of added-value	Feed autonomy (%)	0	0
	Autonomy for renewal (%)	0	0
	Control of selling price (% direct selling or short)	0	0
	Feed cost (€/kg)	+1	+0.5
Transmissibility	Specific investment for material (€)	0	0
	Specific investment for housing room or building (€)	0	0
	Flexibility of infrastructures (use for other goals)	0	0
	Sanitary break duration (j)	–1	0
Environmental dimension			
Energy use	Lighting of building time (h)	0	0
	Cooling and heating time of building (h)	0	0
	Specific equipment use (h)	0	0
	Building cleaning time (h)	0	0
	Distance between livestock unit and feed supply (km)	0	0
Biomass use	Feed consumption (kg)	0	+0.5
	Litter use (kg)	0	0
	Biomass produced (kg)	0	0
Land link	Distance between livestock and feed supply (km)	0	0
	Distance between livestock unit and renewing animals (km)	0	0
	Distance between livestock unit and litter production (km)	0	0
	Distance between livestock unit and spreading of manure (km)	0	0
Biodiversity	Animal diversity (No.)	0	0
	Diversity of the soil fauna (No.)	0	0
	Diversity of herb layer on rangelands (No.)	0	0
	Diversity of shrub layer on rangelands (No.)	0	0
	Quality of rangelands (% degraded area)	0	0
Social dimension			
Working conditions	Batch duration (d)	–1	+1
	Handling of animals each batch (No.)	0	0
	Daily working (h)	0	0
	Sanitary break duration (d)	–1	+0.5

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Social dimension			
Work hardship	Painful posture for food (h/d)	0	0
	Painful posture for animal handling (h/batch)	0	0
	Exposure to degraded ambiance: odour, humidity (h/d)	0	0
Quality of products	Variability of products (% at slaughter)	0	0
	Animal live weight (kg)	–1	–1
	Dressing percentage (%)	–1	0
	Fatness (%)	0	0
	Downgrading rate at slaughter (%)	0	0
Animal living Conditions and welfare	Life on wired cage (% of life)	0	0
	Natural lighting (% of life)	0	0
	Possibility of expression of natural behaviour (yes/no)	0	0
	Protection against climatic hazards (yes/no)	0	0
	Enrichment of living environment (ye/no)	0	0
Breeding practices and welfare	Mortality (%)	–1	+0.5
	Legs health (score)	ND	ND
	Ad libitum feeding (% life)	0	0
	Handling (No./animal)	0	0

ND: not determined.

mortality were supplemented with quantitative indicators (feet injuries, relative length of life indoors and in wire cages or *ad libitum* feeding) and qualitative indicators related to the living environment (enrichment, light, natural behaviour). The land link was evaluated on the basis of the origin of feed and the space allotted to animals, litter and manure spading. The indicators were transformed (quantitative indicators) into or expressed (qualitative indicators) in scores according to the following scale: [–1; –0.5; 0; +0.5; +1] depending on whether innovations (I or E system) had a strongly negative (such as –2 standard deviation for quantitative data), moderately negative, zero, moderately positive or strongly positive (such as +2 standard deviation for quantitative data) effect for the indicator compared to the control system (S). The score of each indicator was then aggregated within criteria so that each criterion is expressed with a score between –1 and +1.

Statistical analysis

All data were analysed using the Statistical Analysis Systems Institute Package (SAS, 2012) except data on meat quality, which were analysed using the Statview® software program, version 5 (Abacus Concepts, Berkeley, CA, USA). Live weight, litter size, body composition, productivity (kg/AI) and fertility (kindling rate) considered as a Bernouilli variable (range 0-1), were submitted to an analysis of variance taking the fixed effect of the breeding system (3 levels: I, S and E), the parity at insemination (3 levels: nulliparous, primiparous, and multiparous of the 3rd and 4th cycle), and the interaction into account. Since kits were not identified individually at weaning, the individual weight at day 63 was analysed using the single effect of the breeding system. Carcass and meat quality data were subjected to analysis of variance using 2 fixed effects (breeding system: 3 levels; sex: 2 levels) and their interaction. When significant, means between treatments were compared using the Bonferroni test. Mortality of reproductive does and kits was analysed using a Chi square test.

Sustainability was assessed using descriptive analysis. No statistical tests were performed, as some indicators were measured with one data item per system (i.e., energy use, working time) or using qualitative data.

RESULTS AND DISCUSSION

Doe mortality

For groups I, S and E, respectively, 94, 108 and 90 does were introduced into each room at the 1st AI. Just before the 4th AI, 10, 15 and 15 were added to replace those that had died or were culled. The mortality rate of females from the 1st to the 4th AI did not differ significantly according to breeding system (19.2, 20.3 and 20.0%, for groups I, S and E, respectively).

Weight and body composition of does

The weight of does at insemination was significantly lower for group I Table 4). The weight of does significantly increased with parity. An interaction between the breeding system and parity was observed. On one hand, the weight of nulliparous does was significantly lighter in group E (subclass means of 3489 *vs.* 3709 and 3698 g, respectively, in groups I and S; $P<0.001$). This can be linked to their younger age at the 1st AI (16.6 *vs.* 19.6 and 20.6 wk of age in groups I, S and E, respectively). On the other, the mean weights at AI were lower for primiparous and multiparous does in group I (4307 *vs.* 4516 and 4514 g and 4461 *vs.* 4698 and 4782 g, respectively, in groups S and E). These results are in agreement with those of Pascual *et al.* (2013), who showed that the total body energy of rabbit does increases from the 1st AI to the 4th AI (34.8 *vs.* 59.4 MJ, Figure 1b). Parigi-Bini and Xiccato (1993) observed large energy losses (28%) by primiparous does during lactation due to largely simultaneous requirements for lactation, body growth and pregnancy. At the 4th AI, the total energy of fertile does' bodies was the lowest in group I compared to the 2 other groups (55.11 *vs.* 59.88 and 64.18 MJ for groups I, S and E, respectively; Figure 1c). This is probably the consequence of an energy deficit associated with intensive reproductive rhythm (Fortun-Lamothe, 2003). Therefore, the feeding strategy used here, based on the use of a high-energy diet for females submitted to the more intensive system (I system), failed to guarantee them a good body condition. Moreover, Feugier and Fortun-Lamothe (2006) demonstrated that limiting the nutritional requirement of females by shortening the length of superposition between lactation and pregnancy reduces body fat mobilisation in primiparous does.

Reproductive performance

The average fertility during the experiment was 74.2%, which is not far from that found in French rabbit farms (82.9%, Coutelet, 2014), considering that no hormonal stimulation was used to induce oestrus, nor dam-litter separation before AI, particularly for the intensive group. For the 4 reproductive cycles, the fertility was lowest in group I compared to the 2 other groups (65.9±47.3 *vs.* 76.6±42.4 and 80.0±40.4%, in groups I, S and E; Table 4). This result is in agreement with previous results (Theau-Clément *et al.,* 1990, 2000; Blocher and Franchet, 1990; Theau-Clément and Roustan, 1992; Theau-Clément, 2007). The lighting schedule used here was therefore not sufficient to enhance the fertility of females in the I system (RR of 35 d; Theau-Clément *et al.,* 1990; Theau-Clément, 2007).

Figure 1a highlights the breeding system×parity interaction. The kindling rate significantly decreased for group I throughout the experiment (48.2 *vs.* 78.2 and 90.1% in groups I, S and E, respectively), which could be linked to their poorer body condition (Figure 1c).

At birth, litter size was lower in group I (9.7±3.3 *vs.* 10.3±3.6 and 10.5±3.4 born alive for groups I, S and E, respectively; Table 4). The total born number increased with parity and, consequently, with the doe's age. At birth, at day 28 (after standardisation at day 3) and at weaning (age varying with the breeding system), the number of kits was the highest in group E (10.5, 8.9 and 8.8, respectively) and the lowest in group I (9.7, 8.1 and 7.8), but the litter size

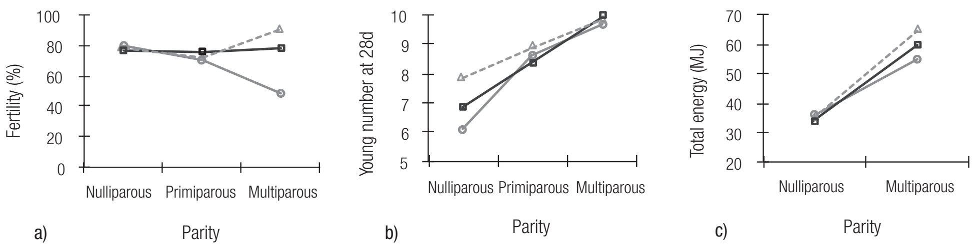

Figure 1: Fertility (a), number of kits at 28 d (b) and total energy measured at 17.6 wk (nulliparous) and at the 4th AI (multiparous; c) according to breeding system and parity. Intensive: –○–, Semi-intensive: –□–, Extensive: -△-.

Table 4: Influence of breeding system and parity of does on their reproductive performance and body composition.

	No.	AI weight (g)	Fertility (%)	Total born	Born alive	Stillborn	Litter size at 21 d	Litter size at 28 d	Litter size at Weaning	Total energy[1] (MJ)
Average	1065	4189	74.2	10.6	10.0	0.6	8.8	8.3	8.1	47.9
RMSD		361	42.8	3.1	3.2	1.7	0.8	1.1	1.5	7.2
Breeding system (BS)										
Intensive	338	4159[a]	65.9[a]	10.3[a]	9.7[a]	0.7	8.8	8.1[a]	7.8[a]	45.4[a]
Semi-intensive	401	4304[b]	76.6[b]	10.9[b]	10.3[b]	0.7	8.8	8.4[b]	8.1[b]	46.8[ab]
Extensive	326	4261[b]	80.0[b]	11.1[b]	10.5[b]	0.7	8.9	8.9[c]	8.8[c]	49.5[b]
P-value		<0.001	<0.001	0.016	0.014	NS	NS	<0.001	<0.001	<0.001
Parity (P)										
Nulliparous	416	3632[a]	77.8	8.9[a]	8.5[a]	0.4[a]	7.9[a]	6.9[a]	6.4[a]	34.8[a]
Primiparous	327	4446[b]	72.6	11.4[b]	11.0[b]	0.6[a]	8.8[b]	8.7[b]	8.5[b]	-
Multiparous	322	4646[c]	72.2	11.9[c]	11.0[b]	1.0[b]	9.9[c]	9.8[c]	9.8[c]	59.7[b]
P-value		<0.001	NS	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
BS×P		*P*<0.001	*P*<0.001	NS	NS	NS	*P*=0.056	*P*<0.001	*P*<0.001	*P*<0.001

RMSD: root-mean square deviation. AI: artificial insemination. NS: *P*>0.05. Within columns, means with different letters are significantly different at *P*<0.05. [1]Total energy was measured at 17.6 wk and at the 4th AI.

increased as parity increased. Figure 1b highlights the fact that litter size is strongly dependent on parity; nulliparous does in group E had the highest litter size at day 28 and at weaning, whereas nulliparous does in group I had the lowest litter size. This result is surprising and interesting because the does in group E had been inseminated at the earliest age (16.6 wk) and are therefore the lightest does at the time of the first AI, whereas they produced the highest number of young rabbits at 28 d and at weaning. This result is in opposition to that of Rommers *et al.* (2004) who underlined the relevance of the maturity level of young rabbit does at the time of first mating. This raises the question of the optimal age of rabbit does at the first insemination in current breeding systems, as well as that of genetic lines.

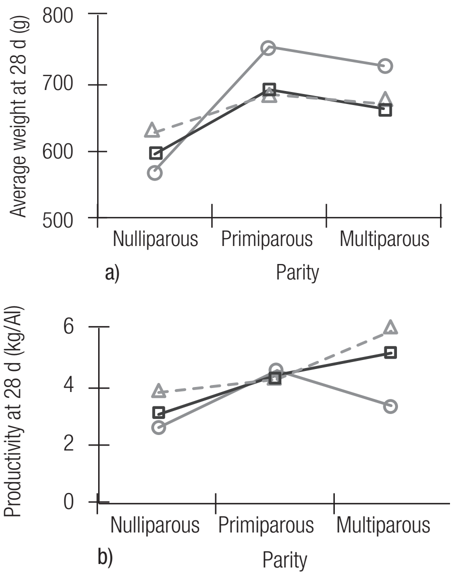

Figure 2: At day 28, average weight (a) and productivity (b) according to breeding system and parity. Intensive: —○—, Semi-intensive: —□—, Extensive: - -△- -.

Kit growth and mortality

At birth, the average weight of kits did not vary according to breeding system (Table 5). The average weight of kits at day 21 and 28 was highest in group I. This result can best be explained by the more energetic diet given in group I to meet the high nutritional needs associated with the intensive reproduction rhythm.

At weaning, due to their older age (35 d), kits in group S were heavier than those in groups I and E. The individual weight at day 63 decreased with the extensification of the reproductive rhythm (2284, 2201 and 2182 g, respectively, for groups I, S and E). During the pre-weaning period, the growth rate of kits produced by nulliparous does was lower than kits produced by older does. Nevertheless, an interaction between breeding system and parity was particularly observed at day 28 (*P*<0.001), which was more evident in primiparous and multiparous groups than in nulliparous ones (Figure 2a). The average weight of suckling rabbits at 28 d was higher for group I (primiparous: 756 *vs.* 693 *vs.* 679 g; and multiparous: 724 *vs.* 661 and 669 g, respectively, for groups I, S and E). This result could be explained by the higher energy content of the diet offered to the females in group I (Figure 2a), the

Table 5: Influence of breeding system and parity of does on their productivity and rabbit growth.

		Average weight of kits				Individual	Productivity of females	
	No.	Birth (g)	21 d (g)	28 d (g)	Weaning[1] (g)	weight at day 63 (g)	28 d (kg/AI)	Weaning (kg/AI)
Average	1065	63.8	403	654	841	2214	3.98	4.94
RMSD		10.1	44	74	102	302	2.62	3.34
Breeeding system (BS)								
Intensive	338	64.4	417[c]	682[b]	856[b]	2284[c]	3.47[a]	4.17[a]
Semi-intensive	401	63.5	398[a]	649[a]	911[c]	2201[b]	4.16[b]	5.59[b]
Extensive	326	63.5	407[b]	657[a]	766[a]	2182[a]	4.64[c]	5.38[b]
P-value		NS	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Parity (P)						-		
Nulliparous	416	63.5[a]	369[a]	595[a]	780[a]	-	3.09[a]	3.69[a]
Primiparous	327	62.4[a]	429[b]	710[c]	888[c]	-	4.38[b]	5.42[b]
Multiparous	322	65.4[b]	424[b]	684[b]	865[b]	-	4.80[c]	6.04[c]
P-value		0.007	<0.001	<0.001	<0.001		<0.001	<0.001
BS×P		NS	*P*=0.003	*P*<0.001	*P*<0.001		*P*<0.001	*P*<0.001

RMSD: root-mean square deviation. AI: artificial insemination. NS: $P>0.05$. Within columns, means with different letters are significantly different at $P<0.05$.

[1]Kits were weaned at 32, 35 or 30 d *post partum* in the intensive, semi-intensive and extensive systems, respectively.

lower litter size at day 28 and/or the lower fertility of does, which could have implied a lower frequency of does in which lactation was fully overlapped to gestation, condition that induces a strong reduction of milk yield and, thus, of growth of the suckling kits.

Kit mortality before and after weaning decreased as the reproduction rhythm extensified (11.4, 7.3 and 1.9%, and 18.3, 15.3 and 10.6%, for groups I, S and E, respectively; $P<0.05$).

Productivity

The productivity at day 28 was the highest for group E (4.64±2.52 kg/AI) and the lowest for group I (3.47±3.04 kg/IA). This result was mainly due to the performance of both nulliparous does, which was significantly higher in group E (3.72 *vs.* 2.56 and 3.00 kg/AI for groups E, I and S; Figure 2b) despite the earlier age at 1st AI, and of multiparous does, which was significantly higher for group E and lower for group I (5.93 *vs.* 3.37 *vs.* 5.10 kg/AI, respectively). It is interesting to note the less variable and positive progression of productivity of does in group 49 during the beginning of their production cycle. At weaning, due to the variation in age, the ranking of groups was modified compared to productivity at day 28. At the time of sale depending on the system, the weight of rabbits per AI was 2.32, 2.46 and 2.42 kg, respectively, for groups I, S and E at an age of 63 d for group I, and 70 d for groups S and E. Overall productivity for the 4 successive cycles at day 63 was 30, 38 and 42 kg/female over 140, 168 and 196 d. Interestingly, the difference in productivity between systems is mainly the result of the combined effect of the lower fertility and higher mortality in the I system and not due to lower weight of rabbits at day 28 or 63.

The reduction of RR (35 d) in the I system aimed to reduce the production costs and maximise the use of the livestock buildings. However, extrapolated to 1 full year, and assuming similar results, productivity per female at 63 d would be 79, 83 and 78 kg of rabbits, respectively, for groups I, S and E. Regardless of fluctuations related to parity or age of does under our experimental conditions, productivity per insemination increased with the more extensive reproductive rhythm. This result agrees with Theau Clément *et al.* (2000) and Castellini *et al.* (2010), and may be the consequence of a reduction in the duration of concurrent lactation and pregnancy that corresponded to a reduction in the energy deficit (Xiccato *et al.,* 2005).

Carcass and meat quality

The slaughter weight increased as the RR decreased (2348, 2586 and 2626, respectively, for I, S and E), leading to a carcass weight and a percentage of perirenal fat that was higher for both the S and E groups compared to the

Table 6: Influence of the breeding system and sex on rabbit carcass quality measurements.

	No.	Slaughter weight (g)[1]	Carcass weight (g)[1]	Dressing percentage (%)	Perirenal fat (%)	Hind part/Fore part ratio
Average	300	2520	1413	56.0	1.46	1.04
Breeding system (BS)						
Intensive	100	2348[a]	1267[a]	53.9[a]	1.25[a]	1.03[a]
Semi-intensive	100	2586[b]	1482[b]	57.3[b]	1.53[b]	1.05[b]
Extensive	100	2626[c]	1491[b]	56.8[b]	1.59[b]	1.02[a]
P-value		<0.001	<0.001	<0.001	<0.001	<0.001
Sex (S)						
Males	150	2501[a]	1410	56.3	1.38[a]	1.03
Females	150	2540[b]	1417	55.7	1.54[b]	1.04
P-value		<0.001	0.09	0.06	<0.001	NS
BS×S		NS	NS	*P*<0.05	NS	NS

Within columns and trait, means with different letters are significantly different at *P*<0.05.
[1]Kits were slaughtered at 63, 70 and 70 d *post partum* in the intensive, semi-intensive and extensive systems, respectively.

I group (Table 6). These differences can mostly be explained by the slaughter age, earlier in the I group. Indeed, as rabbits grow older, the heavier and fatter they become (Dalle Zotte, 2002). Live weight and perirenal fat percentage were greater for females than males (2540±14 *vs.* 2501±13 g, and 1.54±0.04 *vs.* 1.38±0.04%, respectively), in agreement with Lazzaroni *et al.* (2009). The interaction between the reproductive system and the sex was significant for the dressing percentage (Figure 3), even though within system the dressing percentage did not vary according to the sex. Rabbits in the I group obtained the lowest yields regardless of their sex, probably due to their earlier age at slaughter (Rao *et al.,* 1978; Dalle Zotte, 2002). Females in the E group had a lower dressing percentage than males in the S group and both sexes of I system. The hind part to fore part ratio was significantly higher in the S group. This could partly be due to the higher age at weaning in the S group, as Zita *et al.* (2007) showed that the older the rabbits were at weaning, the higher the loin yields were.

The reproductive system had no impact on the ultimate pH of meat in the lumbar region (Table 7). However, the intensity of lightness and yellow colour was higher for the meat of rabbits in the I and E groups than those in the S group. The meat pH of the hind legs was lower in the I and E groups than in the S group. Meat has a higher intensity of lightness but a lower intensity of colour in rabbits in the I and E groups than those in the S group. Sex had no impact on the final meat pH and a very limited impact on meat colour. Several studies have reported that the ultimate pH of rabbit meat decreases as slaughter age increases (Hulot and Ouhayoun, 1999). However, in accordance with our results, some authors found no impact of age on ultimate pH (Dalle Zotte, 2002) or an increase as rabbits grow older (Lambertini *et al*., 1996). The impact of the reproductive system on pH and the intensity of lightness could also be due to the weaning age. Indeed, Bivolarski *et al.* (2011) found a less acidic and darker meat when rabbits were weaned at 35 d compared to 21 d. The acidification of the hind leg meat of rabbits in the I and E groups compared to those in the S group could have impaired the water-holding capacity of the meat, as a correlation between these parameters has been shown in rabbit (Hulot and Ouhayoun, 1999). However, differences between reproductive systems were very limited (<0.1 pH unity) and probably have no effect on meat transformation or consumer perception. In the same way, the impact of the reproductive system on meat appearance is probably too weak to affect consumer acceptability.

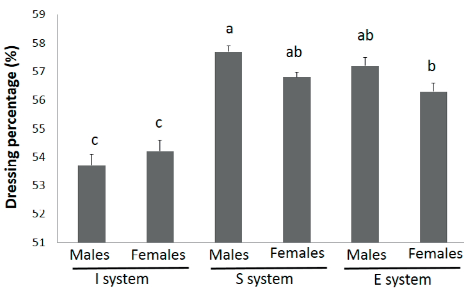

Figure 3: Dressing percentage according to breeding system and animal sex. I system: Intensive system; S system: Semi intensive system, E system: Extensive system. Bars not sharing letters were significantly different at *P*<0.05

Table 7: Influence of the breeding system and sex on rabbit meat quality measurements.

	No.	Lumbar region 24 h pH	Lumbar region colour L*	a*	b*	Hind legs 24 h pH	Hind leg colour L*	a*	b*
Average	300	5.72	55.0	5.03	5.04	5.80	52.80	4.85	3.32
Breeding system (BS)		NS							
Intensive	100	5.73	56.38[b]	4.88[a]	5.22[b]	5.80[a]	54.09[c]	4.03[a]	2.70[a]
Semi-intensive	100	5.72	52.69[a]	4.53[a]	4.28[a]	5.84[b]	51.09[a]	6.08[c]	3.53[b]
Extensive	100	5.72	55.91[b]	5.67[b]	5.61[c]	5.77[a]	53.22[b]	4.46[b]	3.72[b]
P-value		NS	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001
Sex (S)									
Males	150	5.72	55.21	5.23[b]	5.12	5.79	53.06[b]	4.93	3.40
Females	150	5.72	54.78	4.83[a]	4.95	5.81	52.51[a]	4.77	3.23
P-value		NS	NS	<0.05	NS	NS	<0.05	NS	NS
BS×S		0.07	0.39	0.93	0.48	0.80	0.96	0.28	0.65

Within columns, means with different letters are significantly different at *P*<0.05. L: lightness; a: redness; b: yellowness.

Sustainability assessment

The Table 3 reported the scores obtained by alternative systems for each indicator. Figure 4 shows that the 2 alternative systems mainly modified the sustainability profile of the production system in terms of the economic and social criteria. The I system improves the score for the "economic viability" (+0.17) and "labour efficiency" (+0.13) criteria as the result of the larger number of reproductive cycles performed annually. However, this causes a negative effect on the "working condition" (–0.50) criterion. The weaker performance observed by the reproductive cycle, particularly due to the higher mortality rate for females and growing rabbits, decreased the scores on the "efficiency of the production process" (–0.60) and "breeding practices respectful of animal welfare" (–0.33) criteria. The score

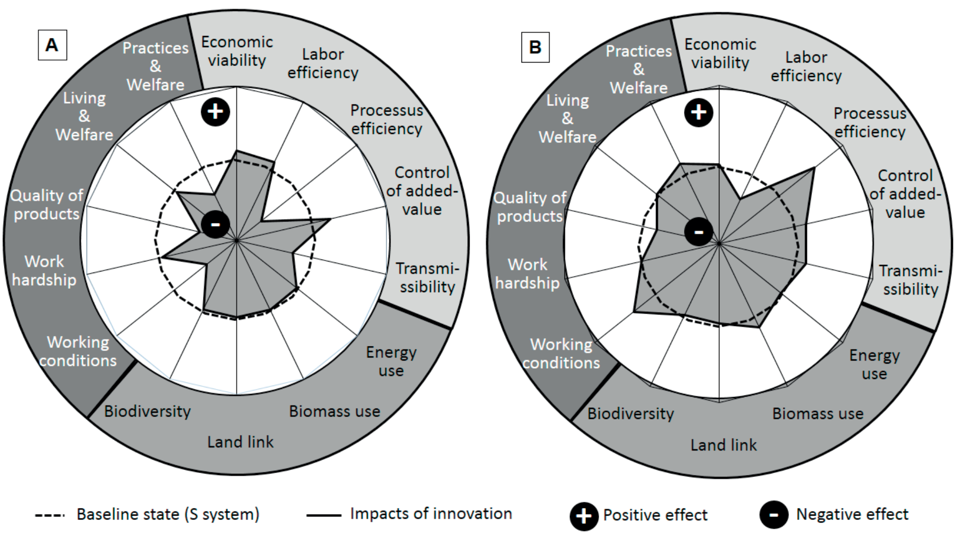

Figure 4: Impacts of alternative practices (A: Intensive *vs.* Semi intensive system; B: Extensive *vs.* Semi intensive system) on sustainability of rabbit production system.

on the “quality of products” (–0.50) criterion is reduced due to the lower animal weight at slaughter and lower carcass yield. An adjustment of the system, such as feeding strategy, could help to reduce these disadvantages.

In the E system, the animal performance per reproductive cycle was improved, which increased the score for the “efficiency of the production process” (+0.55) criterion. However, this is linked to a reduction in the number of batches per year, which reduces the score on the “labour efficiency” (–0.38) criterion but improves the score on the “working condition” (+0.38) criterion. Some other positive effects were observed such as in “control of the added-value” (+0.12) due to lower feed cost, and “biomass use” (+0.17) due to lower feed intake. The positive effect on the “breeding practices respectful of animal welfare” criterion (+0.12) is due to a positive effect on kit viability.

The multicriteria assessment method helps to provide a broader vision than the analysis of animal performance alone. In this regard, the I system, which was based on economic and environmental incentives, had no effect on environmental performance but a positive effect on 2 of the 5 economic criteria (economic viability and labour efficiency). However, it has a negative effect on several social criteria (animal welfare, working condition and quality of product). In contrast, the E system, which was based on social incentives, also had a positive effect on one economic criterion (process efficiency) and one environmental criterion (biomass use). This sustainability assessment could be improved by using a quantitative evaluation instead of semi-quantitative scoring as was done here and which is of low precision. Some other methods have been developed to evaluate the sustainability of other livestock production systems (Lairez *et al.,* 2015) and might be adapted to rabbit production. Additionally, an assessment of the breeding unit (reproduction and fattening periods) can be considered as being too restrictive in terms of environmental impacts. To this end, the life cycle analysis method makes it possible to take impacts upstream and downstream of the rearing units (from cradle to grave) into account and was previously used in a relevant way to compare livestock systems (pig: Basset-Mens *et al.,* 2007; poultry: Leinonen *et al.,* 2012).

CONCLUSION

This study aimed to evaluate the effects of 2 alternative breeding systems compared to the current dominant French rabbit production system in terms of performance and sustainability. Present results showed that a simultaneous change in several breeding practices could lead to new coherent and functional systems. Under our experimental conditions, an early 1st insemination (16.6 wk) associated with an extensive reproduction rhythm (49 d) resulted in higher productivity (kg/AI) at day 28 and 63 than in the control breeding system. An intensive reproduction rhythm (35 d) combined with a 1st AI at 20.6 wk, slaughter at 63 d and an adapted feeding strategy for females failed to improve productivity (kg/female over 4 cycles) at day 28 and 63 compared to the control breeding system. However, a multicriteria assessment showed that both alternative systems improved various aspects of sustainability beyond productivity. Present results also showed that an assessment of performance over a long period, for example over 4 successive reproductive cycles as in our case, is necessary to observe the system dynamics. Further methodological developments are needed to evaluate the consequences of alternative breeding practices, both quantitatively and beyond the rearing unit.

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