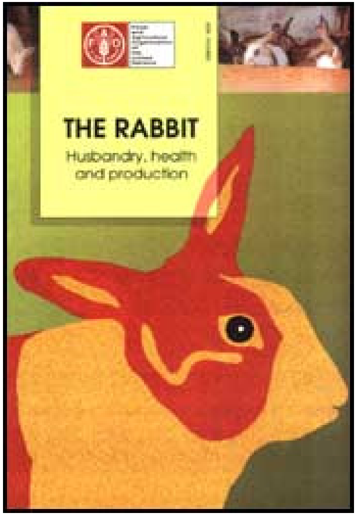
The Rabbit - Husbandry, Health and Production



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FAO Animal Production and Health Series No. 21

(new revised version)

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ISSN 1010-9021

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1997

Rabbits reared with techniques adapted to specific environments can do much to improve the family diet of many of the neediest rural families, at the same time supplying a regular source of income.

The purpose of this work is to bring together as fully and objectively as possible all the available data on rabbit husbandry, health and production. It is also intended as a contribution to the preparation and execution of rabbit development programmes, particularly in developing countries.

A team of scientists from the French National Institute for Agricultural Research (INRA), a world-renowned rabbit authority, was marshalled to cover the many and varied aspects of rabbit production.

David Lubin Memorial Library Cataloguing in Publication Data

Lebas, F.

The rabbit: husbandry, health and production
(new revised version)
ISBN 92-5-103441-9

(FAO Animal Production and Health Series, no. 21)
ISSN 1010-9021

1. Rabbits
2. Animal husbandry
3. Pathology

I. Title
II. Series
III. FAO, Rome (Italy)

IV. Coudert, P.
V. de Rochambeau, H.
VI. Thébault, R.G.

FAO code: 21
AGRIS: L01

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Foreword

Despite considerable progress in food production in the last 30 years, 800 million people in the world are still undernourished. This is not only because of food deficits and inadequate distribution: the incomes of the poorest are too small to allow them to procure wholesome food in sufficient quantities.

Livestock production is a major component of farm economies in developing countries, contributing not only food but also hides, fibres, fertilizer and fuel, as well as a modest, interest-producing capital which can easily be mobilized when unforeseen needs arise. In addition, livestock, whether large or small, are part of the social and cultural reality of several million small farmers, for whom husbandry represents an element of economic stability and sustainability. Both human and livestock populations have grown considerably in the last 30 years, but the rates in developed and developing countries are not comparable. Whereas the global human population has risen by 75 percent since 1960, in the developing countries the rate of increase was 97 percent and in the industrialized countries 28 percent. All species of livestock populations increased, but monogastrics (pigs and poultry) much more than ruminants.

Small-animal husbandry can be a very lucrative operation for both landed and landless small farmers; providing work for women, children and the handicapped (the least privileged social strata), producing substantial income and helping to upgrade the family diet. Many small domesticated species (guinea-pigs, capybara, cane rats, etc.) meet these objectives, but rabbit husbandry is far more prevalent, particularly in the Mediterranean area. Certain traditional rabbit production systems particularly adapted to hot, dry, semi-arid countries have been successfully developed.

Backyard rabbitries are particularly well suited to small farmers, whether they own land or not. The advantages are closely related to the reproductive and feeding behaviour of rabbits and the fact that the species is both profitable and easy to integrate:

- as a small monogastric herbivore, the rabbit easily accommodates a fairly wide range of cellulose-rich foods;

- it is adaptable to the family diet and food preservation techniques available on small rural and peri-urban farms;

- it is highly productive in terms of offspring (kg/year/dam) thanks to mating-induced ovulation, short gestation and lactation periods and great prolificacy;

- it produces highly nutritious, low-fat, low-cholesterol meat;

- it is easy to transport and market and the recurrent costs for maintaining animals beyond the optimum marketing age are low;

- labour costs are low and the work can be done by family members: women and children, or perhaps aged or handicapped people, usually the most vulnerable and least privileged social strata, for whom rabbit husbandry, like that of other small animals, represents an attractive and remunerative occupation;

- it represents a contribution to the family income;

- investment is low: infrastructure and equipment can easily be put together by the breeder and not much space is needed.

Backyard rabbitries are the perfect answer to today's demand for sustainable development projects. For this reason, the Food and Agriculture Organization of the United Nations (FAO) and governmental and non-governmental development organizations have given firm and virtually universal support to rabbit projects in the developing countries. In the last ten years, FAO's Animal Production and Health Division (AGA) has supported and developed rabbit projects in Egypt, Ghana, Guinea-Bissau, Equatorial Guinea, Haiti, Mexico, Rwanda, Sao Tome and Principe and the Democratic Republic of the Congo (former Zaire).

However, projects which have been successful have not had the expected catalytic effect and others have heavily regressed or completely disappeared. It would be a good idea to pinpoint the reasons for these failures and seek the most appropriate solutions before attempting to relaunch such activities.

Constraints may concern:

- social, cultural and economic factors: customer acceptance of rabbit meat and ease of marketing;

- a lack of local resources available for balanced, low-cost, locally adapted rations;

- the existence of rabbit housing and management styles that inhibit the range of rabbit territorial, social, sexual, material and feeding behaviours;

- the presence of diseases representing a set of syndromes, rather than specific pathologies: if so, the appropriate approach would be an ecopathological one;

- breeder training: breeders may be unfamiliar with this species, which has very different behavioural characteristics from other domesticated species. Training should include useful theory and solid practical apprenticeship.

By the year 2010, the world population will have risen from the present 5.4 billion to 7.2 billion, moving past nine billion by 2025. This increase will be felt mainly in the developing countries, where the corollary will be sizeable growth of the peripheries of urban conurbations, increased pressure on available land and major changes in the composition of animal populations. There will also be substantial impact on available natural resources and on the future demand for livestock products. This will have a profound effect on the choice of feed resources and livestock systems.

More land will have to be allocated for food production, reducing the feed resources (natural rangeland, pastures, forage) available to feed this growing population, as can already be seen in Asia. Even so, appropriate technology can release additional harvest residues and agro-industrial by-products which can be used for livestock feed. Clearly, enhanced food production requires more efficient utilization of natural resources and the development of alternatives such as rabbit husbandry.

This is why this manual, first published in 1984, is now being reissued. This very successful publication, translated into English and Spanish and reissued in 1990, has long been out of print. An update thus became imperative in light of the major new developments and progress in rabbit husbandry in the last ten years. Publication of the handbook, delayed for many months, coincided with the Sixth World Rabbit Congress held in Toulouse from 8 to 12 July 1996. This meeting reported on the latest and best rabbit technologies, as well as those which can contribute effectively to food self-sufficiency in low-income food-deficit countries through sustainable production models.

FAO is indebted to the National Institute for Agricultural Research (INRA) team under the leadership of François Lebas for their contribution to this edition, their fine work and the many concrete instances of fruitful, joint collaboration over the last few years.

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Acknowledgements

Much of the information contained in this book comes from work and research conducted by its authors and their colleagues in the National Institute for Agricultural Research (INRA) in France. The authors feel it only fair to mention the names of those colleagues with whom they work daily and from whom they have "borrowed" an amount of data.

- *Animal Genetics Improvement Station, Toulouse Centre: R. Rouvier, B. Poujardieu, G. Bolet, A. Roustan, J.-M. Brun, F. Tudela*
- *Rabbit-breeding Research Laboratory, Toulouse*

Centre: J. Ouhayoun, T. Gidenne, J.-M. Perez, F. Hulot, L. Fortun, D. Delmas

- *Rabbit Pathology Laboratory, Tours Centre: D. Licois, F. Viard*
- *Magneraud Pluridisciplinary Unit, Poitou-Charentes Centre: P. Mercier*
- *Animal Physiology Station, Jouy-en-Josas Centre: B. Moret*
- *INRA Special Committee on Rabbits, Poitou-Charentes Centre: J.-L. Vrillon*

The authors also wish to thank Mr Kpodekon, Rabbit Research and Data Centre, Cotonou University, Benin, for his contribution to this book.

Chapter 1 INTRODUCTION AND BACKGROUND

World production and trade

Best known for being prolific, rabbits are also herbivores which efficiently convert fodder to food. The whole point of meat production is to convert plant proteins of little or no use to people as food into high-value animal protein.

In efficient production systems, rabbits can turn 20 percent of the proteins they eat into edible meat. Comparable figures for other species are 22 to 23 percent for broiler chickens, 16 to 18 percent for pigs and 8 to 12 percent for beef.

A similar calculation for the energy cost of these proteins is even more unfavourable to ruminants, as shown in Table 1. When cattle or sheep are raised for meat production, most of the energy consumed by the herd or flock is used to maintain breeding females which have a low prolificacy: a maximum of 0.8 to 1.4 young per year against 40 for female rabbits. Even with the theoretical lower energy cost when cattle are raised for both milk and beef, rabbit meat is still more economical in terms of feed energy than beef. Rabbit meat production is therefore an attractive proposition, especially when the aim is to produce quality animal protein.

Rabbits can also easily convert the available proteins in cellulose-rich plants, whereas it is not economical to feed these to chickens and turkeys - the only animals with higher energy and protein efficiency. The traditional grain and soycakes fed to these domestic poultry put them in direct competition with humans for food. For countries with no cereal surpluses, rabbit meat production is thus especially interesting.

Historical background

A little history

The domestication of the major livestock species (cattle, sheep, pigs) and the small species (poultry) is lost in the dawn of prehistory. But rabbit domestication dates back no further than the present millenium.

Indeed, the wild rabbit *Oryctolagus cuniculus* of southern Europe and North Africa is thought to have been discovered by Phoenicians when they reached the shores of Spain about 1000 BC. In Roman times the rabbit was still emblematic of Spain. The Romans apparently spread the rabbit throughout the Roman Empire as a game animal. Like the Spaniards of that time, they ate foetuses or newborn rabbits, which they called *laurices.*

Rabbits had still not been domesticated, but Varron (116 to 27 BC) suggested that rabbits be kept in *leporaria,* stone-walled pens or parks, with hares and other wild species for hunting. These *leporaria* were the origin of the warrens or game parks that subsequently developed in the Middle Ages. It is known that monks were in the habit of eating *laurices* during Lent as they were considered "an aquatic dish" (*sic*). In France, it became the sole right of the lord of the manor to keep warrens. Rabbits were hunted little, and were captured with snares, nooses or nets.

Several breeds of rabbit were known in the sixteenth century and this is the first indication of controlled breeding. Domestication can therefore be traced to the late Middle Ages. This was probably mainly the work of monks, since it provided them with a more delectable dish than the tougher wild rabbit.

TABLE 1 Average performance of different animal species and energy cost of proteins they produce

During the sixteenth century breeding seems to have spread across France, Italy, Flanders and England. In 1595, Agricola mentioned the existence of grey-brown (wild), white, black, piebald (black and white) and ash-grey rabbits. In 1606, Olivier de Serres classified three types of rabbit: the wild rabbit, the semi-wild or "warren" rabbit raised inside walls or ditches, and the domesticated or hutch-bred rabbit. The meat of the last is described as insipid and that of the wild or semi-wild type as delicate.

At the beginning of the nineteenth century, after the abolition of seigneurial privileges, rabbit rearing in hutches sprang up all over rural western Europe and also in city suburbs. European colonial expansion saw the introduction of the rabbit in many countries where it was unknown, such as Australia and New Zealand.

In Europe, breeders usually had a few does and a stock of fattening animals, from which they took according to their needs, as from a larder. The animals were fed mainly on green forage picked daily. In winter the breeders supplemented forage with hay, beetroots and even grains, often from stocks intended for large livestock. Rabbits were kept in the backyard, with the poultry. Reproduction was extensive (two or three litters a year).

From that time on there is frequent mention of the fur as a by-product (the breed now called Argenté de Champagne was described as "rich"), and the already long-existing Angora mutant was recorded.

From backyard to rational production

Beginning in the late nineteenth century and picking up speed in the twentieth, hutch rearing led to a rabbit population explosion made possible by the selection, protection and multiplication of breeds and mutants unadapted to the wild. Breeders formed associations. Breeding techniques were rationalized and hutch hygiene improved.

Breeding standards were laid down: each adult breeding animal was raised in a separate hutch because rabbits kept in a confined space became aggressive. Young rabbits for fattening were left together, but in this case the males were castrated. Feeding was the same as in the previous century, green fodder and grains, but the first feeding trials produced certain guidelines. The Second World War saw the extensive development of rabbit production throughout Europe and Japan to cope with meat shortages. Under these demanding conditions, rabbits demonstrated their highly efficient feed-conversion capacity.

In the 1950s, production slumped in Japan and the northern European countries as other meats with more flavour became available, such as frozen beef from the Southern Hemisphere. But in the Latin countries of Europe where people know how to cook rabbit, particularly in France, rabbits were still produced. In the late 1950s, New Zealand rabbits, wire-mesh cages and balanced pelleted feeds were all introduced into France and Italy from the United States. At the same time, diseases hitherto unknown and apparently linked with the new production techniques (mucoid enteritis and respiratory ailments) appeared and others disappeared (cenuriasis) or tapered off (coccidiosis).

These new techniques, originally better adapted to the climate of

California than to that of northern Italy or France, demanded many modifications in production which were often discovered by trial and error. The hutches especially, which had always been kept outside, were put in closed buildings. Ventilation and lighting problems had to be solved.

The time spent on cleaning cages and collecting food was reduced abruptly. This freed breeders to spend more time on the animals themselves. In the late 1960s and early 1970s, the work of authors such as Prud'hon *et al.* (1969) led to a sharp drop in weaning age, from eight to four weeks. Postkindling matings replaced postweaning matings. Breeders were able to put into practice Hammond and Marshall's early observations (1925) about postkindling fertilization of does because feeds were so much improved as to obviate the danger of abortion in lactating pregnant does through malnutrition.

At the same time came the explosion of the New Zealand White rabbit and its offshoot, the Californian rabbit. The traditional European breeds (Fauve de Bourgogne, Argenté de Champagne, French Belier) underwent a regression. As adults it is difficult for these breeds to live on the mesh floors of the cages - the pads of their paws not being adapted like those of the New Zealand White and Californian rabbits.

French and Italian breeders worked to improve substantially the first New Zealand White and Californian rabbits imported from the United States. In France, the two breeds were combined to produce specialized hybrid strains according to the design conceived by the French National Institute for Agricultural Research (INRA). In the late 1970s, these strains crossed the French border to Italy, Spain, Belgium and the Federal Republic of Germany where, in large commercial production units, they tended to supplant the traditional breeds. Other hybrid strains were produced at the same time, especially in Hungary and the United Kingdom, but in almost every case the new strains were bred from these original two breeds.

Traditional varicoloured rabbits have been gradually replaced by white rabbits. This is having a considerable impact on the market for skins. Before the 1970s, furriers tended to favour the easy-to-dye white skins. Today the reverse is true - white skins are too common. At the same time, improved production techniques have lowered the slaughter age of rabbits in Europe which has reduced the value of the fur. The hair of the skins is "loose" because the animals are too young.

Production trends in France since the 1950s are given in Table 2. Industrial rabbit production (specialists prefer the word "rational" to industrial, as the breeder's expertise is still very important) in Europe today is typically in units of 200 to 1 000 hybrid does reared in buildings with artificial or controlled ventilation. The breeding females are under artificial lighting for 15 to 16 hours a day and produce all through the year. All animals are reared in one- to four-storey mesh cages (flat-deck and battery). Male and female breeding animals are raised in cages in groups of five to ten (France and Spain) or one to three (Italy). Young males are not castrated because they are sold for slaughter before or just at puberty. All the animals are fed exclusively with balanced pelleted feed. Drinking water is automatically distributed to every cage.

TABLE 2 Production trends in France from 1950 to 1990 in the most productive rabbitries

Criteria	1950	1960	1970	1980	1990
Rabbits produced (sold) per breeding doe	20-25	30	45	60	65
Average interval between litters *(days)*	90-100	70	54	42	40
Concentrate feed necessary to produce 1 kg live rabbit *(kg)*	(*)	6	4.5	3.6	3.3
Type of			Pure-		

Type of rabbit	Common, of no specific breed	Pure breeds	Pure bred does crossed with improver buck	Specialized hybrid strains	Specialized hybrid strains
Working hours per doe per year (*hours*)	16	16	10	7.5	6.0
Labour used to produce 1 kg carcass *(minutes)*	27	22	9.5	6.2	4.3
Number of breeding does in breeding units	80-100	100-150	200-250	350-400 up to 1 000	600-4000

Percentage of investment in retail price of rabbit *(%)*	<3	5-8	12-15	18-20	18-20

* Rabbits were not fed concentrates at this date.

At the same time there is a sizeable increase in private (sophisticated buildings and breeding installations) and producer-group investments (technical advisers). Typically, rational production consists of a very quick succession of all phases of the reproduction cycle. This demands extremely close and time-consuming supervision by the breeder. The technical adviser, not being directly involved in these day-to-day tasks, is of great assistance in the medium-and long-term running of a unit. His/her salary and ancillary costs amount to a sizeable investment for a group of producers (1 to 3 percent of the sale price of a rabbit).

In many countries of Eastern and Western Europe (e.g. Poland, Hungary, France, Italy and Belgium), a more traditional production system, very similar to that of the first 40 or 50 years of this century, still contributes a considerable part of the national output: over 90 percent in Hungary and nearly 40 percent in France. These traditional units are usually very small, with two to 12 breeding females.

World production

National statistics do not generally include rabbit production, but a few available basic statistics allowed Lebas and Colin (1992) to estimate a world output of roughly 1.2 million carcasses. A more recent estimate (1994) by the same authors, including almost all countries in the world, suggests a possible 1.5 million tonnes. This would mean a per caput annual consumption of roughly 280 g of rabbit meat; a theoretical figure in that most inhabitants in a great many countries consume no rabbit meat whatsoever against the 10 kg/year consumed by French farmers and 15 kg/year per caput in Naples, Italy. Europe is indeed the centre of world rabbit production (Figure 1). The foremost world producers, far surpassing all other countries, are Italy, the Commonwealth of

Independent States (CIS) countries (particularly Russia and the Ukraine), France, China and Spain (Table 3). In all, Europe accounts for 75 percent of world production. China is second, specifically certain central Chinese provinces such as Szechuan. Production areas are also found in some regions of Africa, Central America and Southeast Asia, particularly Indonesia. Rabbits are not reared in most countries of the Near East. Table 4 gives some indication of per caput consumption.

European trends, 1960 to 1980

Rabbit production in Italy was still traditional in the early 1970s. However, faced with as strong a demand for the product in the industrialized north as in the more traditional south, production units mushroomed between 1975 and 1990. The greatest concentration and largest rabbitries are found in the Venice area, but production is also substantial throughout the country.

TABLE 3 Major rabbit-producing countries in 1990*

	Estimated		Estimated

Country	**production (*carcass weight*)**	**Country**	**production (*carcass weight*)**
	Thousands of tonnes		*Thousands of tonnes*
Italy	300	Portugal	20
CIS (former USSR)	250	Morocco	20
France	150	Thailand	18
China	120	Viet Nam	18
Spain	100	Philippines	18
Indonesia	50	Romania	16
Nigeria	50	Mexico	15
United States	35	Egypt	15
Germany	30	Brazil	12
Czechoslovakia (former)	30		

Poland	25	**Total 22 major producers**	**1311**
Belgium	24	Other countries	205
Hungary	23	**Total estimated world production**	**1516**

* Countries producing more than 10 000 tonnes.
Sources: Lebas and Colin, 1992; Colin and Lebas, 1994.

***FIGURE 1 Estimate of annual production of rabbit carcasses in different countries* (dead weight in thousands of tonnes)**

Database
Countries producing 100 000 tonnes or more

China
CIS (former USSR)
France
Italy
Spain

Countries producing 20 000 to 99 000 tonnes

Belgium
Czech Republic
Germany
Hungary
Indonesia
Morocco
Nigeria
Poland
Portugal
United States of America

Countries producing 5 000 to 19 000 tonnes

Algeria
Brazil
Colombia
Denmark
Egypt
Ghana
Greece
India
Malaysia
Mexico
Netherlands
Philippines
Romania
Slovakia
Sri Lanka
Thailand
United Kingdom
Venezuela
Viet Nam
Yugoslavia (former)

Countries producing 1 000 to 4 900 tonnes

Albania
Angola
Argentina
Bangladesh
Bolivia
Bulgaria
Burundi
Canada
Chile
Côte d'Ivoire
Democratic People's Republic of Korea Democratic Republic of the Congo (former Zaire)
Ecuador
Estonia
Ireland
Japan
Jordan
Kenya

Latvia
Libyan Arab Jamahiriya
Lithuania
Malta
Mozambique
Myanmar
Nepal
Pakistan
Peru
Puerto Rico
Republic of Korea
Rwanda
South Africa
Sudan
Switzerland
Syrian Arab Republic
Tunisia
Turkey
Uruguay
Zambia

Zimbabwe

Countries producing less than 1 000 tonnes

All other countries

TABLE 4 Estimated annual consumption of rabbit meat by country (in kg per inhabitant)

Country	Weight
Malta	8.89
Italy	5.71
Cyprus	4.37
France	2.76
Belgium	2.73
Spain	2.61
Portugal	1.94
Czechoslovakia (former)	1.72

CIS (former USSR)	0.75
Morocco	0.78
Slovenia	0.77
Greece	0.70
Romania	0.64
Netherlands	0.63
Malaysia	0.50
Poland	0.50
Tunisia	0.48
Nigeria	0.45
Germany	0.44
Bulgaria	0.39
Ghana	0.32
Thailand	0.31
Venezuela	0.30
Philippines	0.29
Egypt	0.27

Indonesia	0.27
Algeria	0.27
Viet Nam	0.27
Syrian Arab Republic	0.25
Colombia	0.24
Canada	0.23
Jamaica	0.20
Mexico	0.18
United States	0.14
Argentina	0.12
South Africa	0.11
Hungary	0.10
Brazil	0.08
China	0.07
Benin	0.04
Democratic Republic of the Congo (former Zaire)	0.04

Japan	0.03

Source: Lebas and Colin, 1992: Colin and Lebas, 1994.

Global production rose from roughly 120 000 tonnes in about 1975 to nearly 300 000 tonnes in 1990.

The situation in France is somewhat different. Output stabilized at about 275 000 tonnes a year from 1965 to 1972, then slumped abruptly and now stands at roughly 150 000 tonnes. This situation is in line with the rapid drop in the number of very small producers who consumed much of their own production but who, because there were so many of them, supplied an appreciable share of the rabbits marketed. During the same period many newly established rational units of 50 to 500 did not only close the small-scale producer gap, but also managed to increase slightly the tonnage of rabbits marketed, which rose from 80 000 to 90 000 tonnes in the years 1960 to 1965 to 100 000-110 000 tonnes at present. A considerable research effort aimed at improving production techniques was responsible for this increase.

The traditional production sector in Spain produced little during the 1960s. The many rational units that were opened from 1970 onwards led to a spectacular leap in the output and marketing of rabbit meat. The present total is 100 000 tonnes. Production models were transposed directly from France.

Lagging about 15 years behind Spain, Portugal developed rational production incorporating the progress made in French, Italian and Spanish rabbitries. Portugal, with an annual per caput carcass output of 2 kg, is on a par with Belgium for volume of production: 24 000 tonnes per year.

Rabbit meat production and consumption in other Western European countries are still low. However, there seems to be a slight upturn in Germany, where breeders are being encouraged to increase their output. There is a large number of fancy breeders in Germany who raise a few pedigree animals as a hobby and also eat a small proportion of the rabbits produced for this purpose. Production and consumption in Sweden and Norway are very low. Rabbit breeding is still a tradition in Denmark, although the national output, once mostly exported to Germany, has now dropped.

Hungary stands out among Eastern European countries. This predominantly agricultural country encourages family-scale rabbit production with five to 20 does. At the same time, the large production complexes with 10 000 to 15 000 breeding females established in the 1970s and 1980s have been abandoned because of management problems. They have been downsized and serve primarily to supply selected breeders for small-scale operations. The young fattened animals produced on family farms are collected and almost all exported to Italy. In the early 1970s exports to Italy consisted mainly of live animals. The rabbits were slaughtered in the Milan area. Most rabbits from Hungary are now exported as fresh carcasses. In Poland, small family rabbitries (five to 20 breeding females) are still the rule. The rabbits produced are expected to provide good-quality meat as well as fur for marketing. Therefore they are usually slaughtered late (four to six months) for better skin quality. Some animals are collected as in Hungary, but exported as frozen carcasses (generally heavy). The sizeable Czechoslovakian production is mainly for national consumption but, as in Germany, there are many (80 000-90 000) fancy breeders raising a few pedigree rabbits as a hobby.

North and South America

Rabbit production and consumption in the United States are concentrated primarily in the three Pacific States and in the southern States of Missouri and Arkansas. A frequent estimate of national output is 15 000 to 17 000 tonnes, but an updated review by Colin (1993) suggests the figure may be as high as 35 000 tonnes. Young rabbits of approximately 1.8 kg live weight are eaten as "fryers". On the east coast there is virtually no market and the only rabbits are pets.

Rabbit production in Canada is modest, mainly concentrated in the provinces of Quebec and Ontario, where it is subsidized by the provincial governments. The slaughtered carcasses are a little heavier than in the United States.

In Mexico, the promotion of backyard rabbitries in rural and peri-urban areas has led to a total annual output of 10 000 tonnes, from these small units, producing mainly for home consumption, and commercial units combined. The latter are small (20 to 100 does) and use balanced concentrate feeds almost exclusively. The family units rely on forage (alfalfa, maize or sorghum stems) and kitchen wastes. This rabbitry, unfortunately decimated by viral haemorrhagic disease (VHD) in 1990, is now being rehabilitated.

In the Caribbean area, rabbit production is basically family style and forage-based.

The rabbits are often small local breeds descended from animals imported some tens or hundreds of years ago. However, notable efforts have been made in Cuba to develop improved breeds and use more intensive production methods. In Guadeloupe and Martinique in the French Antilles, intensive commercial production in small units of 25 to 100 does has grown side by side with traditional production in the last decade. This development is based on animals and concentrate feeds imported from France or produced locally. Performance is good: does produce 30 to 40 young a year and these are sold at 2.2 to 2.4 kg at about 80 days.

In South America the biggest producers are Brazil and Uruguay, in large commercial units with thousands of breeding females. The animals, generally raised extensively, are fed locally manufactured balanced concentrate feeds.

Asia

Rabbit production does not seem to have truly developed in Asia except in Indonesia and, particularly, China. The Philippines, Malaysia, Thailand, Viet Nam and the Republic of Korea also produce a small amount of rabbits. No official statistics are published in China on the production and consumption of rabbit meat and it is difficult to approach the question of production in a country of a thousand million inhabitants without official statistics. However, it does appear that rabbits for export (mainly to Europe) come from the nearly 20 million Angora rabbits produced. They are usually slaughtered very young, after the second or third clipping at most. Production is mixed: angora wool plus meat. Thus, financially, meat appears to be the byproduct and angora wool the main product, fetching 55 to 70 percent of the return for each animal. The animals are fed forage and a little grain and grain byproducts. Production units do not appear to be spread throughout China, but rather concentrated in certain villages. This enables better support facilities and facilitates the marketing of a product which remains, in principle, traditional. In other Chinese provinces, such as Szechuan, there is substantial production of meat rabbits intended primarily for local consumption. Part is, in any case, collected for export to hard-currency countries.

Africa

There is a tradition of rabbit production in the five Mediterranean countries of Africa. Per caput production varies from Egypt's 0.27 kg to Morocco's nearly 0.78 kg. The traditional production systems in the southern parts of these regions feature an original habitat where rabbits are group-reared in burrows dug into the earth.

In sub-Saharan Africa, the two main producers are Nigeria and Ghana and to a lesser extent the Democratic Republic of the Congo, Cameroon, Cote d'Ivoire and Benin.

There is commercial production in these countries, but most rabbitries are family-owned, with part of the output for market. The national rabbit production development programme in Ghana, for example, proposes a system where small family units keep only three to six breeding animals, so they can be fed on local products - forage, cassava, etc. - and produce surplus animals for sale.

International trade

The rabbit meat market

Few countries are involved in the international trade: the annual trade figure is over 1 000 tonnes of carcass equivalent. Only nine countries are exporters, only six are importers and eight are both.

The actual volume of international trade is quite small: 6 or 7 percent of world output, according to the data source in Table 5. A total of 23 countries account for 95 percent of the international trade (imports and exports alike), implying that rabbit meat production is generally for domestic consumption.

TABLE 5 Major rabbit meat importing and exporting countries

(in millions of tonnes of carcass equivalent per year)

Country	Exports	Imports	Balance
Austria	0	1.0	- 1.0
Belgium	10.3	13.0	- 2.7
Canada	1.0	3.0	- 3.0
China	40.0	0	+ 40.0
Croatia	1.0	0	+ 1.0
Czechoslovakia (former)	3.0	0	+ 3.0
France	5.0	11.0	- 6.0
Germany	0	5.0	- 5.0
Hungary	22.7	0.7	+ 22.0
Italy	0.65	30.0	- 29.35
Japan	0	3.0	- 3.0
Mexico	0	3.0	- 3.0
Netherlands	3.75	3.70	+ 0.05

Poland	6.0	0	+ 6.0
Republic of Korea	0	1.2	- 1.2
Romania	1.0	0	+ 1.0
Serbia	1.5	0	+ 1.5
Singapore	0	1.0	- 1.0
Spain	0.5	2.5	- 2.0
Sri Lanka	0	1.0	- 1.0
Switzerland	0	5.0	- 5.0
United Kingdom	0.2	9.0	- 8.8
United States	2.0	3.0	- 1.0
Total	**94.1**	**97.6**	
Total world trade	**100**	**100**	

Source: Colin and Lebas, 1994.

The two biggest exporting countries are China (40 000 tonnes) and Hungary (23 700 tonnes). It is difficult to get a clear idea of

Chinese exports for two reasons. First of all, interannual fluctuations in the volume of trade are great: Chinese exports to France in 1989 were 9 400 tonnes, but only 2 500 in 1991. This is partly because of true production fluctuations in China, e.g. resulting from the VHD epidemic, and partly because of storage potential and carryover, as Chinese rabbit meat is almost exclusively sold frozen. The second reason is that China sometimes exports directly to developing countries, making it very difficult to gather data.

In Hungary, all output is aimed at the export market: less than 5 percent is for domestic consumption. Hungary is an exception here: only Croatia is near with 50 percent of the national output exported.

The main buyers in order of importance are Italy, Belgium, France and a few other Western European countries: the United Kingdom, Germany, the Netherlands and Switzerland. Other Eastern European countries also supply the above: the Czech Republic and Slovakia with 3 000 tonnes, Poland with 6 000 tonnes, Romania with 1 000 tonnes, and the former Yugoslavian countries of Croatia and Serbia.

The biggest importer in absolute terms is Italy, also apparently the prime consumer. The major Italian suppliers are Hungary, China, former Yugoslavia and sometimes Romania and Poland. Belgium is second, but with very strong export flows. France is the third importer in terms of quantity, importing from 4 000 to 12 000 tonnes depending on the year, mainly from the same suppliers as Italy, but with China in first place.

Imports for national consumption are largest in Switzerland with about 60 percent, which is partially explained by the very strict legislation on the conditions for production, resulting from the influence of the "eco-lobby". France is Switzerland's main supplier, followed by Hungary and China.

Some countries such as Belgium and France are both importers and exporters, with export prices generally topping import costs. France thus buys rabbits cheaply from China and sells rabbits at a much higher price to Switzerland. Likewise, Belgium, the

Netherlands and even the United Kingdom import from China and the Eastern European countries, while exporting part of their own output to France. In a similar vein, the United States imports from China and exports to Canada. China exports all rabbit meat in frozen form, whereas the Eastern European countries export mainly fresh meat. Some live rabbits are also exported from the Netherlands to France or from the former Yugoslavian countries of Slovenia and Croatia to Italy.

The market for rabbit skins

Data on skin marketing are much scantier than for rabbit meat. France appears to be the main producer of raw skins, but the practice of reimportation after partial treatment rather complicates the figures. France uses 56 percent of the skins it produces, about 70 million.

About 60 percent of these are poor-quality skins from which only the hair is recovered (12 to 20 percent of dry pelt weight). The best-quality skins are used after tanning for garments (5 to 8 percent) and linings, gloves and so on.

Most other producers also market rabbit skins but the CIS and Poland, for example, apparently make domestic use of all the skins they produce. Australia must be considered a producer, as it exports the skins of wild rabbits killed in extermination campaigns (small skins).

The main importers of raw skins are developing countries such as the Republic of Korea and the Philippines, with the low-cost labour to do the dressing. After fairly complete processing, these skins are re-exported to developed countries such as the United States, Japan, Germany and Italy.

Angora wool

Used mainly in textiles, the wool of the Angora rabbit forms a special sector of the international wool trade. World production is modest but the value per unit of weight is high: 40 to 50 times that of greasy wool.

Europe's share of the ever-growing world output, now estimated at 8 000 to 10 000 tonnes, is at present about 250 to 300 tonnes a year. Production is mainly concentrated in the Czech Republic and Slovakia (80 to 120 tonnes a year), France (100 tonnes), Hungary (50 to 80 tonnes) and, to a lesser extent, Germany (30 to 40 tonnes). But tonnages have again fallen in recent years as a result of marketing problems. A small amount is also produced in the United Kingdom, Spain, Switzerland, Poland and Belgium. Elsewhere in the world, Chinese production is by far the highest in the world at 8 000 to 9 000 tonnes a year. Japan also has a small output of 50 to 60 tonnes. Small quantities are also produced in Argentina, the Democratic People's Republic of Korea, the Republic of Korea and India.

There is brisk trading in both raw angora wool and the spun yam. The main end-users are Japan, the United States, Germany and, particularly, Italy. The trade is characterized by regular four-year cycles due not to production, which is in fact regular, but to fluctuations in demand dictated by fashion. Since 1985, however, world prices have remained at rock-bottom levels.

Rabbit meat quality

Carcass composition

Carcasses are presented in different ways in different countries. Traditionally in certain African countries rabbits for the market are simply bled and gutted (only abdominal white offals). This was also true of Italy only a few years ago.

In France until recently the carcasses were sold skinned, with the thoracic viscera, liver and kidneys, and the head and paws still covered with fur. This changed in 1980 and now the paws must be removed.

In Canada and the United Kingdom the carcasses are dressed much as beef carcasses: no head, no viscera and, of course, no paws. So slaughter yields can vary greatly from one country to another. Yields also vary among breeds (Table 6) and according to age (Table 7) and diet (Tables 8 and 9). Slaughter yield improves with age: for a given carcass weight, animals with a high growth rate, receiving more balanced feed, generally have a better carcass yield. Too much roughage in the diet tends to overdevelop the digestive tract and thereby lower yield. A fibre-rich feed that did not lower the speed of growth would not modify slaughter yield, however.

TABLE 6 Slaughter yields of different rabbit breeds and crosses at 10 to 12 weeks, in Belgium

Breeds and crosses	**Live weight (*kg*)**	**Carcass yield**		**Proportion of rump (legs, back) to front portion**	**Dissectable fat (*g*)**	**Edible offals (liver, heart, kidneys) (*g*)**
		Old French presentation (*%*)	**Ready to cook (*%*)**			
Blanc de Termonde (BT)	2.29	65.0	57.7	1.51/1	75	95
New Zealand White (NZ)	2.49	64.6	57.2	1.54/1	47	87
Californian	2.13	65.6	58.4	1.54/1	55	73

(Calif.)	2.13	65.6	58.4	1.54/1	55	73
Bleu de Beveren (BB)	2.05	61.1	54.7	1.50/1	55	95
BT × NZ	2.33	62.7	55.9	1.62/1	90	87
BT × hybrid	2.26	63.2	55.7	1.56/1	43	95
Commercial hybrid	2.81	66.0	59.4	1.56/1	85	110
Calif. × BB	2.14	62.8	56.1	1.52/1	100	100

Source: Reyntens *et al.,* 1970.

TABLE 7 Slaughter yield of New Zealand Whites, by age[1]

	Age in weeks			
	9	**11**	**13**	**15**
	1.70	2.12	2.47	2.67
Live weight at slaughter[2] (kg)				

Carcass weight *(kg)*	1.18	1.48	1.76	1.93
Slaughter yield *(%)*	69.2	69.8	71.6	72.1

[1] Italian presentation with skin.

[2] After 24-hour fast.

Source: Di Lella and Zicarelli, 1969.

TABLE 8 Effect of feed type on slaughter yield: role of supplementary bulk feed

	Low-bulk feed		**High bulk feed**	
Straw content *(%)*	0		20	
Crude fibre content *(%)*	4		12	
Presentation (choice)	alone	+ straw	alone	+ straw
Percentage of straw in free choice *(% DM)*	-	15.9	-	6.1
Live weight at 70 days *(kg)*	1.52	1.72	1.96	1.88

Live weight at 70 days *(kg)*	1.52	1.72	1.96	1.88
Carcass weight *(kg)*	0.94	1.0	1.20	1.14
Slaughter yield *(%)*	61.4	57.7	61.3	60.6

Source: Reyne and Salcedo-Miliani, 1981.

TABLE 9 Impact of balanced feed on slaughter yield of Fauve de Bourgogne rabbits[1]

	Balanced feed	**Alfalfa + maize[2]**	**Dehydrated alfalfa only**
Age at 2.2 kg *(days)*	78	88	96
Conversion rate *(DM)*	3.92	4.80	6.90
Slaughter yield *(%)*	63.7	59.7	56.8
Fattening cost for 1 kg carcass *(index)*	100	89.8	123.9

[1] Average live weight at slaughter 2.2 kg.

[2] The ratio chosen by the animals was 36 percent maize and 64 percent dehydrated alfalfa.
Source: Lebas, 1969.

Meat composition

Compared with the meat of other species, rabbit meat is richer in proteins and certain vitamins and minerals. However, it has less fat, as shown in Table 10.

TABLE 10 Meat composition of different animal species Values given per 100 g of meat

TABLE 11 Proportion of the principal fatty acids in fat deposits of different animal species

Fatty acids	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3
Tallow (ruminants)	4	27	2	24	42	2.5	-
Fat (pigs)	1	27	3	12.5	45	8	0.5

Fat (poultry)	0.1	26	7	7	40	20	-
Fat (rabbits)	3.1	29	6	6.1	28	17.9	6.5

Source: Adrian, Legrand and Frangne, 1981; Ouhayoun *et al.,* 1981.

Rabbit fat contains less stearic and oleic acids than other species and higher proportions of the essential polyunsaturated linolenic and linoleic fatty acids (Table 11).

The anatomical composition of the rabbit carcass varies with age. The proportion of muscle mass to body weight remains constant: over 2 kg live weight for a strain weighing 4 kg (adult animal). But the proportion of fatty tissue tends to increase. This ratio shows up in meat composition, as Table 12 shows.

TABLE 12 Changes in hindleg muscle tissue composition in New Zealand Whites, according to age

	Age

	30 days	**70 days**	**182 days**
Degree of maturity *(% of adult weight)*	17	55	100
Water	77.7	74.9	72.7
Proteins (N × 6.25)	18.2	20.2	21.3
Fats	2.8	3.7	4.8
Mineral salts	1.2	1.2	1.2

Source: Ouhayoun, 1974.

TABLE 13 Water losses from grilling rabbit meat, according to age and fat content

	Age of rabbits		
	86 days	**96 days**	**105 days**
Carcass weight *(kg)*	1.40	1.54	1.63

Kidney fat *(% carcass)*	1.5	2.2	3.4
Loss from cooking hindleg *(%)*	30.9	27.6	27.3
Loss from cooking back *(%)*	34.1	30.9	30.8
Fat content			
Leg *(%)*	4.8	4.9	6.0
Back *(%)*	1,5	1.7	1.6

Source: Fischer and Rudolph, 1979.

The proportion of oleic add in the fat also increases with age and palmitic add decreases.

Organoleptic properties

The organoleptic properties of rabbit meat, like those of other species, are tenderness, juiciness and flavour. Rabbit meat does not have a very strong flavour. It is comparable to, but not identical to, chicken.

Tenderness varies with muscle age and depends on changes in the proportion and type of conjunctive tissue supporting the muscle fibres. The younger the rabbits are slaughtered, the more tender the meat will be. On the other hand, flavour tends to develop with age. Although little research has been done on this, it is known that flavour improves with the quantity of internal fat in the muscle. In the same way, juiciness depends largely on the fat content of the carcass. The fatter the carcass the lower its water content, but the better it retains what juice it does have (Table 13).

Slaughter conditions, especially the onset of rigor mortis, can modify the tenderness and juiciness of rabbit carcasses.

Selection for growth rate combined with confined rearing favour the anaerobic metabolism of rabbit muscle tissue. Animals raised in rational rabbitries therefore have a higher portion of white muscle fibre, which gives the meat a lighter colour.

Customer appeal

In Latin countries, which are traditional rabbit consumers, customer appeal is no problem. Rabbit meat is even classified as "sought after" and is eaten on special occasions. However, it is less frequently served when a guest is invited to join the family at table. In Anglo-Saxon countries, rabbit meat is not a traditional food. It is thought of as wartime fare, conjuring up memories of food shortages. A century ago, however, tens of thousands of rabbits were imported every week from the Netherlands for the London market.

In other countries the situation varies greatly. Although the Koran in no way prohibits rabbit meat, production and consumption are virtually nil in most Arab countries. Yet rabbits are a traditional food in certain Maghreb countries such as Egypt and the Sudan.

In Mexico, people were not in the habit of eating rabbit meat until an advertising campaign boosted consumption. A reverse example is offered by Greece. A rational development programme of large-scale commercial production was implemented in mainland Greece in the late 1960s with relative success in technical terms. But marketing made no real headway as Greeks were not in the habit of eating this meat. There had been no advertising campaign to promote it so consumers did not buy it. Paradoxically, on the island of Crete, consumption is 10 kg per person per year.

The only religious bans concern the Hebrew religion (consumption in Israel outside the Arab population is nil) and certain Hindu sects (general ban on eating meat). Formerly, there was also a religious ban in force in Japan which forbade the eating of meat from four-legged animals. When rabbits were introduced into Japan in about 1350 by a Dutchman, the meat was sold as chicken. In modern Japan rabbit meat is eaten, although the total amount is still modest (1 000 tonnes from domestic production plus 3 000 tonnes imported from China).

In the 1981 INRA-FAO survey of 64 developing countries reporting on the development potential for rabbit production in their countries, 70 percent thought it feasible and 22 percent considered that social customs would not favour it. The remaining 8 percent were against it for religious or other reasons.

Rabbit meat consumption is much easier to develop where people are already used to eating widely different kinds of meat, as from hunting. This would be generally true of sub-Saharan Africa. People with monotonous diets will find it harder to accept this new product. However, the example of Mexico, with its traditional diet of maize and kidney beans, shows that a well-planned development campaign can do much to promote the necessary change in eating habits.

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Chapter 2 NUTRITION AND FEEDING

Anatomy and physiology

In an adult (4 to 4.5 kg) or semi-adult (2.5 to 3 kg) rabbit the total length of the alimentary canal is 4.5 to 5 m. After a short oesophagus there is a simple stomach which stores about 90 to 100 g of a rather pasty mixture of feedstuffs.

The adjoining small intestine is about 3 m long and 0.8 to 1 cm in diameter. The contents are liquid, especially in the upper part. Normally there are small tracts, about 10 cm long, which are empty. The small intestine ends at the base of the caecum. This second storage area is about 40 to 45 cm long with an average diameter of 3 or 4 cm. It contains 100 to 120 g of a uniform pasty mix with a dry matter content of about 22 percent. The caecal appendix (of 10 to 12 cm) has a much smaller diameter at the end. Its walls are composed of lymph tissues.

Very near the end of the small intestine, at the entrance to the caecum, begins the exit to the colon. The caecum thus appears to be a blind pouch branching off from the small intestine-colon axis

(Figure 2). Physiological studies show that this blind pouch-reservoir forms part of the digestive tract: the contents circulate from the base to the tip passing through the centre of the caecum, then return towards the base, along the wall. The caecum is followed by a 1.5 m colon: this is creased and dented for about 50 cm (proximal colon) and smooth in the terminal section (distal colon).

These various organs are shown in Figure 2, which also presents data on the size and features of their contents.

The alimentary canal, which develops rapidly in the young rabbit, is nearly full size in an animal of 2.5 kg, when it has reached only 60 to 70 percent of adult weight.

Two major glands secrete into the small intestine: the liver and the pancreas. Bile from the liver contains bile salts and many organic substances which aid digestion, but has no enzymes. The reverse is true of pancreatic juice which contains a sizeable quantity of digestive enzymes allowing the breakdown of proteins (trypsin, chymo-trypsin), starch (amylase) and fats (lipase).

Generally speaking, the length of the small intestine (3 to 3.5 m) and its relatively small capacity contrast with that of the storage area (the stomach and caecum), which hold 70 to 80 percent of the total dry matter content of the digestive tract. The water content can vary markedly from one segment to the next owing to bodily secretions and water absorption.

Digestive tract and caecotrophy

Feed eaten by the rabbit quickly reaches the stomach. There it finds an acid environment. It remains in the stomach for a few hours (three to six), undergoing little chemical change. The contents of the stomach are gradually "injected" into the small intestine in short bursts, by strong stomach contractions. As the contents enter the small intestine they are diluted by the flow of bile, the first intestinal secretions and finally the pancreatic juice.

After enzymatic action from these last two secretions the elements that can easily be broken down are freed and pass through the intestinal wall to be carried by the blood to the cells. The particles that are not broken down after a total stay of about one and a half hours in the small intestine enter the caecum. There they have to stay for a certain time, from two to 12 hours, while they are attacked by bacterial enzymes. Elements which can be broken down by this new attack (mainly volatile fatty acids) are freed and in turn pass through the wall of the digestive tract and into the bloodstream.

FIGURE 2 The digestive system of the rabbit

The contents of the caecum are then evacuated into the colon. Approximately half consists of both large and small food particles not already broken down, while the other half consists of bacteria that have developed in the caecum, fed on matter from the small intestine.

So far, the functioning of the rabbit's digestive tract is virtually the same as that of other monogastric animals. Its uniqueness lies in the dual function of the proximal colon. If the caecum contents enter the colon in the early part of the morning they undergo few biochemical changes. The colon wall secretes a mucus which gradually envelops the pellets formed by the wall contractions.

These pellets gather in elongated clusters and are called soft or night pellets (more scientifically, caecotrophes). If the caecal contents enter the colon at another time of day the reaction of the proximal colon is entirely different.

Successive waves of contractions in alternating directions begin to act; the first to evacuate the contents normally and the second to push them back into the caecum. Under the varying pressure and rhythm of these contractions the contents are squeezed like a sponge. Most of the liquid part, containing soluble products and small particles of less than 0.1 mm, is forced back into the caecum. The solid part, containing mainly large particles over 0.3 mm long, forms hard pellets which are then expelled. In fact, as a result of this dual action, the colon produces two types of excrement: hard and soft. Table 14 shows the chemical composition of these pellets.

The hard pellets are expelled, but the soft pellets are recovered by the rabbit directly upon being expelled from the anus. To do this the rabbit twists itself round, sucks in the soft faeces as they emerge from the anus, then swallows without chewing them. The rabbit can retrieve the soft pellets easily, even from a mesh floor. By the end of the morning there are large numbers of these pellets inside the stomach, where they may comprise three quarters of the total contents.

From then on the soft pellets follow the same digestive process as normal feed. Considering the fact that some parts of the intake may be recycled once, twice and even three or four times, and depending on the type of feed, the rabbit's digestive process lasts from 18 to 30 hours in all, averaging 20 hours.

The soft pellets consist half of imperfectly broken-down food residues and what is left of the gastric secretions and half of bacteria. The latter contain an appreciable amount of high-value proteins and water-soluble vitamins. The practice of caecotrophy therefore has a certain nutritional value.

The composition of the soft pellets and the quantity expelled daily are relatively independent of the type of feed ingested, since the bacteria remain constant. In particular, the amount of dry matter recycled daily through caecotrophy is independent of the fibre content of the feed (Table 7-15). The higher the crude content of the feed and/or the coarser the particles, the sooner it passes through the digestive tract.

On the other hand, this particular function requires roughage. If the feed contains few large particles and/or it is highly digestible, most of the caecal contents are pushed back to the caecum and lose elements which nourish the "normal" bacteria living in the caecum. This would appear to increase the risk of undesirable bacteria developing in this impoverished environment, some of which might be harmful.

It is thus advisable to include a minimum of roughage in the feed, enabling the rabbit's digestive process to be completed fairly rapidly. In theory, roughage is provided by the crude-fibre content of the feed, as this is normally rather hard to digest. However, certain fibre sources (beetroot pulp, fruit pulp in general) are highly digestible (digestibility of crude fibre varies from 60 to 80 percent). Recommendations now made on quantities of indigestible crude fibre to be fed are therefore given below. Table 16 gives the chemical composition of various raw materials which can be fed to rabbits.

Caecotrophy regulation depends on the integrity of the digestive flora and is governed by intake rate. Experiments have shown that caecotrophy starts eight to 12 hours after the feeding of rationed animals, or after the intake peak of animals fed ad lib. In the latter case, the intake rate and hence the function of caecotrophy are governed by the light regime to which the animals are subjected.

Caecotrophy also depends on internal regulatory processes as yet not understood. In particular, the removal of the adrenals halts caecotrophy. Cortisone injections of animals without adrenals causes the resumption of normal behaviour. The digestive process of the rabbit appears to be highly dependent on adrenalin secretions. Hypersecretion associated with stress slows down digestive activity and entails a high risk of digestive ailments.

TABLE 14 Composition of hard and soft faeces: averages and range for ten different feeds

Components	Hard pellets		Soft pellets	
	Average	Range	Average	Range
	(Percentage)			
Moisture	41.7	34-52	72.9	63-82
Dry matter	58.3	48-66	27.1	18-37
	(Percentage of dry matter)			
Proteins	13.1	9-25	29.5	21-37
Crude fibre	37.8	22-54	22.0	14-33
Fats	2.6	1.3-5.3	2.4	1.0-4.6
Minerals	8.9	3.1-14.4	10.8	6.4-10.8
Nitrogen-free extract	37.7	28-49	35.1	29-43

Note: Balanced concentrate feeds, green and dry forages.
Source: Proto, 1980.

TABLE 15 Intake and excretion of dry matter by growing

rabbits eating isonitrogenous feeds containing two levels of straw in place of maize starch

	Experimental feeds	
	Low fibre content	**High fibre content**
Straw content *(%)*	5	20
Crude-fibre content *(%)*	10.8	16.8
Daily dry-matter intake *(g)*	60±28	67±28
Dry matter excreted each day in:		
hard pellets *(g)*	20±5	33±8
soft pellets *(g)*	10±4	10±5

Note: Average ± 1 standard deviation from the mean.
Source: C. Dehalle, personal communication, 1979.

Caecotrophy first starts to function in young rabbits (domesticated or wild) at the age of about three weeks, when they start eating solid feed in addition to mother's milk.

Feeding behaviour

Feeding behaviour studies have basically involved rabbits receiving balanced concentrates or fed ad lib on dry feed (cereals, straw, dry forage).

The feeding pattern of newborn rabbits is imposed by the dam. A doe feeds her young only once every 24 hours (although some does will nurse their young twice). Suckling lasts only two or three minutes. If there is not enough milk the young try to feed every time the doe enters the nestbox, but she will hold back her milk. This behaviour signals insufficient milk production in the doe.

TABLE 16 Chemical composition of different raw materials suitable for feeding rabbits

From the third week of life the young rabbits begin to move about, taking a few grams of mother's milk and a little drinking water if available. In a few days the intake of solid feed and water will exceed the milk intake. During this period the changes in feeding behaviour are remarkable: the young rabbit goes from a single milk feed a day to a large number of alternating solid and liquid feeds distributed irregularly throughout the day: 25 to 30 solid or liquid meals every 24 hours.

Table 17 gives an example of changing feeding behaviour in New Zealand White rabbits, aged from six to 18 weeks.

The number of solid meals, stable up to 12 weeks, tends to decrease slightly thereafter. The total feeding time in a 24-hour period exceeds three hours at age six weeks. It then drops off rapidly, to less than two hours. At any age, feed containing over 70 percent water, such as green forage, will provide rabbits with ample water at temperatures below 20°C.

The consumption of solid and liquid intake fluctuates over a 24-hour period, as shown in Figure 3. Much more liquid and solid feed is consumed in the dark than in the light.

Intake in experimental hutches is very high just before the lights are switched off. As the rabbit grows older the nocturnal nature of its feeding habits becomes more pronounced. The number of feeds during light periods drops and the morning "feeding rest" tends to lengthen. The feeding habits of wild rabbits are even more nocturnal than those of domesticated rabbits.

The intake of feed and water depends on the kind of feed and also on the type of rabbit and its age and stage of production. Taking as a reference animal an adult fed ad lib (140 to 150 g of dry matter per day, for example, for a 4 kg New Zealand White): at four weeks a young rabbit eats a quarter of the amount an adult eats but its live weight is only 14 percent of the adult's. At eight weeks the relative proportions are 62 and 42 percent; at 16 weeks they are 100 to 110 and 87 percent.

A doe's ad lib feeding during the reproduction cycle varies greatly (see Figure 4). The intake during the final days of pregnancy drops off markedly. Some does refuse solid food just before kindling. Water intake, however, never stops completely. After kindling, the feed intake increases very rapidly and can exceed 100 g dry matter/kg live weight a day. Water intake is also high at that time: from 200 to 250 g a day per kg of live weight. A doe that is both pregnant and lactating will eat the same amount as a doe that is lactating only.

TABLE 17 Changing feed habits of nine New Zealand White male rabbits aged from 6 to 18 weeks, given water and balanced feed ad lib in a room kept at 20±1°C

	Age in weeks		
	6	**12**	**18**
Solid feeds *(89% DM)*			
Total quantity *(g/day)*	98	194	160
No. of meals per day	39	40	34
Average quantity per meal *(g)*	2.6	4.9	4.9
Drinking water			
Total quantity *(g/day)*	153	320	297
No. of drinks per day	31	28.5	36
Average weight of one drink *(g)*	5.1	11.5	9.1

Water/feed ratio *(DM)*	1.75	1.85	2.09
Water content calculated for whole of solid feed and drink intake	65.3	66.4	68.8

Source: Prud'hon, 1975.

FIGURE 3 Hourly distribution of daily intake of water and balanced pelleted feed of a 12-week-old rabbit aver a period of 24 hours

Feeding and environment

The rabbit's energy expenditure depends on ambient temperature. Feed intake to cope with energy needs is therefore linked to temperature.

Laboratory tests on growing rabbits have shown that at temperatures between 5°C and 30°C intake of pelleted feed dropped from 180 to 120 g a day and water intake rose from 330 to 390 g (Table 18).

A closer analysis of feeding behaviour shows that as temperature rises the number of solid and liquid meals eaten in 24 hours drops. From 37 solid feeds at 10°C the number drops to only 27 at 30°C (young New Zealand White rabbits). The amount eaten at each meal drops with high temperatures (5.7 g from 10°C to 20°C down to 4.4 g at 30°C) but the water intake goes up, from 11.4 to 16.2 g between 10°C and 30°C.

A recent study by Finzi, Valentini and Fillipi Balestra (1992) shows a marked increase in the water/food intake rate at higher temperatures (20°C, 26°C and 32°C), which was already known, but the various ingestion and excretion ratios are also modified (Table 19). The authors propose that these ratios, the easiest to measure locally, be used to identify thermal stress in rabbits.

If drinking water is not provided and the only feed available is dry with a moisture content of less than 14 percent, dry matter intake drops to nil within 24 hours. With no water at all, depending on temperature and humidity, an adult rabbit can survive from four to eight days without any irreversible damage, although its weight may drop 20 to 30 percent in less than a week.

FIGURE 4 Changing intake of balanced concentrate feed (89 percent DM) in a doe during gestation and lactation

Rabbits with access to drinking water but no solid feed can survive for three or four weeks. Within a few days they will drink four to six times as much water as normal. Sodium chloride in the water (0.45 percent) reduces this high intake, but potassium chloride has no effect (sodium loss through urination). The rabbit is therefore very resistant to hunger and relatively resistant to thirst; but any reduction in the water supply, in terms of water requirements, causes a proportional reduction in dry matter intake, with a consequent drop in performance.

The growth performance of rabbits is significantly reduced if they are given salted drinking water with a sodium content higher than 1 percent.

Work in Egypt by Ayyat, Habeeb and Bassuny (1991) showed a 12 to 16 percent slowing of growth speed at sodium contents of over

1.5 percent (Table 20). Solid granulated feed ingestion remained unchanged by water salinity whereas water intake increased slightly with salinity: 14 to 16 percent in the trial by Ayyat and colleagues. However, even at sodium contents exceeding 2 to 4 g (6 g of Rashid salt), no mortality was reported from this eight-week trial, and the rabbits still grew at a rate of 23 g/day:77 percent compared with the control.

Feeding preferences

Given a choice of several feeds rabbits are often unpredictable. When dehydrated alfalfa and dry grain maize are offered the ratio chosen is 65 percent alfalfa to 35 percent maize. With alfalfa and oats the ratio is 60 to 40. But if the maize grains are rather moist, say with a 14 to 15 percent moisture content which could cause storage problems, the proportion of maize rises to 45 to 50 percent. When rabbits are offered rations containing dehydrated alfalfa with a variable saponin content, which gives the feeds varying degrees of bitterness, they choose the relatively bitter feeds. Such feeds are ignored by rats and pigs, as shown by

Cheeke, Kinzell and Pedersen's (1977) tests in the United States.

TABLE 18 Changing feed and water intakes of growing rabbits in changing temperatures

Ambient temperature	5°C	18°0	30°C
Relative humidity	80	70	60
Pelleted feed eaten* *(g/day)*	182	158	123
Water drunk *(g/day)*	328	271	386
Water/feed ratio	1.80	1.71	3.14
Average weight gain *(g/day)*	35.1	37.4	25.4

* Balanced pelleted feed containing 20 percent crude protein and 11 percent crude fibre, rich in protein and energy.
Source: Eberhart, 1980.

TABLE 19 Impact of ambient temperature on intake and excretion ratios in adult rabbits

Ratios	**20°C**	**26°C**		**32°C**	
	Average A	**Average B**	***B/A (%)***	**Average C**	**C/A *(%)***
Water/feed	1.7	3.5	206	8.3	489
Urine/feed	1.0	1.6	167	4.0	413
Water/faeces	1.9	5.5	287	11.2	583
Urine/faeces	1.1	2.5	234	5.3	493

Source: Finzi, Valentini and Fillipi Balestra, 1992.

TABLE 20 Impact of drinking-water salinity on rabbit growth performance

Salt added to water (g/litre)	**0**	**1.5**	**3.0**	**4.5**
Water content *(ppm)*				
Ca	11	99	187	275

Mg	11	21	31	41
K	8	143	278	413
Na	399	901	1 403	1 905
Cl	107	753	1 399	2045
Bicarbonates	320	395	470	545
Total minerals	906	2409	3912	5415
Live-weight gain *(g/day)*	29.7±1.4	28.9±0.9	24.3±1.0	22.6±1.1
Feed intake *(g/day)*	125	139	126	124

Source: Ayyat, Habeeb and Bassuny, 1991.

Feeding rabbits forage plus supplementary concentrate feed raises problems when the forage is not very palatable. The experimental findings in Table 21 demonstrate that in ad lib feeding of both high-bulk (straw, in this trial) and high-energy pelleted feeds rabbits are unable to adjust intake for maximum growth. A breeder faced by such a situation should limit the daily dose of concentrate feed or, generally speaking, the proportion of the more palatable feed. The problem sometimes arises with certain low-value green forages.

The situation changes if the rabbit is faced with two high-energy foods, as in Gidenne's (1986) trial with ad lib feeding of balanced pelleted feed and green banana. In this example, the ad lib trial rabbits grew as much as the control group and their digestible energy intake was identical. However, between weaning at five weeks and the close of the 12-week trial, the banana intake dropped from 40 percent to 28 percent of the daily dry matter intake.

Growing rabbits receiving a pelleted feed lacking in sulphur amino acids or lysine, with access to pure water as well as those missing amino acids in solution, choose the amino acid solution over pure water. Thus they grow as well as control rabbits receiving balanced feed.

Nutritional needs

Various research experiments carried out in many countries (especially France) in the last 20 years or so have resulted in reliable recommendations for the manufacture of rabbit feeds for meat and milk production in temperate European conditions.

The experimental technique consists of manufacturing feeds in exact but varied mixes, feeding them to rabbits and assessing production by weight gain or number and weight of young in a litter. The best feeds are thus established and the best mixes selected, allowing nutrition experts to draw up recommendations for several categories. The most common feed categories in intensive European rabbitries are for breeding females (lactating does, pregnant or not), young rabbits of weaning age (post-weaning or peri-weaning feeds, the latter also consumed by the mother) and rabbits for fattening. Also included in the range supplied by livestock feed manufacturers is a mixed feed that can acceptably cover the nutritional needs of all rabbit categories providing the breeder's objective is not maximum productivity.

TABLE 21 Feed intake and growth of New Zealand White rabbits aged between five and nine weeks, receiving ad lib a concentrated feed rich or poor in fibre, with and without

wheat-straw pellets 5 mm in diameter

	Fibre-rich feed		Fibre-poor feed	
Feed composition *(%)*				
Straw	20		0	
Protein	16.1		15.6	
Crude fibre	11.7		4.1	
Method of administration	**Alone**	**+ straw**	**Alone**	**+ straw**
Intake *(g/day)*				
Feed (F)	94.7	88.3	63.4	63.3
Wheat straw (S)	-	7.4	-	12.2
Total F and S	94.7	95.7	63.4	75.5
Gain in live weight *(g/day)*	31.7	31.0	22.4	26.6

Source: Reyne and Salcedo-Miliani, 1981.

These standards have been established for environmental conditions in Europe and are also based on the relative costs of nutrients in European countries. They are reference standards, but can be varied slightly for better economic performance according to locally available cheap feed resources. The upper and lower limits (which should not be exceeded) are listed at the end of this chapter.

Lactating does need the richest, most concentrated feed. They produce a milk three times richer than cow's milk, at the rate of 100 to 300 g per day, and have few reserves in relation to the demand made on them. The next category is growing rabbits (far more research work has been done on this than any other category). Young rabbits are followed by pregnant non-lactating does. Their feed can be slightly less rich than that of young growing rabbits. The last category is bucks, which do not need a rich diet.

Table 22 details the chemical composition of theoretically ideal feeds for each rabbit category. There are four broad classes of standards. First, standards on proteins and protein composition (distribution of amino acids). Proteins must supply the elements to build or rebuild rabbit bodies. The proportion of indigestible fibre serves to provide the slight congestion essential for the proper functioning of the digestive tract. The corresponding proportion of fibre can also be estimated by the acid detergent fibre (ADF) content as per Van Soest or, preferably, indigestible ADF. Energy is needed to regulate body temperature as well as for the general functioning of the body. Minerals and vitamins are building blocks for certain parts of the animal (skeleton, etc.) and for the enzymes which use energy to build and rebuild the body proteins continually. Table 22 also includes a column showing the chemical composition of a mixed feed suitable for all animals in a production unit. Its composition represents a compromise between the requirements of growing rabbits and those of lactating does. The other categories can, in fact, eat a richer feed without suffering any major drawbacks. Further on in the text it will be explained under what circumstances it is desirable to use mixed or more specialized feeds. But, first, the various feed requirements are explored in greater depth.

Nitrogen. The rabbit's response to the quality of the proteins in its diet, long a controversial issue, has now been established beyond doubt. Researchers have found that growing rabbits need feed that contains certain amounts of ten of the 21 amino acids that made up the proteins. These are called the basic or essential amino acids. With two additional amino acids which can partially replace two of the essential amino acids, this is the full list for rabbits: arginine, histidine, leucine, isoleucine, lysine, phenylalanine plus tyrosine, methionine plus cystine, threonine, tryptophane and valine.

Studies on the quantities needed have been virtually confined to arginine, lysine and the sulphur amino acids (methionine and cystine). Expressed as a percentage of the ration, the lysine requirements for growing rabbits are 0.6 and, for sulphur amino acids, 0.7 percent. The lysine intake of breeding does should be considerably higher under intensive milk production to feed nine to 12 young. The arginine intake should be at least 0.8 percent, and a little more for growing rabbits. The toxicity thresholds of lysine and arginine are well above the recommended intake levels. For the sulphur amino acids, however, there is a slender margin between the amount the rabbit needs and an excess dose that would diminish its performance.

TABLE 22 Recommended chemical composition of feeds for intensively reared rabbits of different categories

Components of feed, assumed to contain 89 percent dry matter	**Young rabbit (4 to 12 weeks)**	**Lactating doe**	**Peri-weaning**	**Mixed (maternity + fattening)**
Crude proteins *(%)*	16	18	15	17
Digestible proteins *(%)*	11.5	13.3	10.8	12.4
Amino acids				
Methionine + cystine *(%)*	0.60	0.60	0.55	0.60
Lysine *(%)*	0.70	0.90	0.65	0.70
Arginine *(%)*	0.90	0.80	0.80	0.90
Threonine *(%)*	0.55	0.70	0.55	0.60

Tryptophane *(%)*	0.13	0.20	0.12	0.13
Histidine *(5)*	0.35	0.43	0.35	0.40
Isoleucine *(%)*	0.60	0.70	0.67	0.65
Phenylalanine + tyrosine *(%)*	1.20	1.40	1.10	1.25
Valine *(%)*	0.70	0.85	0.68	0.80
Leucine *(%)*	1.05	1.25	1.00	1.20
Energy and bulk				
Digestible energy *(kcal/kg)*	2500	2650	2400	2550
Metabolizable energy *(kcal/kg)*	2380	2520	2280	2420
Fats *(%)*	3-5	4-5	3	3-4
Crude fibre *(%)*				
Indigestible crude fibre *(%)*	12	10	14	12
ADF *(%)*	18	14	20	18

Ratio digestible proteins/digestible energy *(g/1000 kcal)*	45	51	46	48
Minerals				
Calcium *(%)*	0.40	1.20	1.00	1.10
Phosphorus *(%)*	0.30	0.50	0.50	0.60
Potassium *(%)*	0.60	0.90	0.60	0.90
Sodium *(%)*	0.30	0.30	0.30	0.30
Chlorine *(%)*	0.30	0.30	0.30	0.30
Magnesium *(%)*	0.25	0.25	0.25	0.25
Vitamins				
Vitamin A *(IU/kg)*	6000	10000	10000	10000
Vitamin D *(IU/kg)*	1000	1000	1000	1000
Vitamin E *(ppm)*	50	50	50	50
Vitamin K *(ppm)*	0	2	2	2
Vitamin C *(ppm)*	0	0	0	0

Vitamin B_1 *(ppm)*	2	-	2	2
Vitamin B_2 *(ppm)*	6	-	6	4
Vitamin B_6 *(ppm)*	2	-	2	2
Vitamin B_{12} *(ppm)*	0.01	0	0.01	0.01
Folic acid *(ppm)*	5	-	5	5
Pantothenic acid *(ppm)*	20	-	20	20
Niacin *(ppm)*	50	-	50	50
Biotin *(ppm)*	0.2	-	0.2	0.2

Source: Lebas, 1989.

The recommended amounts of other essential amino acids have been estimated simply on the basis of regular satisfactory diets. Where these essential amino acids are supplied by protein in the diet, 15 to 16 percent crude proteins should be enough for fattening rabbits. Rabbits will always eat more of a balanced feed containing essential amino acids than the same feed without amino acids.

Amino acid balance can easily be achieved with plant protein alone as in almost all balanced European feeds. Proteins of animal origin can be used by rabbits but are absolutely unnecessary: all that counts is the amino acid intake, not the substratum.

The optimum dose of crude protein for the breeding doe seems to be roughly 17 to 18 percent. An increase of protein content to 21 percent leads to higher milk production but slightly reduces the number of young rabbits weaned in a given period.

Lastly, various attempts to replace true proteins by non-protein nitrogen (urea and ammonium salts) have almost all been economic failures, because these sources of nitrogen either degrade or are absorbed too early for the micro-organisms in the caecum to take them up. For a highly nitrogen-deficient ration (30-50 percent below requirements), however, or for a non-protein source which breaks down at average speeds in the intestine (such as biuret), there is a certain amount of uptake. In any case, it is highly recommended that rabbits receive their nitrogen ration in the form of true proteins with balanced amino acids.

Energy and crude fibre. The energy needed for organic synthesizing is usually supplied by carbohydrates and to a lesser extent by fats. Where there is an excess of proteins these also help to supply energy after deamination.

The growing rabbit, like the breeding doe, adjusts its feed intake according to the energy concentration of the feeds offered to it where the proteins and other dietary components are balanced. For a growing New Zealand White or Californian rabbit the daily intake is around 220 to 240 kcal of digestible energy (DE) per kg of metabolic weight ($W^{0.75}$). For the lactating doe the average amount is 300 kcal DE/kg $W^{0.75}$ and tops 360 kcal during maximum milk production (15th to 20th day of lactation). So it is hard to set a strict energy requirement, but it has been shown that intake is only correctly regulated between 2 200 and 3 200 kcal DE/kg of feed.

Because of this, concentrated energy feed must also contain all the other required nutrients in concentrated form so that a smaller volume of feed will supply the rabbit's needs.

Energy intake regulation functions well in temperate climates so long as variations in energy content are linked to the presence of fairly digestible carbohydrates (e.g. starch/fibre substitution). At high temperatures (28° to 32°C), however, and/or where more than 10 percent of the digestible energy is provided by fat, regulation may suffer and the animals may easily consume more of the fattier feed owing to the absence of extra heat from the consumption of lipids.

The rabbit is known to have a specific need for essential fatty acids (linoleic acid), but a conventional diet containing 3 to 4 percent fats generally supplies this. The only reason for including more fat in the diet would be to raise the energy concentration, as fats provide approximately twice as much energy as carbohydrates for the same weight. Depending on the kind of basic diet (basic energy level, protein content and quality), such an input of fats might or might not be nutritionally useful. The feed energy for breeding does or growing/fattening rabbits can be supplied in the form of starch. A young rabbit less than 40 days old, however, digests starch poorly as the digestive apparatus has not yet attained functional maturity. For this reason, post- and particularly peri-weaning feeds used for 20- to 40-day rabbits should not contain over 12 to 13 percent starch to avoid digestive problems.

In European feed rations, the poor digestibility of the fibrous parts of raw materials such as alfalfa and straw (digestibility 10 to 30 percent) makes them secondary to starch, for example, in covering energy needs. However, the fibrous components from tender, usually young, plants are much more digestible (30 to 60 percent). They can then provide 10 to 30 percent of energy requirements in favourable conditions.

The fibrous parts have another function: as bulk. Content is generally evaluated on the basis of crude fibre, although this analytical technique is far from perfect. To get enough bulk for growing rabbits a 13 to 14 percent crude-fibre content seems satisfactory. For lactating does a slightly lower content is acceptable (10 to 11 percent). The more digestible the fibrous parts the higher the total input needed to supply at least 10 percent indigestible crude fibre.

Minerals and vitamins. Studies on the calcium and phosphorus requirements of growing rabbits have shown they need much less than lactating does. Does transfer large amounts of minerals into their milk: 7 to 8 g a day in full lactation, of which about one quarter is calcium.

Any sodium, potassium or chlorine imbalance in the diet can cause nephritis and birth accidents. The risk is particularly high when plants used in the feed have been fertilized with high rates of potassium.

Some authors mention improved growth performance with excess intake of copper sulphate: 200 ppm copper. As with pigs, this must be an effect of the growth-factor type.

Even so, the importance of copper sulphate as a growth factor is not universally conceded and some authors have noted negative consequences (higher mortality) with supplements of about 150 to 200 ppm.

Rabbits require water-soluble (B group and C) as well as fat-soluble vitamins (A, D, E, K). Micro-organisms in the digestive flora synthesize sizeable quantities of water-soluble vitamins which are utilized by the rabbit through caecotrophy. This intake is sufficient to cover maintenance requirements and for average production as far as the B group vitamins and vitamin C are concerned. However, fast-growing animals respond favourably to the addition of 1 to 2 ppm of vitamins B_1 and B_6, 6 ppm of vitamin B_2, and 30 to 60 ppm of nicotinic acid (vitamin PP) in the diet. The addition of vitamin C will not influence growth, even at 1 percent of diet, for better or for worse, under temperate conditions.

For fat-soluble vitamins, research has focused more on deficit or excess than on the exact determination of requirements. The recommendations proposed thus comprise a certain safety margin. However, excessive intakes of Vitamin A (100 000 IU/kg of feed) or Vitamin D (3 000 IU/kg of feed) can entail serious disturbances, particularly in breeding females. It is therefore advisable not to feed megadoses of vitamins to rabbits.

Deviating from standard recommendations

Feeds formulated in accordance with the standards given in Table 22 are satisfactory for intensive production. Rabbits can also be reared on feeds only approximating these standards, but the absolute performance level will be lower, although not necessarily uneconomical. Certain indicative values are given in Table 23. Reducing the protein intake of lactating does to 12 to 13 percent of the diet will not affect prolificacy but will cause a regular reduction of milk production and a parallel drop in the weight of the young at weaning.

Additionally, it is better to consider the protein/energy ratio in relation to the intake of bulk fibre, rather than the protein rate in itself.

Some research indicates that rabbits need a certain minimum of fibre for regular digestion: 9 to 10 percent of indigestible crude fibre. Otherwise, there is increasing mortality from diarrhoea, although the low roughage/mortality association is not systematic and may affect experimental lots in random fashion.

TABLE 23 Decline in performance at levels of protein or selected essential amino acids in the feed below recommended values, and minimum acceptable levels

Reduction of proportion in ration	Decrease in weight gain		Increase in feed conversion rate		Minimum acceptable levels *(%)*
	Absolute value *(g/day)*	Percentage	Absolute value *(g/day)*	Percentage	
Proteins (1 point)	-3	-8.5	+0.1	+3	12
Methionine (0.1 point)	-2	-6	+0.1	+3	0.40
Lysine (0,1 point)	-5	-14	+0.1	+3	0.40

Arginine (0.1 point)	-1.5	-4.5	+0.1	+3	0.50

A crude-fibre content of 13 to 14 percent appears sufficient for growing rabbits. It is not possible to establish a reliable relationship between the intake of fibrous parts and mortality in fattening rabbits at rates of 12 to 16 percent of crude fibre.

Finally, as indicated above, excessive fibre intake usually alters the digestible energy content of the feed below the intake regulation threshold.

If this is accompanied by a higher digestible protein/digestible energy ratio, rabbits will suffer energy deficit and protein surplus at the same time, favouring the excessive production of proteolytic digestive flora which produces ammonia and leads to increased digestive problems (Figure 5, curve A).

While an intake of more than 16 percent of fibrous parts is linked to a reduction in digestible proteins, entailing a static or reduced ratio of digestible protein to digestible energy, no harmful effect on the viability of fattening rabbits is observed (Figure 5, curve B). The only alteration is in growth performance due to the energy deficit.

Where a high intake of fibrous parts places the feed exactly at the minimum threshold for energy regulation (2 250 to 2 300 kcal DE), and protein intake is excessive, there is a very high risk of blockage from constipation in growing rabbits. Similarly, mineral bulk can reduce energy concentration.

As for minerals, where calcium and phosphorus in the diet are insufficient, lactating does draw on their bodily reserves, principally those stored in the bones, but the total store is small compared with the amount exported. Under these conditions, intensive production of does is not feasible. As an indication, the minimum and maximum thresholds are given in Table 24 for various minerals, some vitamins and essential amino acids. It should be stressed that the optimum feed rate for some animals is close to the maximum tolerable rate. This is true of vitamin D and phosphorus in breeding does and for sulphur amino acids in growing rabbits. Where too much is supplied performance may drop, to the breeder's surprise, and the risk is particularly high if he or she uses supplements that are added to the feed or drinking-water. Toxicity symptoms can closely resemble the symptoms of deficit, as is true of vitamin A.

In the case of multiple deficiencies, it is difficult to predict the animals' reaction. Direct experiment for on-site measurement of the actual consequences of the proposed feed are recommended in this case. The norms proposed in Table 22 can be used as a reference method of using complementarities meeting the animals' needs.

FIGURE 5 Role of fibre intake in the health of fattening rabbits

Feed manufacture and storage

In Europe, rabbits are fed dry raw materials which complement one another to make a balanced feed. Once the best proportions have been established, the raw materials are weighed and put in a blender. They are usually first crushed into meal for a uniform feed mixture. If the mixture were intended for feeding chickens or pigs it could be given to the animals at this stage, but the rabbit has a very low tolerance for the dust inevitably present in meal. This problem is solved by compacting the mixture in a pelleting machine.

The ideal diameter for ordinary feeds is 3 to 4 mm, 5 mm being the maximum diameter to avoid waste (Table 25). The pellets should be no longer than 8 to 10 mm. The pelleting operation heats the product through friction, which improves nutritional value by some 5 to 7 percent compared with the meal mixture.

Using certain recipes rabbits can actually be fed feed in meal form (Table 26). What must be avoided at all costs is a very fine meal which would disturb the normal functioning of the rabbit's upper respiratory tract which, although a good filter for dust, clogs quickly. Meal must not be given as feed where rabbits drink from receptacles containing water. The water will soon get dirty and the rabbits will immediately stop drinking and eating. A valve-type automatic watering system is recommended where meal is fed. Feeding tests on mash (60 percent meal, 40 percent water) show it is feasible provided the feeding racks are kept scrupulously clean (Table 26).

TABLE 24 Recommended limits for the incorporation of various minerals, vitamins and selected amino acids in rabbit feed

	Deficit	Observed minimum with no problems	Optimum	Observed maximum with no problems	Toxicity symptoms	Stage
Minerals *(ppm)*						
Calcium	700	3000	4000	25000	40000	Growth
	3000	8000	12000	19000	25000	Reproduction
Phosphorus	1 200	2600	3000	8000	-	Growth
	4000	4500	6000	8000	10000	Reproduction
Sodium	-	2000	3000	6000	7000	Growth
Potassium	3000	6000	6000	16000	-	Growth

	-	-	9000	16000	20000	Reproduction
Chlorine	1 700	2500	3200	4200	-	Growth
Magnesium	200	-	2500	3500	4200	Growth
Manganese	-	-	8.5	-	50	Growth
	0.6	-	13.0	-	-	Reproduction
Iodine	-	-	0.2	-	10000	Growth
	-	-	0.2	-	100	Gestation
Fluoride	-	-	0.5	-	400	Growth
Copper	2	3	5	150-200	200-300	Growth
Zinc	2	7	50	85	-	Growth
Vitamins *(/kg)*						
Vitamin A *(IU)*	-	3000	10000	20000	75000	Reproduction
Vitamin D *(IU)*	-	600	1 000	2000	3000	Reproduction
Vitamin E *(mg)*	17	-	50	-	-	Growth
	17	25	50	-	-	Reproduction

Amino acids *(g/16 gN)*						
Lysine	2.50	3.75	4.40	7.5	9.4	Growth
Sulphur AA	2.50	3.00	3.75	4.4	5.0	Growth
Arginine	3.00	3.75	5.60	12.5	-	Growth
Tryptophane	-	0.75	0.80	1.60	-	Growth

In Europe, depending on local conditions and the size of the production unit, feed is usually delivered in 25 to 50 kg bags or in bulk. Bags are stored in a shed providing shelter from high temperatures and rain, and located near the rabbits but out of their reach. They are stored in piles away from damp ground or walls. The usual solution is a false wooden floor.

TABLE 25 Influence of pellet diameter on growth[1] of Californian rabbits aged from 5 to 12 weeks

	Diameter of pellets (mm)		
	2.5 mm	**5 mm**	**7 mm**
Feed consumption *(g/day)*	117^a	122^a	131^b

Weight gain *(g/day)*	32.4^a	33.7^a	32.0^a
Feed conversion rate	3.7^a	3.7^a	4.1^b

[1] On the same line, two values having the same index letter do not differ from one another at the threshold P = 0.05.

Note: The apparent overconsumption of 7 mm diameter pellets is due to inevitable partial waste.
Source: Lebas, 1971b.

TABLE 26 Effect of presentation of feed on growth of young rabbits, according to various authors

Author	Presentation	Feed intake (*g DM/day*)	Live-weight gain (*g/day*)	Feed conversion rate (*in DM*)

Lebas, 1973[1]	Meal	82	29.7	2.78
	Pellets	94	36.0	2.62
King, 1974[2]	Meal	79	20.7	3.80
	Pellets	85	22.9	3.70
Machin *et al*., 1980[3]	Meal	78	27.9	3.06
	Mash (40% water)	102	26.5	3.80
	Pellets	104	33.1	3.30

[1] Ration composed of 58.8 percent maize, 25 percent soycake, 15 percent barley straw, 0.2 percent dl-methionine, 4 percent minerals and vitamins.

[2] Ration composed of 10 percent fishmeal, 20 percent grass meal, 40 percent wheat bran, 12.5 percent oats, 17.5 percent middlings; in addition, 1.5 percent molasses was mixed with the pellets.

[3] Ration composed of 62 percent barley, 17.5 percent soycake, 12.8 percent barley straw, 5 percent molasses, 0.25 percent lysine, 0.05 percent methionine, 0.3 percent minerals. The test was run at 25°C.

The room or shed is designed to hold one and a half to two months' supply. Deliveries should actually be made monthly, so feed can be used within one and a half months of manufacture. At delivery, about 10 to 15 days' supply should be left over from the previous month.

For bulk delivery, feed is stored in silos that are filled from the top and emptied from the bottom. They should be completely emptied and disinfected for bacteria, fungi, etc. at least once a year.

Transport costs and, especially, a desirably fast turnover of feed stocks make mixed feed (see Table 22) appropriate for rabbitries with fewer than 200 breeding does. In units with more than 300 does it is preferable to use two or three types of feed: one suitable for lactating and breeding does, one for the weaning period and the last for growing rabbits in all other categories (e.g. young growing rabbits).

Feeding systems

Balanced pelleted feeds

The traditional European diet for rabbits used to be cereals, bran and forage (green in summer and dried in winter). In winter, breeders also fed the animals fodder beets or carrots. This style of feeding is definitely on the way out, especially in the big producer countries such as France, Italy and Spain.

In modern production systems, which account for most of the output, the animals are given balanced pelleted feeds conforming to the standards already described. A single feed type is generally used for all categories, corresponding to the mixed feed listed in Table 22. In intensive-reproduction rabbitries, all rabbits except bucks are fed ad lib. Under less intensive regimes, does receive the same feed ration from the weaning of one litter to the birth of the next. The ration is normally 3 to 35 g DM per kg of live weight per day.

Growing rabbits raised in a group are always fed ad lib. One watering point is sufficient for 10 to 15 animals. The watering system must be checked regularly to ensure the animals do not suffer from lack of water because of defective apparatus. One feeding rack is enough for six to ten rabbits, but at least two are needed as a safety measure in case the pellet flow should get blocked. Each feeding place along the rack should be 7 to 8 cm long.

Breeders calculate the quantities of feed for total daily consumption for all animals as follows:

- young fattening rabbits (four to 11 weeks): 110 to 130 g;
- lactating does with litters (weaning at four weeks): 350 to 380 g;
- adult (maintenance) rabbits: 120 g;
- for the rabbitry as a whole: 1 to 1.4 kg of feed per

mother cage per day.

Well-run rabbitries, as in France or Italy, calculate 3.8 kg of pelleted feed consumed for each kg of live weight marketed. This calculation includes breeding rabbits. The best rabbitries use only 3.4 kg of feed to produce 1 kg live rabbit. This represents a feed expenditure of 5.9 to 6.7 kg per kg of carcass. Keeping in mind the protein content of the feed and the carcasses, this means a yield of 190 to 220 g of high-grade animal protein from 1 kg of plant protein, a return of 19 to 22 percent for the best production units.

Forage utilization in developing countries

Pilot trials in Germany have demonstrated that growing rabbits enclosed or penned in a natural meadow receiving no fertilizer can produce 240 kg of protein per hectare (1.2 tonnes of meat) annually in the form of carcasses. This gives some idea of the forage utilization potential of rabbits, although in the trials the rabbits exhibited a modest growth rate (20 to 25 g a day compared with the 30 to 40 g of cage- or hutch-raised rabbits) and a relatively high feed intake.

Climate and soils in most developing countries, however, are very different from those found in Germany. Direct grazing also poses problems of fencing and risks from predators to the point where this technique cannot be recommended. For this reason the authors have reviewed the various wild or cultivable plants used in both tropical and non-tropical regions to feed rabbits reared in confinement. Cereals are intentionally left out as they are needed for human nutrition in most developing countries.

Before reviewing the various plants which rabbits can use, a reminder is needed of rabbits' extreme sensitivity to mould, particularly aflatoxin. The hygiene of the fodder and by-products used must be beyond reproach and it is particularly important to avoid uncontrolled fermentation.

Wild and cultivated fodders suitable for rabbit feed. The following information only concerns plants that have been positively tested in station and other trials for use as rabbit feed. They are listed under their Latin names in alphabetical order. The countries where they are used are indicated where possible.

A "high" nutrient value means the feed has a higher dry matter content than is required for rabbits. Unless otherwise indicated, nutrient content, where shown, is expressed as a percentage of dry matter. For detailed chemical compositions, readers should refer to the general documents in the bibliography, particularly Göhl's work on tropical forages published by FAO (1982). Digestibility of the nutrients has not usually been determined for the rabbit specifically. Lacking these data, reference should be made to forage digestibility for ruminants, but absolute values cannot be transposed, especially for the fibrous fraction.

Alysicarpus vaginalis. A one-leaf clover distributed ad lib to growing rabbits as a supplement to concentrates gave performances not significantly different from the control. This plant, grown in South America, is a good source of protein.

Amaranthus spp. This forage has a 20 percent protein content. It has been tried out in Malawi to supplement a concentrate containing 39.5 percent grain maize, 26 percent maize bran, 34 percent groundnut oilcake and 0.5 percent table salt. Reproduction and growth were satisfactory: 20 rabbits per doe per year; growth of 15 g per day from four to 16 weeks. Amaranthus is routinely fed to rabbits at the Bunda Agricultural College in Lilongwe, Malawi. Modern hybrid varieties conventionally grown for human food can also be used for feeding rabbits.

Arachis hypogaea. Groundnut oilcake is a high protein feed (50 percent). It can be used for feed when not overpolluted by aflatoxins. The whole groundnut can also be fed, but this puts the rabbit into direct competition with people for food so this solution should only be considered under exceptional circumstances. Groundnut tops provide green fodder and hay with a high protein content. This is the conventional use at the Bobo-Dioulasso centre in Burkina Faso. The tops can also be used after harvest, but their protein content is less: about 15 percent before the groundnuts are removed and less than 10 percent after threshing. The proteins in both the tops and the groundnut cake lack the essential sulphur amino acids.

Azolla spp. This family of aquatic ferns can fix atmospheric nitrogen. Trials in Italy have shown that *Azolla caroliniana* can be incorporated into rabbit feed despite the poor digestibility of the proteins. Other Italian trials on *A. filiculoides* produced similar conclusions in a trial where this sun-dried fern fully replaced soy cake in the ration at 23 percent. However, the protein content of azolla (30 to 32 percent) is less lysine-rich than soy (4.5 as compared to 5.9 percent protein) and the lignin content is high, reducing digestibility. *A. microphylla* is comparable to *A. caroliniana* but *A. pinnata,* with a lower protein content of 9 percent, is not as palatable.

Bauhinia variegata. Angora rabbits are successfully fed the leaves of this tree as a supplement to concentrates in India. The protein content is 16 percent.

Beta vulgaris. Fodder and fodder sugar beets supply much of the winter feed in traditional European rabbit production. Where they can be grown, beets can supply a good percentage of the energy demand. The fibrous fraction is highly digestible (80 percent). Beet leaves are also good for rabbits. They contain 17 to 18 percent protein, but are very rich in minerals, especially potassium, which can cause digestive problems.

Brachiaria mutica. Fed to breeding does in the Philippines, para grass has proved far more satisfactory than elephant grass *(Pennisetum purpureum)* or guinea grass *(Panicum maximum).* However, its low protein content (10 to 13 percent) requires a nitrogen supplement (legumes, supplementary feed).

Brachiaria ruziziensis. In Burkina Faso this forage plant is part of the basic ration produced at the Bobo-Dioulasso centre for its rabbitry. Like all grasses, however, it has a low protein content (8 to 13 percent). For proper utilization it should be supplemented by high-protein feeds. The forage could be grown together with *Stylosanthes,* for example, for a more balanced feed than either plant can provide alone.

Cajanus cajan. Hay from this tree legume (called "guandu" in Brazil) can successfully be incorporated into balanced feed for growing rabbits as a substitute for alfalfa hay. Pigeon pea hay thus constitutes an interesting source of protein (15 to 25 percent depending on when it is harvested) and fibre (30 to 35 percent crude fibre).

Celtis australis. The leaves of this tree are used to feed Angora rabbits in India. Compared with the dry-matter content, the protein content is low at 12.4 percent as is crude fibre at 14.6 percent, but the fat content is fairly high at 5.7 percent and the 17.7 percent ash content is quite high.

Chamaecrista aeschynomene. This tropical legume is commonly used to feed Creole rabbits in Guadeloupe and Martinique.

Cocos nucifera. Rabbits like the green coconut meat left after the milk has been drunk. In Guadeloupe and Martinique they are fed to rabbits as a bulk dietary supplement. A trial on growing rabbits in Sri Lanka showed that coconut could form 20 or even 30 percent of the diet.

Cucurbita foetidissima. Growing naturally in the semi-desert area of northern Mexico, this member of the gourd family has an enormous root that is 65 percent starch. The crushed root is sun-dried in two or three days and as much as 30 percent can be added to balanced concentrate in place of grain sorghum for breeding and fattening rabbits. Trials at the University of Chihuahua in Mexico demonstrated no toxic effect.

The tops and especially the fruit are rich in protein (12 to 30 percent), but utilization trials have not yet been run on rabbits. Their very bitter taste, which is unattractive to other animals, is not necessarily an obstacle for rabbits. More tests are needed on the possibilities of this interesting semi-desert plant.

Daucus carota. A traditional feed for European farm rabbits, carrots can be grown in many tropical countries. They are used in Zambia, in particular, to feed rabbits. Both leaves and roots have a comparable protein content of 12 to 13 percent, but the leaves - like beet leaves - are very rich in minerals.

Dendrocalamus hamiltonii. The leaves of this tree have been successfully used to feed Angora rabbits in India as a supplement to commercial concentrates. The protein and crude-fibre contents of 15.6 and 23.2 as a percentage of dry matter are fairly low, but the 18.4 percent ash content is particularly high.

Eichhornia crassipes. Rabbits will eat the leaves and bulbs of water hyacinth, but only 24 percent of the energy provided by the green plant is digestible. Incorporating 25 percent water hyacinth meal in a balanced feed gives good results. Amounts of 50 percent or more are less satisfactory. The arsenic content of the rabbit meat (especially the liver and kidneys) in water hyacinth trials raised grave doubts about the plant's potential for feeding rabbits where it grows in polluted water.

In rabbitries located near the Congo River in the Democratic Republic of the Congo, breeders use a local water hyacinth of which the rabbits are very fond. In New Caledonia, a local hyacinth called water lily is also a traditional feed. The whole of the plant - stem, bulb and roots - is eaten.

Erythrina glauca. Rabbits find the leaves of this tree very palatable. A trial in Colombia showed that this (30 percent) protein source produced daily growth rates of 11.5 g as a simple supplement to sugar-cane juice. The proportion of *Erythrina* leaves actually rose from 50 percent of the daily DM consumption at the onset of the trial to 65 percent eight weeks later.

Grewia optiva. The leaves of this tree contain about 17 percent protein. An Indian ad lib feeding trial to supplement a concentrate produced an Angora wool output equivalent to that of the control fed the concentrate alone.

Gynura cusimba. The leaves of this forage plant, abundant in Nepal in the dry season, contain 27 percent protein. Rabbits like it but cattle, sheep and goats will not touch it. This difference in feed preferences is a reminder that observations valid for one species do not necessarily apply to another.

Hibiscus rosa-sinensis. The branches of these shrubs, which are used as living fences in the Caribbean, can be fed to rabbits, as is now the practice in Haiti. The young shoots contain some 15 percent protein and 16 percent crude fibre. However, a trial on ad lib distribution of hibiscus leaves and a balanced pelleted feed demonstrated very poor nutritional uptake of this fodder.

Indigofera arrecta. This legume grows wild in Mozambique, even during the dry season without irrigation. It is easy to grow from the seeds of the wild plant picked in season. Its high (25 percent) protein content makes it a valuable source of nitrogen for rabbits in Mozambique, especially during the dry season.

Ipomoea batatas. Sweet potatoes are a good source of energy (70 percent starch content) for human consumption and can easily be grown in a family garden. Surplus or specially grown crops could be used as an energy feed for rabbits. The tops when well developed are also a valuable feed because of their high protein content -16 to 20 percent. Sweet potato is used as forage for rabbits in Mauritius, Guadeloupe and Martinique, mainly in backyard rabbitries. A trial in Mozambique produced good performance with sweet potato leaves as a dietary supplement. They are highly digestible, and trials in many tropical countries have confirmed the nutritional value of sweet potato tops.

Ipomoea tiliacea. This convolvulacea grows wild in Guadeloupe and Martinique and is the traditional basic feed for Creole rabbits. It is not planted but simply picked from the hedges where it grows wild.

Lathyrus sativus. Vetch is often grown with oat in North Africa; the vetch/oat duo is used as green fodder for livestock and rabbits like it very much. In ad lib feeding with concentrated feed, it produced acceptable growth or reproduction rates. Much of the food value is lost when the product is stored, however, and rabbits tend not to like it.

Lespedeza spp. These legumes, which provide a protein-rich green forage for rabbits, could also be dried and fed as hay.

Leucaena leucocephala. This is probably the legume most studied in station rabbit trials. Its attraction is its high protein content (28 percent) and the fact that it can be grown during the dry season. Sowing and tillage are no problem in soils where *Leucaena* grows naturally (e.g. Mauritius). In the absence of symbiotic bacteria, bacterial seeding can be used (Guadeloupe and Martinique).

The presence of the amino acid mimosine, which competes with tyrosine and phenylalanine, is to some authors a limiting factor for *Leucaena leucocephala.* They suggest that a prudent top ration of this acacia for rabbits would be 25 percent (Mozambique). But growth trials on the island of Mauritius show that *Leucaena* can replace 40 and even 60 percent of balanced feeds without adversely affecting animal growth or health (Figure 6). In these trials, even where this acacia was used alone, the authors noted no incidence of diarrhoea or symptoms attributable to mimosine.

Other trials in Malawi used *Leucaena* as a supplementary fodder for a concentrate feed (described in the paragraph on *Amaranthus)* with good results for both growth and reproduction. Also tested in Malawi as a maize bran supplement, *Leucaena* proved satisfactory for growth (60 g a week) and better than *Tridax procumbens* and, especially, *Pennisetum purpureum.* Used as a supplement to a broiler chicken feed, growth rates of 100 to 110 g a week were recorded.

Despite these encouraging results the problem of mimosine remains. Mimosine toxicity is cumulative and perhaps did not show up in the growth trials, even though these covered the entire fattening period. Several continuous trials in Mauritius, Togo and Malawi, using *Leucaena* at levels of 10 and 20 percent, have not had any ill effects on growth or reproduction. As mimosine is an amino acid, drying the forage does not reduce its toxicity to animals, although no special rabbit trials have been run on this aspect. The addition of iron sulphate chelates mimosine and considerably reduces toxicity for rabbits as intestinal absorption of the chelated form of mimosine is significantly diminished. The iron sulphate supplement should exceed the mimosine content by a factor of four, comprising 2 to 3 percent of the diet.

FIGURE 6 Weight-gain trends in New Zealand White rabbits aged from 6 to 14 weeks in relation to intake of balanced feed *

* Limited quantities of control diet, supplemented by ad lib feeding of *Leucaena leucocephala* (○- - -○) or *Saccharum officinarum* (●—●).

Source: Ramschurn, 1978.

Manihot utilissima. Ghana's rabbit development programme includes growing cassava for feed. The inclusion of from 15 to 45 percent cassava meal (87 percent starch and 2.5 to 3 percent protein) in balanced feeds, supplemented by 200 g green forage daily, has given growth and reproduction results comparable to those obtained with the balanced control feed without cassava. But cassava should not be used to feed rabbits except where the human population already has plenty of energy foods, as in Egypt, for example. Additionally, cassava meal requires a protein and crude-fibre supplement. However, cassava peels contain 6 percent protein and 10 percent crude fibre, and the leaves contain 24 to 28 percent protein, so the potential of these two cassava products for rabbit feed should be tested in comparative trials. Cassava does have a slight tendency to produce goitre, which has no practical impact on growing rabbits but is a potential concern for breeders if it comprises over 30 percent of the diet.

Marremia tuberosa. This protein-rich (24 percent) forage, used in

Mozambique to feed rabbits, grows during the dry season.

Medicago sativa. Alfalfa is unquestionably the standard rabbit forage, wherever it can be grown. It is grown under irrigation in Mexico, Mozambique and Pakistan. It does not grow in hot tropical areas such as the Caribbean. Breeding and growing rabbits can be fed solely on green alfalfa. The hay is harder for them to ingest. Alfalfa's rather high saponin content makes it especially palatable to rabbits.

Mimosa pigra. No negative effects were noted in tests run on this thorny plant in Thailand. It was used to replace *Brachiaria mutica* in rabbit feed. Its 22 percent protein content is comparable to that of *Leucaena leucocephala.*

Morus alba. Mulberry leaves not needed to feed silkworms can be successfully fed to rabbits. Trials in India have even shown that a maintenance diet for adult rabbits can consist exclusively of mulberry leaves. They are used in India to supplement concentrates for Angora rabbits.

Musa spp. Rabbits can be fed on commercial banana rejects. Bananas are rich in energy and poor in protein (5 or 6 percent) and must be supplemented. Rabbit breeders use banana rejects in various African countries and in Guadeloupe and Martinique. The leaves can also be used as green forage (Cameroon, Zambia, Guadeloupe and Martinique). Their protein content is 10 to 11 percent of the dry matter. Data are available on the leaves as rabbit feed, but not on the stems. They contain only 1.5 to 2 percent protein and with a 70 percent nitrogen-free extract could make a useful energy feed. Banana peels can also be used to replace up to 35 percent of the concentrate for growing rabbits.

Neotonia wightii. A trial in Brazil showed that perennial soybean hay can fully replace alfalfa in a balanced ration containing 38 percent of this forage. There is even a marked improvement in the growth rate (41.5 g/day compared with 37.1 g/day with control rabbits fed alfalfa). This legume can be an attractive source of protein and fibre for rabbits.

Opuntia ficus. The aerial part of prickly pear cactus can be fed to rabbits. At levels higher than 40 percent of the feed ration, however, the risk of diarrhoea arises because the fibrous portion is highly digestible.

Oryza sativa. Carefully preserved rice straw or bran can be fed to rabbits. A study in China showed that controlled fermentation of rice straw with bacterial strains of *Trichoderma* and *Azotobacter* can boost the food value and serve as a replacement for wheat bran. Uncontrolled fermentation could, however, produce mycotoxins.

Panicum maximum. In various comparison trials with other forages guinea grass made a poor showing, mainly because of its low protein content - 5 to 10 percent of the dry matter according to ripeness. Despite this, guinea grass is part of the basic feed ration for rabbits in Ghana, Guadeloupe and Martinique. Its function is mainly to provide crude fibre and a small amount of energy. There is another use for guinea grass: dried, the plant is sometimes used as straw litter for the nest box when breeding does are raised on a mesh floor.

Pennisetum purpureum. Feed trials with breeding and growing rabbits using elephant grass gave even poorer results than guinea grass, again because of low protein content (6 to 8 percent). A Malawi trial using elephant grass as a supplement for maize bran produced growth rates of only 15 g a week compared with 60 g with *Leucaena leucocephala;* but it can be used as a source of crude fibre for rabbits, as is done in Guadeloupe and Martinique. A mixed crop where elephant grass supports a climbing legume such as *Pueraria* is planned in the Democratic Republic of the Congo. The combination gives a much more balanced forage. The dried stems of *Pennisetum* can be used as straw litter or bedding for the nest box.

Pistia stratiotes. Comprising 30 percent of the diet of growing rabbits, sun-dried water-lettuce meal was used in Nigeria to produce growth rates equal to those of the control.

Populus spp. Green poplar leaves can be used to replace sun-dried alfalfa leaves as a fodder resource for rabbits. The leaves of the older trees are less protein rich (15 percent of the DM) than the leaves of coppiced poplars (20 to 22 percent of the DM). Trials in the United States used up to 40 percent poplar leaves in the diet.

Prosopis chiliensis. The fruits of this drought-resistant South American native have been introduced in Chile as a supplement to balanced rabbit feed, replacing up to 60 percent of the protein in the basic diet. Growth remained unchanged even when the feed contained up to 29.4 percent of the dried *Prosopis* fruits.

Psilotricum boivinianum. This forage grows without irrigation in the dry season in Mozambique and has a high (20 to 21 percent) protein content, making it an attractive forage feed for rabbits.

Pueraria spp. The legumes of this genus, such as *P. phaseoloides* and *P. javanica,* are recommended as rabbit feed in different countries of Africa, especially Ghana. *P. javanica* is the basic feed of many farm rabbitries in the Democratic Republic of the Congo. Rabbits are very fond of it. Like *Stylosanthes, Pueraria* remain green even in the dry season.

Robinia pseudoaccacia. Various trials in the United States and India on growing or on Angora rabbits showed that *Robinia* leaves can easily replace alfalfa in the diet with only a slight drop in performance.

Saccharum officinarum. Sugar cane can be grown in countries with wet tropical climates and is a good rabbit feed, despite its low protein content (1 or 2 percent). In an early trial in Mauritius, coarsely chopped sugar cane was successfully used to re place one half the balanced concentrate feed ration with no consequent drop in performance. In a complementary trial, the same authors found that, fed ad lib, rabbits chose to replace up to 40 percent of their balanced concentrate feed with chopped sugar cane. In a similar ad lib feeding test, *Leucaena leucocephala* replaced up to 60 percent of the same balanced concentrate feed (see Figure 6). In a New Caledonia trial it was shown that rabbits prefer to eat first the dry leaves, then the green leaves and then the cane itself, chopped small.

Setaria spp. These species of forage are used in Mauritius to supplement concentrated feeds for rabbits. Like all grasses, *Setaria* are poor in proteins.

Solanum tuberosum. Cooked potatoes can very well be used to feed rabbits, but this puts the animals into competition with humans for food. Potato peelings are part of the kitchen waste in many countries and can be used in feed. However, apart from the fact that the peelings should be fed cooked, not raw, great care must be taken not to use the parings of potatoes which have turned green with exposure to light. Laboratory animals stopped growing when they were given 20 g of green potato peelings a day in addition to their normal feed ration.

Sorghum vulgare. Sorghum tops and grain are a good rabbit feed. They are used in Ghana and Mexico.

Stylosanthes spp. Legumes of this genus can be grown in all wet and dry tropical climates. In dry areas they virtually stop growing during the dry season, but remain green. Different species have been used for rabbits, including *S. gracilis* (Ghana, the Democratic

Republic of the Congo, Burkina Faso) and *S. hamata* (Martinique).

Taraxacum officinale. The dandelion is among the wild plants conventionally fed to rabbits in traditional European rabbit production. The use of this composite plant as rabbit feed has also been reported in Togo.

Tridax procumbens. Considered a weed on the Malawi grasslands, the advantage of *Tridax* is that it grows during the dry season. Its 12 to 13 percent protein content also makes it a good rabbit feed. The plant proved satisfactory as a concentrate feed supplement in Malawi. Growth performance trials with *Tridax* as a maize bran supplement, however, were poorer than trials with *Leucaena leucocephala,* although more promising than *Pennisetum purpureum,* probably because of the differing protein content of the three plants.

Trifolium alexandrinum. This Egyptian clover (berseem), typical of the Mediterranean climate, is virtually the only rabbit feed used in the Sudan. Feeding trials in Egypt using the clover alone produced live weights of 1.23 kg at 16 weeks for cross-bred Baladi × Flanders Giant rabbits, with an average weekly gain of 67 g. Like all legumes this clover variety has a high protein content.

Vicia spp. Wild vetches, grown alone or interplanted with grasses, can supply a protein-rich forage attractive to rabbits. The plant grows so quickly, however, that the tendency is to use it as hay, unless planting can be staggered for a continuing crop.

Vigna sinensis. These wild peas of Guadeloupe and Martinique supply nitrogen-rich green forage and grain. Both *V. sinensis* and *V. unguiculata* are used as rabbit feed in these islands.

Zea mays. Although maize grain is needed as food for people inmost developing countries, its use as fodder would be feasible in certain regions. The protein content of maize forage is low, so it requires a nitrogen supplement. Maize is used as forage in Burkina Faso, for instance.

This rather lengthy list of plants that have been tested as rabbit feed does not include every usable plant. There are grasses such as the various species of *Digitaria,* for example, although these are usually poor in protein. Where cabbage can be grown it should be added to the list. Cabbage is a traditional rabbit feed in France. Its 17 to 20 percent protein content is fairly high. Trials in Cameroon suggest that cabbage can form up to 15 percent of the diet.

Agricultural and industrial by-products.

The various agricultural and industrial byproducts will not be reviewed here, as lists of by-products and their composition are usually available for each region. Only a few need special mention. First come the various tropical oilcakes such as groundnut (already described), palm nut and coconut. Cottonseed cake should be used very cautiously, as rabbits are at least as sensitive as pigs to gossypol. However, cottonseed cakes containing up to 700 ppm of free gossypol have been fed to growing rabbits with no problems. In many countries where cottonseed feedcake is available, it is preferable to use it and to accept a drop in performance of 10 to 15 percent compared with a gossypol-free ration rather than attempt to introduce livestock-based meal as a protein source which may be expensive or of poor bacteriological quality. Then there are maize and rice by-products. Brewer's draff and citrus pulp are possible feed sources where the processing plants are not too far from the rabbitry. Rabbits can also be fed waste products from pineapple canneries, as in Côte d'Ivoire, but pineapples are poor in protein.

Brewer's draff from the manufacture of barley-based beer and dolo dregs from millet beer can produce good results. In a test conducted in Burkina Faso, dolo dregs were used as 80 percent of a concentrate feed with 10 percent groundnut cake, 6 percent blood meal and 4 percent bone meal. This was fed with a forage supplement of green *Brachiaria* or dried groundnut tops. Local rabbits grew faster with this feed (104 g a week with land race) than with an imported balanced feed (83 g). Sun-dried brewer's draff is often also incorporated as a protein source for rabbit rations in the urban peripheries of some African cities.

Chapter 3 REPRODUCTION

Anatomy of the genitals

In the male, the oval-shaped testes within the scrotum remain in communication with the abdominal cavity, where they were at birth. The rabbit is actually able to withdraw its testes when frightened or fighting with other males. The testicles descend at about two months. The short, back-slanting penis points forward when erect. Figure 7 shows the relative position of the various organs.

In the female, ovaries are oval-shaped and do not exceed 1 to 1.5 cm. Beneath the ovaries is the oviduct, made up of the duct, the ampulla and the isthmus. Although outwardly the uterine horns are joined at the back into a single organ, there are actually two independent uteri of about 7 cm, opening separately through two cervical ducts into the 6 to 10 cm vagina. The urethra opens midway along the vagina at the vaginal vestibule. The glands of Bartholin and the preputial glands can be identified. The whole is supported by the broad ligament attached at four main points under the vertebral column.

Figure 8 shows the relative position of the various organs.

Reproduction physiology

The male

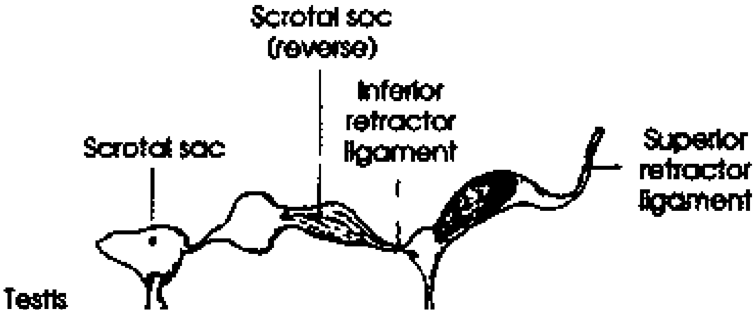
Gonad development and puberty. The gonads begin to differentiate on the 16th day after fertilization. After birth the testes develop less quickly than the rest of the body. From the age of five weeks they begin to grow very rapidly. Accessory glands undergo a similar development, but at a more even rate and are less precocious. Spermatogenesis begins between days 40 and 50. The testicular tubes become active at about 84 days. The first spermatozoa are present in the ejaculate at about 110 days.

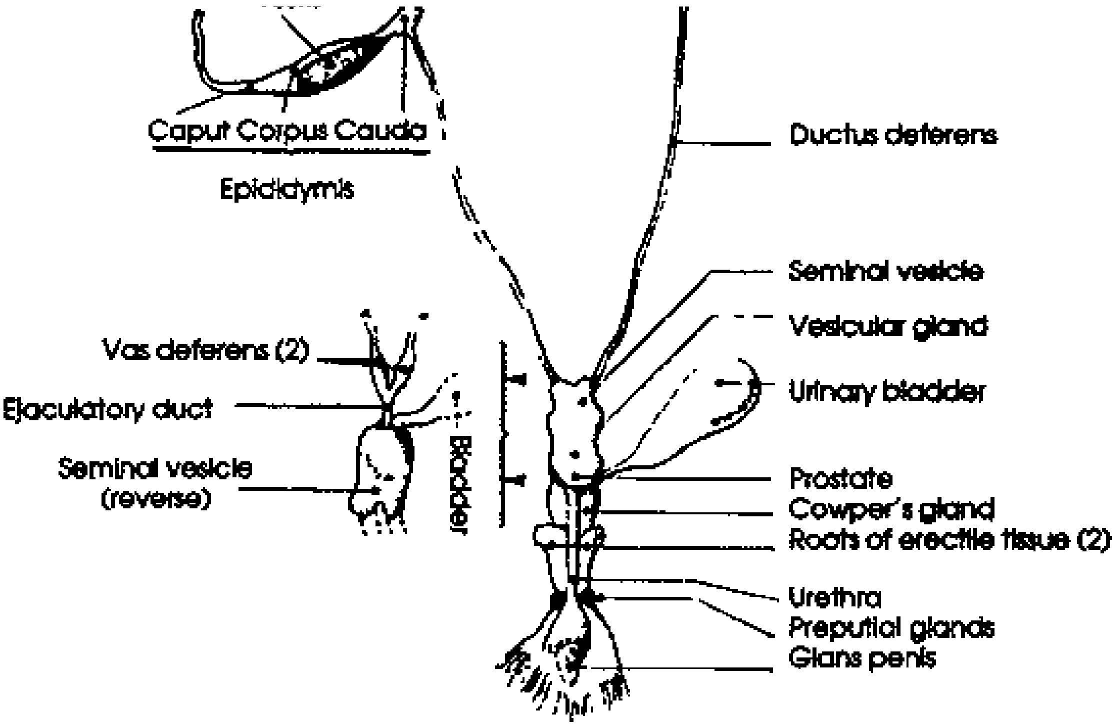
Sexual maturity, defined as the moment when daily sperm production ceases to increase, is reached at 32 weeks by New Zealand White rabbits in temperate climates. However, a young buck in these same conditions can be used for reproduction from the age of 20 weeks. Indeed the first manifestations of sexual behaviour appear at days 60 to 70 when the rabbit makes it first attempts at riding. Coitus may occur for the first time at about 100 days, but the viability of the sperm cells is very weak or nil in the first ejaculates. So first mating should be timed for age 135 to 140 days.

All these figures are to be considered approximate. The onset of puberty varies from breed to breed, but conditions in the rabbitry also play an essential role, particularly feeding, which is even more important than climate.

Sperm production. The volume of semen ejaculated is about 0.3 to 0.6 ml. Concentration is evaluated at 150 to 500 × 10^6 spermatozoa per ml, but both volume and concentration are liable to vary. False mountings, one or two minutes before copulation, increase the concentration of the ejaculate. In two successive servicings the first acts as a preparation for the second, which is less voluminous but more concentrated. During subsequent matings the volume of the ejaculate decreases, while concentration increases between the first and the second ejaculate and then diminishes. The total number of spermatozoa per ejaculate follows the same trend.

FIGURE 7 Genital apparatus of male rabbit





Maximum spermatozoa production is obtained by using the buck regularly once a day. If the buck is used regularly twice a day, each ejaculate has only one half the concentration of spermatozoa. On the other hand, if bucks service several times a day, one day a week, the three or four ejaculates may be concentrated enough to effect fertilization. Further ejaculates contain very few spermatozoa and cannot effect fertilization often enough to be worth while. Daily spermatozoa production is roughly 150 to 300 million, independent of the rate of ejaculation. The maximum epididymis reserve is only one to two billion spermatozoa, only partially mobilizable for repeated ejaculations.

The female

Gonad development, puberty and sexual maturity. As in the male foetus, sexual differentiation takes place on the 16th day after fertilization. Ovogonial division begins on the 21st day of foetal life and continues until birth.

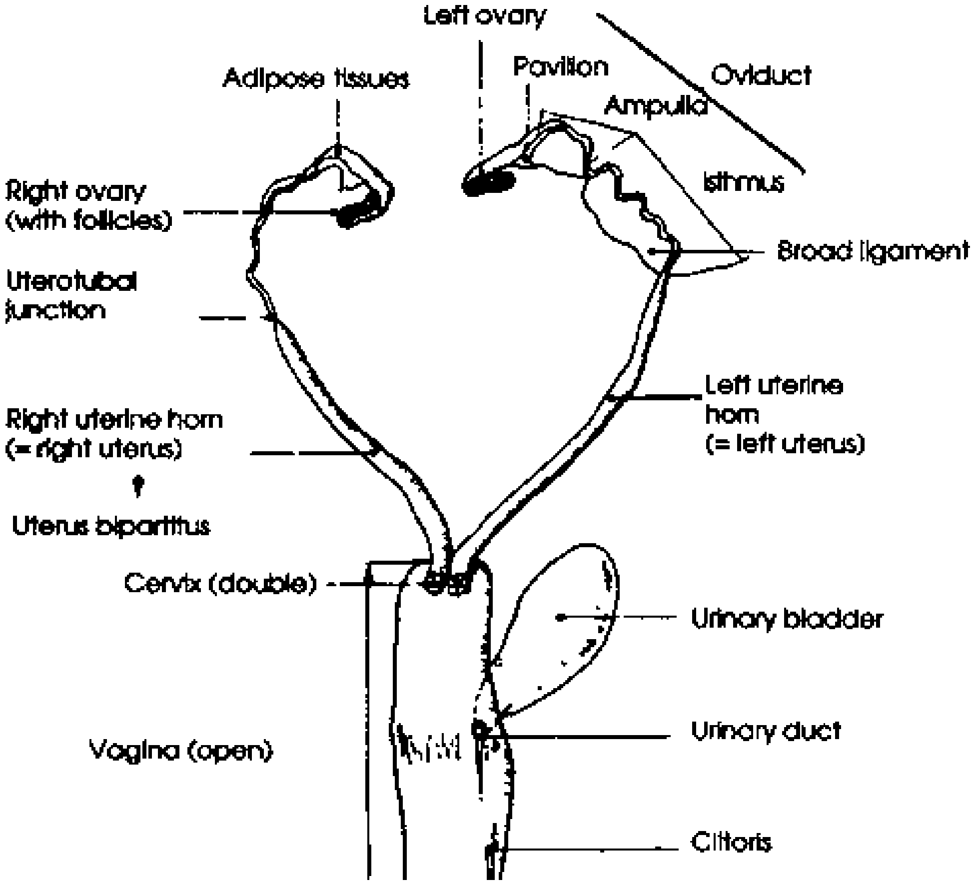
The first follicles appear on the 13th day after birth, and the first antrum follicles at about 65 to 70 days. Does are able to mate first at 10 to 12 weeks, but as a rule this will not produce ovulation. The onset of puberty varies greatly with:

- the breed: sexual precocity is more developed in small or medium breeds (four to six months) than in large breeds (five to eight months). In Europe does are now mated at 120 to 130 days and fertility performance is good;

- body development: precocity goes hand in hand with rapid growth. Does fed ad lib reach puberty three weeks earlier than other does of the same strain receiving only 75 percent of the same daily feed. The body development of the latter is also delayed by three weeks.

Does generally reach puberty when they have grown to 70 to 75 percent of their mature weight. However, it is usually preferable to wait until they reach 80 percent of their mature weight before breeding them. These relative weights should not be considered absolute thresholds for all rabbits, but rather limits applicable to the population as a whole. Sexual behaviour (acceptance of mating) appears long before the ability to ovulate and bear a litter. Such behaviour should not be regarded by the breeder as a sign of puberty, but as prepuberty play.

FIGURE 8 Genital apparatus of female rabbit



The oestrus cycle. In most domestic mammals ovulation takes place at regular intervals when the female is in heat or oestrus. The interval between two periods of oestrus represents the length of the oestrus cycle (four days for rats, 17 for ewes, 21 for sows and cows).

The female rabbit, however, does not have an oestrus cycle with regular periods of heat during which ovulation will occur spontaneously. Does are considered to be in oestrus more or less permanently. Ovulation occurs only after mating. A female rabbit is therefore considered to be in heat when she accepts service and in dioestrus when she refuses.

There are many observations which denote the alternating periods of oestrus during which the doe accepts mating and dioestrus in which she refuses (Figure 9). But the present state of knowledge does not make it possible to predict either the respective lengths of oestrus and dioestrus or the environmental or hormonal factors determining them.

It has been noted, however, that 90 percent of the time when a doe has a red vulva she will accept mating and ovulate, whereas when the vulva is not red the doe will accept service and become fertilized only 10 percent of the time. A red vulva is therefore a strong indication, though not a proof, of oestrus. A doe in heat assumes a characteristic pose, called lordosis, with the back arched downwards and hindquarters raised. A doe in dioestrus tends to crouch in a corner of the cage or exhibit aggression towards the buck.

The sexual behaviour of a female rabbit is thus very special. She has no cycle and can stay in heat for several days running. On the ovary, follicles not having evolved to the ovulation stage through lack of stimulation undergo regression and are replaced by new follicles, which remain for a few days in the pre-ovulating state and may then in turn regress.

In most mammals the progesterone secreted during gestation inhibits oestrus and the pregnant female refuses to mate, but a pregnant doe may accept mating throughout the gestation period. Indeed, in the second half of pregnancy this is the most common behaviour (Figure 10).

A breeder cannot therefore use the sexual behaviour of does as an indication of pregnancy. Mating occurring during gestation has no dire consequences for the embryos. Unlike the phenomenon observed in the female hare, superfoetation (two simultaneous pregnancies at two different stages of development) never occurs in rabbits.

Ovulation. Ovulation is normally induced by the stimuli associated with coitus and occurs ten to 12 hours after mating, as outlined in Figure 11.

Given this sort of pattern, ovulation can be induced artificially by various techniques. Mechanical stimulation of the vagina can cause ovulation, but the outcome is quite random. Injections of luteinizing hormones (LH) or LH releasing hormones (LHRH) can produce results, although repeated injections of the LH hormone lead to immunization and loss of effect beyond the fifth or sixth injection. Injections of LHRH repeated at 35 days for two years, however, have involved no loss of effect: 65 to 80 percent of the does became pregnant from this injection followed by artificial insemination.

Fertilization and gestation. At the moment the ovary follicles are ruptured the oviduct pavilion or infundibulum covers the ovary. When liberated the ovocytes are sucked in by the pavilion. The ovocytes are in fact fertilizable from the moment they are liberated, but they are not actually fertilized until about an hour and a half after release. The sperm is deposited by the male in the upper part of the vagina. The spermatozoa make their way upwards rapidly. They can reach the fertilization area (in the distal ampulla, near the isthmus) 30 minutes after coitus. During their journey the spermatozoa undergo a maturing process which enables them to fertilize the ovocytes. Of the 150 to 200 million spermatozoa ejaculated, only two million (1 percent) will reach the uterus. The rest are defeated by obstacles at the cervix and uterotubal junction.

FIGURE 9 Sexual behaviour and duration of oestrus in five pubescent nulliparous does

The egg reaches the uterus 72 hours after ovulation. On its way through the oviduct the egg divides. The uterine wall differentiates, but the uterine dentellus appears only five to eight days after coitus. It is the synchronization of these phenomena that makes possible the implantation of the egg. Implantation proper takes place seven days after mating, at the blastocyst stage. Distribution of the blastocysts is roughly equidistant in each horn, but the blastocysts never move from one uterine horn to the other. From the third to the 15th day after mating the progesterone rate continues to increase, then remains stationary and finally drops rapidly before parturition. The maternal placenta develops along with the foetus, reaching its maximum weight towards the 16th day of pregnancy. The foetal placenta is visible about the tenth day and becomes larger until birth (Figure 12).

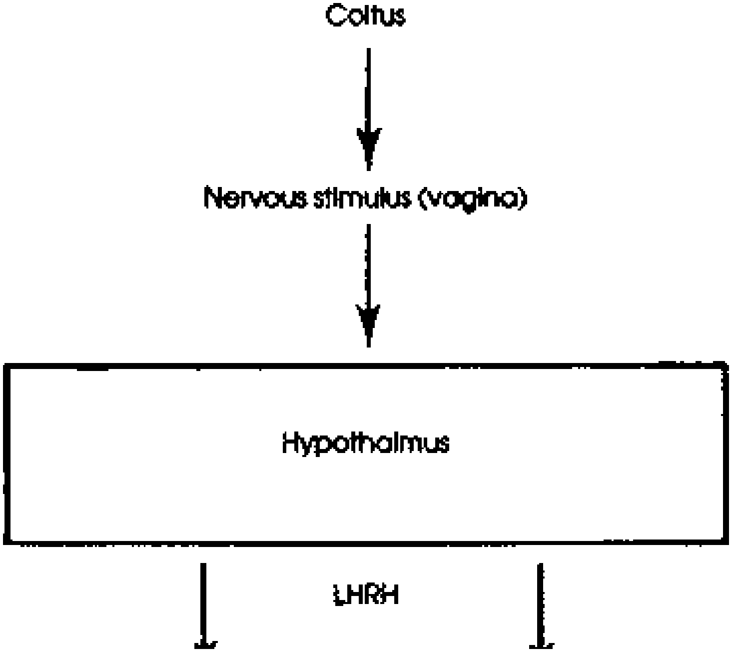
Embryo losses, measured by comparing the numbers of corpus luteum and living embryos, are usually very extensive. Generally speaking only 60 to 70 percent of the eggs become live rabbits. Most embryo mortalities occur in the 15 days before birth. Mortality is partly due to the viability of the embryos and partly to their situation in the uterine horns. External factors also play a part: the season and the physiological condition of the doe (especially her age). For a simultaneously lactating and post-partum pregnant doe (fertile mating 24 hours after giving birth), late embryonic mortality is increased with respect to that observed in a simply pregnant doe under the same circumstances.

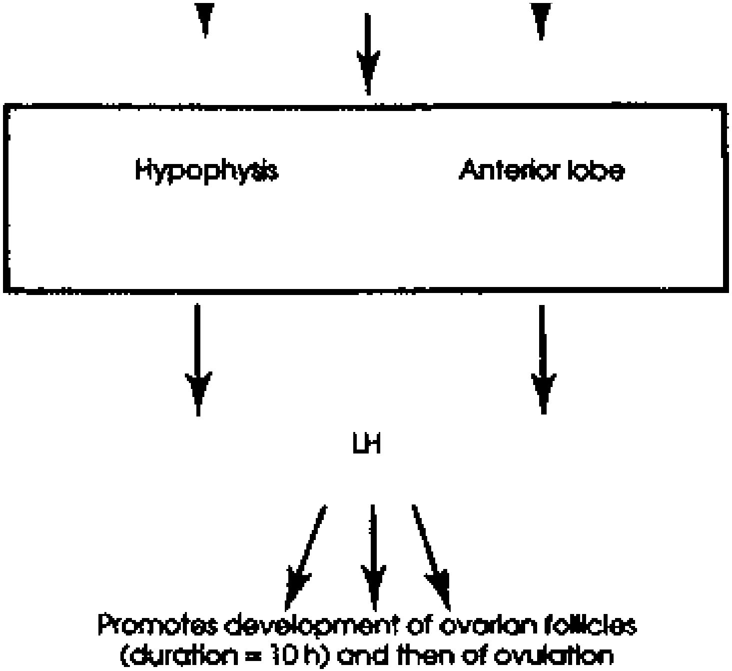
FIGURE 10 Mating acceptance trends in gestating does

Pseudopregnancy. Liberated ova which are not fertilized may occasion a pseudopregnancy lasting 15 to 18 days. At first the corpus luteum and uterus develop as in an ordinary pregnancy, but they do not reach the size or the level of progesterone production of the corpus luteum in pregnancy. Towards the 12th day they regress and disappear under the action of a luteolytic factor secreted by the uterus, undoubtedly prostaglandin. The end of pseudopregnancy is marked by the maternal behaviour of the doe and nest-making, linked to the swift drop in blood progesterone. While such pseudopregnancy is much used in research laboratories on the physiology of reproduction, it is very uncommon in natural-mating rabbitries. When a doe is serviced under unfavourable conditions she does not ovulate, and it is exceptional for ovulation to occur without fertilization (as in mating with a sterile but sexually active buck). Unfertilized ovulation can occur in 20 to 30 percent of artificially inseminated does injected with GnRH. In this case, an injection of prostaglandin PGF_{2a} on the 10th or 11th day will halt the pseudopregnancy and the doe can be fertilized just 14 days after an earlier infertile insemination. Without prostaglandin treatment, the doe cannot be fertilized again until another week has gone by.

Kindling. The mechanism of parturition is not very well known. It seems that the secretion of corticosteroids by the supra-renals of the young plays a part, as in other animal species, in giving the signal for parturition. PGF_{2a} prostaglandins may also be instrumental in starting the process. At the end of gestation the doe makes a nest for the litter with her own fur and materials she has available such as straw and shavings. This behaviour is linked with an increase in the oestrogen/progesterone ratio and with the secretion of prolactin. The doe does not always make a nest, or she may kindle outside the nesting box.

FIGURE 11 Onset of emulation following coitus



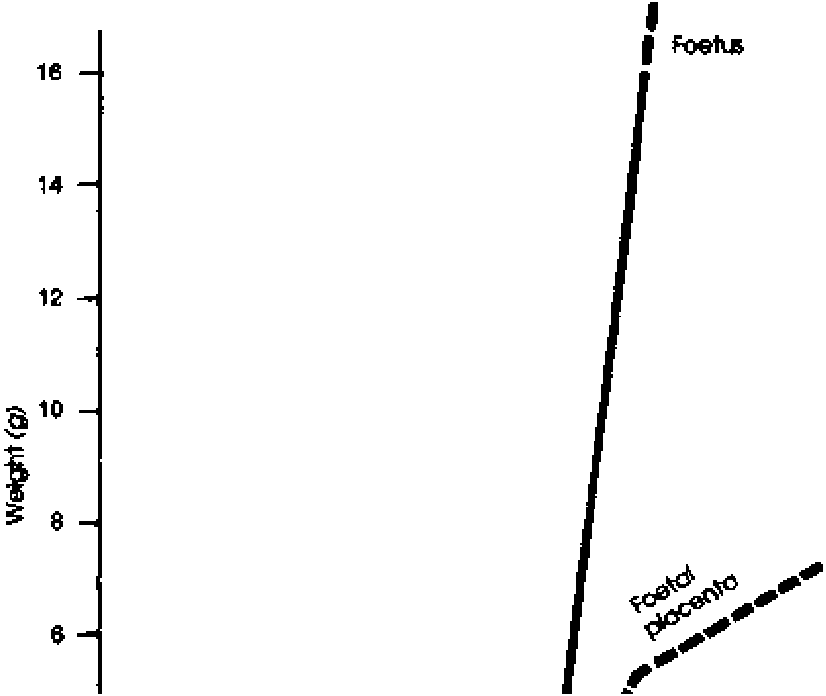


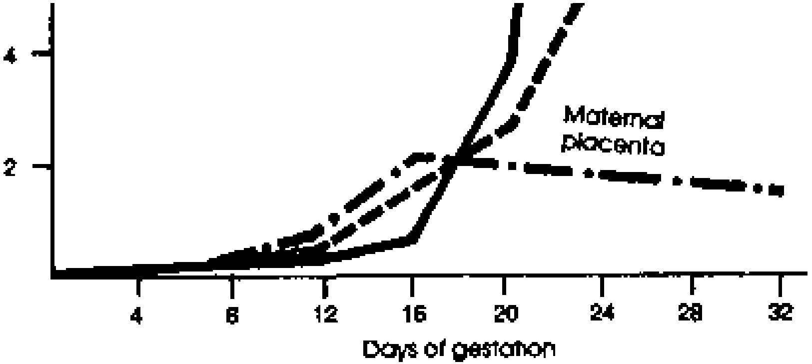
Note: LH = luteinizing hormone; LHRH = LH releasing hormone.

Kindling lasts from 15 to 30 minutes, according to the size of the litter. Litter size varies as much as from one to 20 young. Most litters range between three and 12. In rabbit production units the average is seven to nine, but there are great variations.

After parturition the uterus retracts very quickly, losing more than half its weight in less than 48 hours.

FIGURE 12 Changing weights of foetus and embryonic membranes during gestation





Source: Hammond and Marshall, 1925.

Artificial insemination

Artifical insemination (AI) is a growing practice in European rabbitries, particularly in Italy and France. Currently, a little under 1000 production units are involved, but the practice is growing primarily because of the opportunities for work organization involved: AI can impregnate a great many does on the same day without the need to maintain an excessive number of bucks. This paper, while not fully covering the topic of AI, will simply list the main advantages and drawbacks of the method.

Semen collection and control. *A doe* in heat is put into the buck's cage. The operator holds the artificial vagina with its collection tube between the rabbit's paws. The artificial vagina is kept at a temperature of about 40° to 42°C prior to use, so that it will be at 39°C, the normal vaginal temperature of a doe, at the moment of use. Ejaculation usually takes place immediately following the presentation of the doe.

A basic control of the biological quality of the semen is made for selection of the best ejaculates: no urine, sufficient motility and concentration, etc. The semen is then diluted five to ten times, perhaps in physiological salt solution, within 30 minutes after semen collection, or, always the preferable choice, with a special diluent if it is to be applied within 12 hours. It is possible to freeze the semen, but the poor performance of frozen semen relegates this technique to research laboratory use where there is some interest in maintaining the semen of a specific buck for a long period.

The fact that a high percentage of the ejaculates has to be eliminated on the grounds of poor biological quality means that only a few males need to be retained for every 100 productive females, compared with natural mating.

It is clearly preferable to raise males on wire netting or grating than straw litter which considerably increases bateriological contamination in the semen collected.

Insemination. The semen can be packaged in 0.5 ml pellets or presented in 20,50 or 100 0.5 ml flacons for insertion with a glass cannula. Two techniques co-exist: an insemination gun covered with a single-use sheath, and the glass (or throwaway plastic) cannula. Both techniques have their partisans and their detractors and for both the diluted semen must be delicately inserted deep into the rabbit vagina.

As ovulation is not spontaneous in rabbits, intramuscular injection of an artificial analogue of GnRH (gonadoreline 20 μ g, busereline 0.8 μ g) is used to provoke ovulation at the moment of insemination. AI in rabbits involves a dual intervention: insemination and the injection of an ovulation-producing hormone.

Successful artificial insemination. Assuming that every operation involved in AI is strictly adhered to, practical success in this reproduction method is equivalent to that in natural mating for the same reproductive rate (percentage of gestation, litter size, etc.).

To ensure adherence, insemination centres are now springing up in Italy and France where male rabbits are maintained and their semen collected, controlled and packed by expert staff possessing the necessary techniques and resources. Like the bucks, these resources give full value for money as such centres can work every day of the week. The semen packaged ready for use is then shipped to specially equipped rabbit production units from the insemination centre. Once apprenticed, rabbit breeders can practise insemination themselves, which requires one or two operators, depending on the insemination technique chosen.

A number of breeders owning more than 30 to 40 breeding does do carry out all operations in their own establishment with good technical results. There have, however, been too many failures to suggest that a breeder should begin by practising every operation, from the preparation of artificial vaginas to insemination in the rabbit's genital tract, including the essential quality controls and disinfestation.

From the purely technical standpoint, does found not to be pregnant when palpated have ovulated after artificial insemination, thus developing a pseudopregnancy that made them temporarily infertile. It is therefore futile to reinseminate an empty doe less than 21 days after the preceding insemination, when the pseudo-pregnancy is over. In natural mating, however, a doe can successfully be represented to the male once it is realized she is not pregnant (10 to 12 days after mating). In this case the absence of pregnancy is almost always linked to an absence of ovulation, whereas after artificial insemination the absence of pregnancy is linked to early embryo mortality or the fact that the rabbit has not been fertilized. Treating pseudopregnant rabbits with prostaglandin may reduce the length of the infertile period and the rabbit can successfully be reinseminated after an unsuccessful AI, but not enough is yet known about the specific modalities involved.

Overall, the highest fertilization rates with AI are obtained with receptive does, i.e. those which would have accepted natural mating. This is particularly true for lactating does and is why all (light, hormonal, etc.) treatments that increase doe receptivity also improve the performance of artificial insemination.

Lactation

Milk synthesis depends on prolactin, a lactogenic hormone. During pregnancy prolactin is inhibited by the oestrogens and by progesterone. At parturition there is a rapid drop in the progesterone level. As oxytocin is freed the action of the prolactin is stimulated and permits the milk to mount in a predeveloped gland.

Milk is let down as follows: the doe comes into the nest box to nurse her litter. The stimulus of nursing provokes the secretion of oxytocin, inframammary pressure mounts, the milk is let down and the young suckle. The amount of oxytocin secreted is proportional to the number of young feeding. But the doe sets the number of feeds: just once in 24 hours. Suckling alone will not provoke the secretion of oxytocin; the mother must want to nurse.

Aspects of milk production. Doe's milk is much more concentrated than cow's milk except for the lactose component (see Table 27). After the third week of lactation the milk becomes markedly richer in proteins and especially fats (up to 20 to 22 percent). The already low lactose content tapers off to almost zero after the 30th day of lactation.

Daily milk production increases from 30 to 50 g in the first two days to 200 to 250 g towards the end of the third week of lactation. It then drops rapidly. The decrease is even swifter if the doe has been fertilized immediately after kindling (Figure 13). The lactation curve varies from doe to doe, especially with regard to duration. Measuring the young rabbits' weight at 21 days gives a fairly good estimate of total lactation, as milk production between days zero and 21 is closely correlated with total milk production (r + = 0.92).

An important point is that the doe's milk output increases with litter size but the baby rabbits get less milk each than they would in a smaller litter. Depending on genetic type, milk production will not increase above eight to 12 baby rabbits.

Reproduction and environment

Lighting

In males exposed to artificial lighting for only eight out of 24 hours significantly more spermatozoa are present in the gonads than in those exposed to light for 16 hours, although a slightly larger amount is usually collected in ejaculates from the latter.

Does, however, are far more opposed to mating with only eight hours of light than they are with 16. For both males and females 12 hours of light a day produce average results. The practice in rational European rabbit production units is to light breeding areas artificially for 15 to 16 hours a day. The males and females are together in the same room.

Temperature

The impact of temperature on spermatogenesis has been studied by various authors, but usually for short periods ranging from just a few hours to a few weeks at most. In a prolonged five-week trial, Oloufa, Bogart and McKenzie (1951) noted actual falls in the volume and concentration of ejaculates at a high temperature (33°C). A high temperature also affects sperm motility even after such short periods of exposure as eight hours at 36°C, or medium periods such as 14 days at 30°C. Furthermore, and this seems to be the worst effect, temperatures in excess of 30°C reduce the bucks' sexual urge.

TABLE 27 Average composition of cow's and rabbit's milk

Components	**Rabbit's milk (days 4 to 21)**	**Cow's milk**
	Percentage	
Dry matter	26.10-26.40	13
Proteins	13.20-13.70	3.50
Fats	9.20-9.70	4
Minerals	2.40-2.50	0.70

Lactose	0.86-0.87	5

Source: Lebas, 1971a.

However, these findings should not obscure the fact that rabbits do reproduce effectively in hot tropical or equatorial climates. Breeders should take the precaution of protecting their rabbits against extreme heat; they should avoid direct sunshine and protect the cages with an insulated roof, not just a corrugated metal sheet (which in fact transmits too much heat).

It should be noted that humidity does not seem to have been recorded in the various laboratory tests on the effects of temperature on spermatogenesis.

High temperatures also seem to affect female rabbits negatively. The lower prolificacy attributed to does reared in hot climates (30° to 31°C) would appear to be the result not so much of the temperature itself as a reduction in body weight caused by a lower feed intake in the heat (Figure 14). It would seem, however, that embryo mortality increases when the temperature exceeds 30° to 33°C, although here again decreased feed intake needs to be considered as a possible cause.

Season

In Europe the season is usually analysed in terms of the combined effects of light and temperature. In tropical climates the temperature effect seems to be dominant but an effect due to variations in the length of day light cannot be excluded. The reproduction cycles of the European wild rabbit are strongly influenced by the season. Does breed from the end of winter until early summer (Figure 15). The reproduction period can be longer or shorter, at either end, according to both temperature and availability of feed.

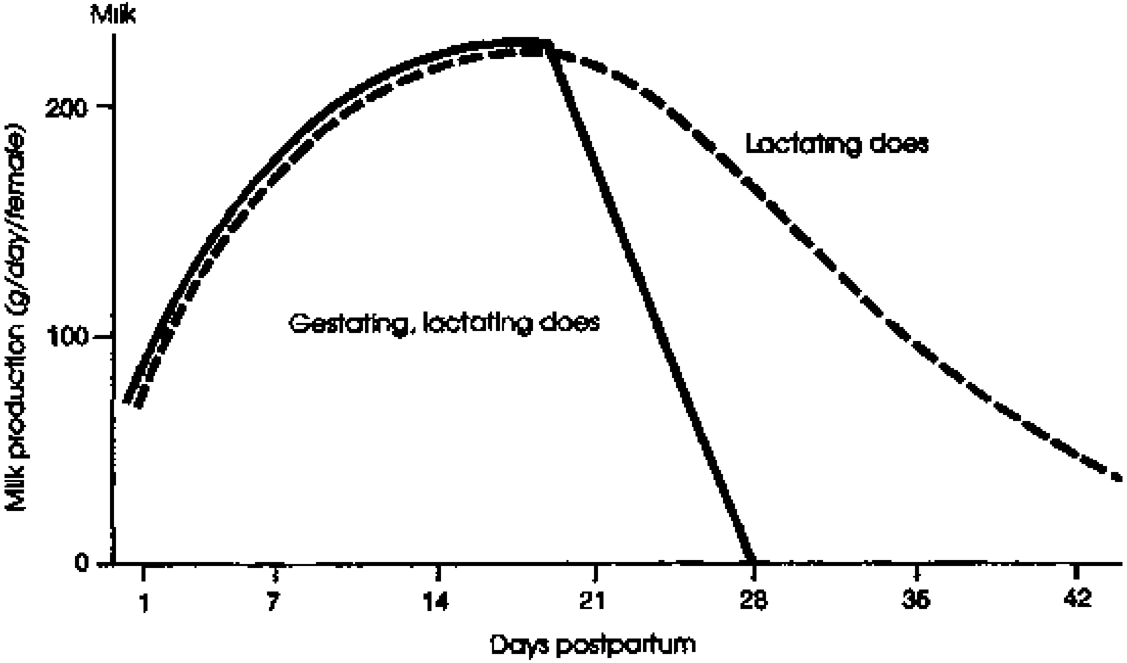
Exposing domestic does to light for 16 out of 24 hours in Europe considerably attenuates this seasonal variation; indeed it nearly suppresses it. Even so, reproduction problems sometimes appear at the end of summer with no direct relation to the temperature. In tropical climates a drop in the rate of reproduction is noted during the same period, the wet season, when temperatures are high and so is humidity.

Rates of reproduction

The physiological features of the male and especially the female are such that the breeder has great latitude in choosing a reproduction method. But for successful rabbit production the choice of method must be preceded by careful study and planning. The goal is to increase doe productivity and reduce inputs.

Productivity, defined as the number of young per doe per unit of time, depends on: the interval between successive kindlings; litter size at birth; and the survival rate of the young.

FIGURE 13 Pattern of milk production in does



Source: Lebas, 1972.

These criteria can be improved by slow, methodical selection and careful management of the rabbitry environment. In practice the crucial factor in increasing productivity is shortening the kindling-to-mating interval. This means non-productive periods must be reduced to the minimum. Before such a strategy is adopted the breeder should consider:

- whether or not it will be exhausting for the does, perhaps leading to premature culling (this depends mainly on feeding conditions);
- whether or not it might cause a spontaneous reduction in doe fertility and prolificacy;
- whether it will lead to more work for the breeder.

The breeder's desire to improve working conditions and reduce labour costs must also be considered. The final objective criteria for selection must be the production of good rabbits for sale or for consumption per unit of time or per production unit labour cost per hour.

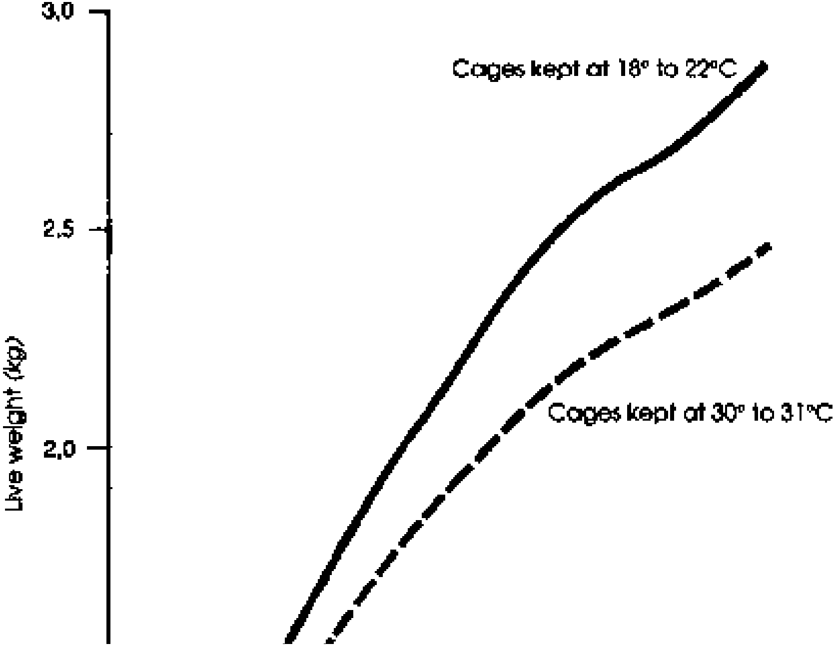
Age at first mating

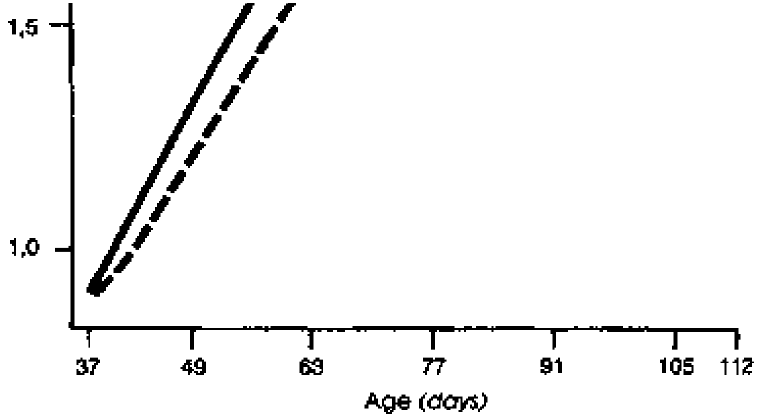
Before discussing the rate of reproduction, the first factor to consider is the age at first mating. Shortening the unproductive period before the first litter would automatically increase productivity. Studies conducted in France on does receiving a balanced concentrated feed showed that female rabbits first serviced at five and a half months had lower annual productivity than females serviced three weeks earlier. The first group had virtually reached their adult weight and were too fat. The best plan is to have does serviced as soon as they reach 80 (or, at the most, 85) percent of the mature weight for their breed. Females can be serviced even earlier if their feed is extremely well balanced (see earlier section on female rabbit physiology).

The three basic reproduction rates

The second method of stepping up production, after earlier servicing, is to accelerate the rate of reproduction. This amounts to shortening the theoretical interval between two successive litters. In fact, the true rate of reproduction is always slower than the theoretical rate because not all does immediately accept the buck and not all are fertilized when rebred. There are three basic rates of reproduction: extensive, semi-intensive and intensive, but all intervening stages are or have been used; the distinction is retained here for illustrative purposes.

FIGURE 14 Changing live weights of young does aged from 37 to 112 days reared in different temperatures

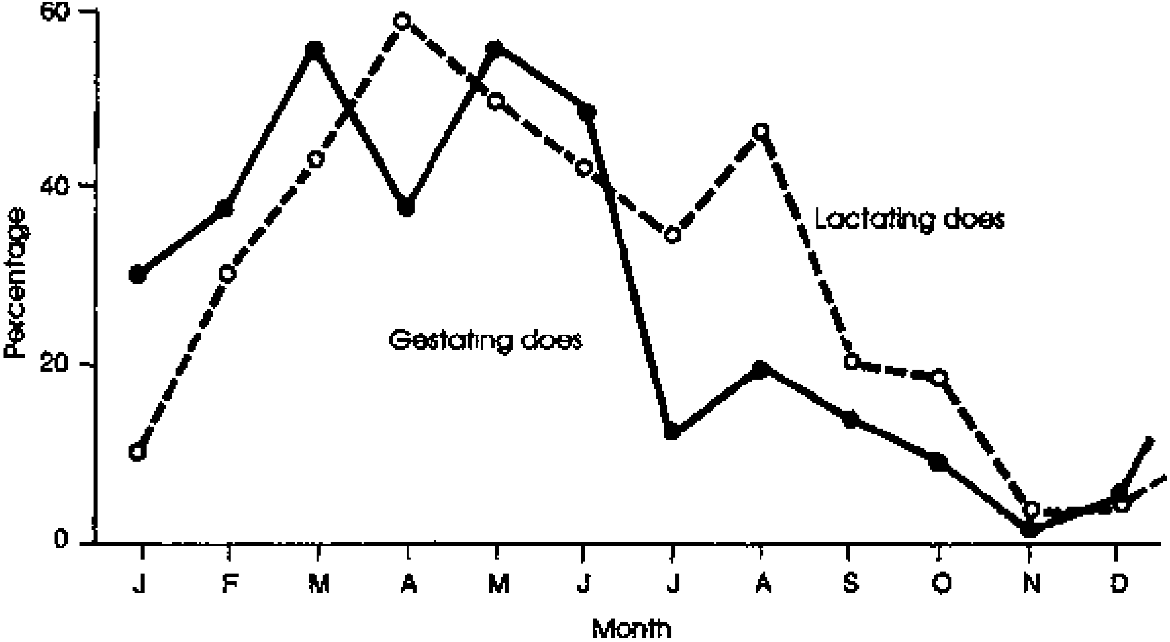




Extensive reproduction rate. The breeder fully utilizes the does' maternal instincts by allowing them to nurse their young for five to six weeks, rebreeding them soon after weaning. Does are therefore serviced once every two and a half months.

Later weaning is in no way advantageous except for fryer production - very young animals which can be sold at eight weeks and have not undergone weaning shock. In the United States and the United Kingdom fryers with a live weight of 1.7 to 1.8 kg are produced this way, using breeds such as the New Zealand White. The mother can be serviced before weaning, about five or six weeks after kindling, which allows two and a half months between litters.

FIGURE 15 Seasonal variation in percentage of gestating and/or lactating wild does in the United Kingdom



Note: Figures are based on wild does shot for each month of the year.
Source: **Stephen, 1952.**

Where the quality or quantity of the feed is not up to standard, it is preferable to wean rabbits at about 40 days. At the same time the breeder should slightly lengthen the resting period between weaning and rebreeding so the doe can build up her reserves again. In any case, weaning later than six weeks offers no particular nutritional advantage. The milk produced by the doe after this period provides at most 3 to 5 percent of the young rabbits' daily feed intake.

Semi-intensive rate. The breeder has does serviced 10 to 20 days after kindling and the young are weaned at four to five weeks. There is no real contrast between pregnancy and lactation for does. For 10 to 20 days the doe is newly pregnant while still nursing. The most important phase of embryo development takes place during the slump in milk production (milk production may even have ceased), so there is no real competition between the demands of gestation and lactation. As these does never have a resting period they need sufficient and well-balanced concentrate feed.

In rational European rabbit production units, a semi-intensive reproduction rate has basically been the rule since the late 1980s: rebreeding 10 to 11 days after kindling; weaning at about 34 to 38 days. At this rate, the work can be programmed by the days of the week, as the plan involves an interval of 42 days (exactly six weeks) between matings: 30 to 31 days of pregnancy + 10 to 11 days following kindling.

Intensive rate. The breeder has the does reserviced just after kindling, taking advantage of the fact that they are then on heat. Weaning should take place at four weeks at the latest, usually at 26 to 28 days. There are three main techniques:

- servicing the same day or the day after kindling: the true postpartum rate;

- servicing scheduled for a specific *day,* generally three or four days after kindling. This corresponds to a constant interval of 35 days (five weeks) between litters; the results of this 35-day rate are economically disappointing because the rate of female acceptance of servicing three or four days after kindling is very low in most rabbit production units, although not all;

- ad lib mating. A buck left together with postpartum does will serve them several times during the 48 hours following kindling. This is the natural rhythm of wild rabbits.

To arrange ad lib mating, breeders have worked out two types of rabbit housing. The first is the corridor-collar type: the does live in individual cages. They have a broad collar around their necks to prevent them from leaving the cage through the calibrated opening leading into a communicating corridor. The buck, however, has free access (at least temporarily) to the does' cages and can mate whenever the doe is ready.

The second is the group system: a buck and perhaps ten does live together in the same cage. They can mate at the optimum times. However, special arrangements must be made to curb the natural tendency of females to kill the offspring of other does when they themselves are lactating or ready to kindle.

Choosing the reproduction rate

Considering the greater nutritional needs of the pregnant doe, especially one which is also lactating, semi-intensive and, especially, intensive reproduction systems are only suitable where does get the right quantity and quality of feed. If these conditions are not met, the does will usually accept the male but later abort.

Abortion extends the interval between litters to match the extensive breeding interval. Figure 16 shows the main periods in the reproduction cycle and how under intensive reproduction the doe has no opportunity to build up reserves.

Numerous comparisons of intensive, semi-intensive and extensive reproduction have been made, principally in France. Twenty years ago the litters of does mated postpartum numbered one less than those of does remated ten or more days after kindling. This is virtually no longer true, mainly because of improved feeding and the selection of strains and lines suitable for intensive reproduction. The systematic use of the most intensive reproduction method, however, makes it difficult to keep female brood stock in good condition, particularly primiparous females. This means a more rapid turnover of stock and the risk of an unfavourable subclinical disease situation, making does more sensitive to any agent of disease or environmental perturbation. After extensive experimentation from 1970 to 1985, European breeders have in fact almost all abandoned the systematic use of postpartum servicing.

In many cases, breeders adopt a variable rate of reproduction, depending on the condition of the does. For instance, a good healthy doe which produces a litter of fewer than seven or eight is immediately remated. If she has given birth to ten or so young the breeder waits about 12 days before having her serviced. In autumn, when it is harder to get the rabbits to mate, breeders systematically take the does for servicing after parturition. This is to take advantage of the strong postpartum oestrus during which 95 to 99 percent accept servicing. Even so, breeders avoid postpartum remating of primiparous does. As has already been mentioned, breeders are increasingly adopting a semi-intensive 42-day rate organized on a weekly basis, as will be discussed in the chapter on rabbit management.

With careful use of a semi-intensive rate, a good breed and balanced feed, European breeders are obtaining 55 to 65 weaned young annually per doe. In the tropics under identical production conditions of rate, breed and feeding, the number of young produced per doe is about 30 to 40.

Using the extensive rate the best breeders obtain 30 to 35 weaned young per doe per year. In a tropical climate, depending on the region and especially on feeding, 15 to 30 weaned young can be produced under extensive reproduction.

FIGURE 16 Distribution (as percentage of productive life) of gestation, lactation and resting periods in does used at different rates of reproduction **(EXTENSIVE)**

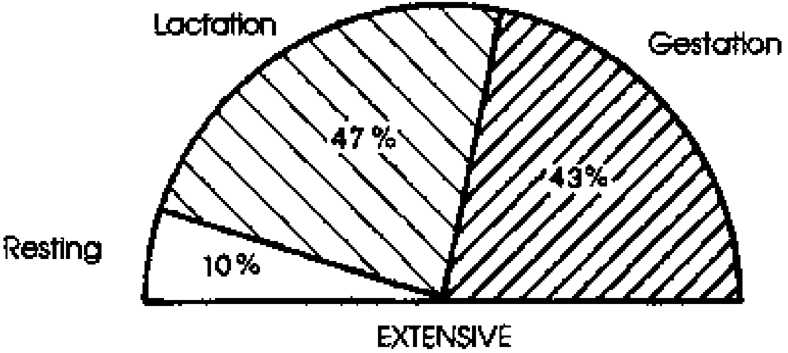


***FIGURE 16 Distribution (as percentage of productive life) of gestation, lactation and resting periods in does used at different rates of reproduction* (SEMI-INTENSIVE)**

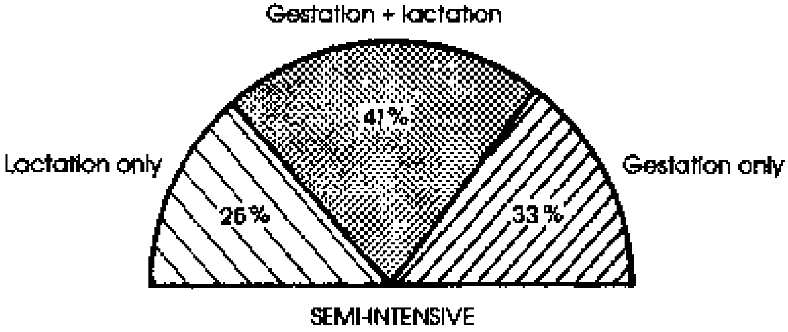
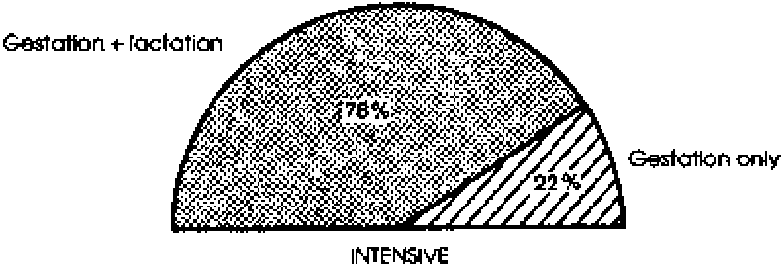


***FIGURE 16 Distribution (as percentage of productive life) of gestation, lactation and resting periods in does used at different rates of reproduction* (INTENSIVE)**



Chapter 4 GENETICS AND SELECTION

Introduction

Domestic rabbits are the descendants of *Oryctolagus cuniculus, a* species native to the western Mediterranean basin (Spain and North Africa). Wild rabbits belong to other genera: *Sylvilagus, Coprolagus, Nesolagus* and *Brachylagus.* The rabbit was domesticated relatively recently: most breeds are created by humans and are no older than 200 or 300 years, which is why there are few locally adapted land races.

The rabbit has been used as an experimental animal in genetics and reproduction physiology since the beginning of the century, but it was not until 1950 that the first findings on quantitative genetics were published, in Venge's study of maternal influence on rabbit birth weight (Venge, 1950). This work paved the way for research on the genetic improvement of the rabbit for meat production. Scientists at the National Institute for Agricultural Research (INRA) in France initiated research and development in this area in 1961, followed by work in other research laboratories in many countries, such as that of the teams of the University of Zagazig in Egypt, of Gödöllö and Kaposvar in Hungary, of Iztnanagar in India, of Milan and Viterbo in Italy, of Valencia, Saragossa and Barcelona in Spain, the Normal team in the United States and the Chinese teams (particularly in Shanghai) and those working in Nitra in Slovakia and in Cracow in Poland. Robinson's excellent 1958 bibliography in *Genetic studies of the rabbit,* based on sound genetic and physiological data, is now outdated by this new research.

Work on rabbit genetics has been regularly updated at world rabbit congresses (Rouvier, 1980; Matheron and Poujardieu, 1984; Rochambeau, 1988). However, experience gained under European production conditions cannot be transferred directly to developing countries. To upgrade their rabbits, breeders should use local animals, either native or from imported populations that have been locally adapted, and make use of the genetic variability that is available.

It does seem that priority should be given to research on rural and backyard rabbit production. These would be small, thrifty, autonomous units requiring little investment and using local resources. They would be reasonably productive.

Genetics of rabbit breeds and populations

Perhaps the best of the various definitions of *breed* is Quittet's: "A breed is a collection of individuals within a species which share a certain number of morphological and physiological characters which are passed on to their progeny as long as they breed among themselves."

One way of assessing the genetic uniqueness of different breeds is to study their origins. A breed is the outcome of the combined impact of artificial and natural selection (environmental adaptation). It is difficult to define exactly what is a breed and what is its background. Artificial selection may be based on a number of different criteria, not necessarily all to do with productivity. The breeding conditions may be either artificial or natural, the environment may gradually change and so on.

Rabbit breeds or populations can also be defined in terms of gene frequencies. This is possible with genes identifiable through their visible or major effects on progeny. Coloration and hair structure are classified as visible effects. Thanks to advanced observation techniques the genes governing blood groups, biochemical and protein polymorphism and hereditary anomalies are now also known. (See Zaragoza *et al.,* 1990.)

For quantitative characters, such as litter size or weight at weaning, which are controlled by a great many non-identifiable genes, rabbit populations can also be defined by their performance. These genes are also assumed to have little effect on overall variability and to function independently, according to the standard assumptions of quantitative genetics. Such characters are also influenced by the environment. The environmental characteristics must be carefully described (number of breeders, the direction of selection, the origin of the population and its range) when describing a population.

The genes are carried by chromosomes organized into 22 pairs (2n=44). About 60 markers have been described. These are genes of visible effect such as colour or coat or morphological anomalies, or genes coding for molecules of which the biological impact is being studied. These two approaches are hard to reconcile, for teams often use only one type of marker. Among the markers described, 37 have been placed on eight autosomes and on chromosome X; 23 markers constitute six linkage groups, and the locus of six markers has still not been found. All these markers are spread over a majority of 22 pairs of rabbit chromosomes. The links between the biological markers and the genes for colour or hair have rarely been tested, however.

Experience has shown that the rabbit can support a slow and gradual increase in inbreeding, but research suggests that mating programmes for small populations should minimize its extent and rate of increase among the stock (Rochambeau, 1990).

Breeds created by selectors, particularly amateurs in the United States and Europe, now conform to official standards. The book of the *Federation française de cuniculture* (FFC) on standards for rabbits describes more than 40 breeds. Each has been bred from animals of local and regional populations, or by crossing existing breeds, or by using mutants for changes in coat colour or structure. Mass selection for size and body morphology has separated these breeds into giant, medium, small and very small. It is interesting to study the origin of the breeds to learn whether they may correspond to original genetic ensembles and to attempt to determine their characteristics.

The characters by which an animal conforms to a breeding standard, such as body size, whether or not it is compact, coat colour and density and ear size, may be related to its resistance to variations in climate. In fact, such factors as coat, skin, body area and weight affect the animals' body temperature.

The currently known genetic determinants of variations in colour and structure are listed below. Coat colour has always been of great interest to breeders.

Coat colour and hair structure

In *The genetics of domestic rabbits,* published in 1930, Castle described six mutations in coat colour and two mutations in patterns; three mutations in hair structure; one mutation in the yellow colouring of the abdominal fat and two linkage groups. A convenient way to detect the effects of various mutations is to describe the rabbit's "wild" colouring. The coat consists of three types of hair: the longer, rectrix guard hairs, stiff at the base; the more numerous tectrix barbed hairs forming the major part of the coat, which share a hair follicle with the third type - the shorter hairs making up the undercoat.

The coat colour of the wild or "agouti" rabbit consists of grey dorsal fur with a much lighter or white ventral area. The long guard hairs are black but appear deeper black at the tips and bluer at the base. The barbed hairs have zones of colour: black at the tips, with a yellow band in the middle and bluish at the base. The fibres of the underfur are bluish at the base and fringed with yellow at the tips. Colouring is thus basically due to the distribution of black and yellow pigments (eumelanin and phaeomelanin) in the hair, especially in the barbed hairs, and over the whole coat (sides and back in relation to belly fur). Mutations in different loci modify this colouring.

Colouring. There follows a list of the international notation of alleles. Arnold (1984) shows the correspondence with the German system.

- Locus *A,* agouti: the non-agouti mutation *a* produces animals without a yellow band in the hair and a lighter belly. Their colouring is uniform. *A* is dominant over *a.* A third allele has been described at this locus, *at* (tan pattern), which is recessive to *A* and dominant over *a.*

- Locus B, black pigment: a recessive *b* allele produces a chocolate brown pigment instead of black in agouti hair.

- Locus C: the C gene is required for the development of pigments in the fur, skin and eyes and hence for the expression of colouring. The recessive c gene inhibits the expression of colouring, causing albinism in recessive *cc* homozygotes. There are several alleles at this locus, quoted below in dominant-to-recessive order:

  C: full expression of colouring.

  c^{ch}: chinchilla, suppression of colour in the intermediate band of the coat.

  c^{h}: Himalayan. Only the hairs at the body extremities are black. The expression of this gene depends on the ambient temperature.

  c: albinism. The albinism locus is epistatic over the colour loci. The cc genotype covers the expression of colour genes situated at other loci.

- Dilution, *D, d:* the recessive mutant *d.* allele affects the intensity of the pigmentation, causing a dilution of the pigment granules. The dominant *D* allele produces normal pigmentation density. The recessive *dd* homozygote is found in the genotypes of blue (black diluted to blue) or beige (yellow diluted to beige) rabbits.

- Normal extension of black *E* or yellow *e*: the *e* gene mutation causes increased yellow pigment in the hair, tending to replace the black (or brown) pigment. Grey, black or brown breeds have the E gene. Yellow and red breeds are recessive *ee* homozygotes.

- Vienna White locus: Vienna White rabbits have completely unpigmented fur but coloured eyes (blue). The original gene is called *V* and its mutated form *v.* Rabbits of the Vienna White breed are therefore recessive *vv* homozygotes. Crosses of this breed with albino rabbits produce coloured progeny.

- Mutations producing a mottled coat: these mutations involve the loci for English *(En, en*) and Dutch (*Du*, *du).* The Papillon rabbit is of the *En en* heterozygous genotype. The *En* gene is incompletely dominant. The *En En* homozygotes are whiter than the heterozygotes, while recessive homozygotes are blacker. The colour genotype of the Papillon rabbit (Giant Checker in English, Mariposa in Spanish) cannot be pinpointed. At the other locus the *du du* genotype produces the white belt characteristic of the Dutch rabbit.

Hair structure mutations. The three main ones are:

- Angora. This is a recessive autosomal mutation expressed as a lengthening of the duration of hair growth at the same speed of growth which produces longer hair. The wild (*L* dominant) gene has mutated into a recessive *l* allele to produce the Angora. The mating of two Angora rabbits always produces Angora offspring. Two rabbits with normal hair can sometimes produce a fraction of

Angora progeny if they are *Ll* heterozygotes.

- Rex. This is a recessive autosomal mutation that causes almost all of the guard hair to disappear. The coat looks different with shorter hair. The symbol for the Rex gene is *r,* and for the dominant wild allele *R.*

- Hairlessness. This is caused by several recessive mutations and is usually lethal.

The genotype of the coat colour and structure in rabbit breeds can be predicted when these loci are known. So far not much gene interaction visibly affecting body colour and breeding characters has been found, but there has been very little research in this area. The Angora and Rex genes are of course exploited to produce angora wool and Rex fur.

Groups of breeds by adult size and origin

There are different kinds of breeds:

- primitive or primary, and geographic, from which all other breeds have come;

- breeds obtained through artificial selection from the above, such as Fauve de Bourgogne, New Zealand White and Red and Argenté de Champagne;

- synthetic breeds obtained by planned crosses of several breeds, such as Blanc du Bouscat and Californian;

- Mendelian breeds, obtained by the fixation of a new character of simple genetic determination, appear by mutation, such as Castorrex, Satin and Japanese.

Breeds are conveniently grouped by adult size, which is also related to production characteristics such as precocity, prolificacy, growth rate and age at maturity. A major determinant of adult size is the origin of the breed.

Heavy breeds*.* Adult weight exceeds 5 kg. Fertility is generally low. The growth potential of the heavy breeds can be exploited, especially in cross-breeding. The Bouscat Giant White, (French) Belier, Flemish Giant and French Giant Papillon are examples. The fur of the (French) Belier varies greatly in colour and can be white, agouti, iron grey or black. Its body build would make it a good meat rabbit. However, it is bred for show and therefore found only in small units, at least in France. The breed is more important in other European countries such as Germany and Denmark.

The Bouscat Giant White is a synthetic albino breed. It is a large rabbit known for its prolificacy and fast growth rate in traditional French rabbitries. The Flemish Giant from Belgium comes in several colours. It is one of the largest rabbits (potential adult weight 7 kg) and is still farm-raised. This breed could furnish a gene pool for improving growth in other breeds; Flemish Giants could be pure-bred for this purpose.

Average breeds. Adult weight varies from 3.5 to 4.5 kg. These are the basic stock of breeds used for intensive rabbit production for meat in western Europe and are the most numerous. Only a few examples are described here.

Silver rabbits are found in several countries (English Silver, German Silver). These varieties differ from the Argenté de Champagne in adult size (English Silver is lighter) and colour. Like Fauve de Bourgogne, Argenté de Champagne is an example of a breed that has developed with selection over many years from a regional population (Champagne). The breed is known for both its fur, once much sought after, and its productivity: high fertility, quick growth, good muscle development and good meat quality. Its adult weight is 4 to 4.5 kg. It is farm-bred in France, usually on straw litter. Research has begun on intensive breeding of Argenté de Champagne.

The Fauve de Bourgogne is also of regional origin. It has spread throughout France and elsewhere in Europe (Italy, Belgium, Switzerland). The Fauve de Bourgogne Rabbit Breeders' Association has established a stud book for this breed, ensuring pure-bred selection.

The New Zealand Red was first exploited in California with a selection system similar to that used in France on the Fauve de

Bourgogne, with the difference that the New Zealand breed was raised on wire-mesh floors which were introduced much earlier in the United States than in France.

The Californian is a synthetic American breed. It was presented for the first time in 1928 in California by its breeder, whose objective was a meat animal with very good fur. The adult weight of the Californian is 3.6 to 4 kg.

The New Zealand White originated as a breed in the United States. It is the albino offspring of coloured rabbits. From the outset it was bred selectively in large meat-production units, especially in southern California (San Diego area), for its breeding qualities: prolificacy, maternal performance, fast growth rate and precocious body development which makes it ready for slaughter at 56 days, the objective being a light carcass. The New Zealand White adult weight (4 kg) slightly exceeds that of the Californian. The New Zealand White was used in the first studies on the rabbit at the Fontana Station in California. Since 1960 this breed has spread through Western Europe and other regions with the growing use of mesh floors for rabbit cages.

The Large Chinchilla rabbit raised in Europe is of German origin. Its adult weight averages 4.5 kg. It can be bred for meat and fur.

Lightweight breeds. These breeds have an adult weight of 2.5 to 3 kg. They include the Small Himalayan, the Small Chinchilla, the Dutch and the French Havana.

The Russian or Himalayan rabbit is white with black extremities. It is thought to have originated in China and spread from there to Russia and Poland. It carries the Himalayan C^h gene mutation.

The lightweight breeds usually develop very quickly and make excellent mothers. They eat less than the medium and large breeds and could be crossed or used pure in developing countries to produce a light, meaty carcass of 1 to 1.2 kg.

Small breeds. These breeds weigh about 1 kg at maturity. They are represented chiefly by the Polish rabbit, with its many variations of coat colour. Selection for small size has led to very low fertility and a marked decrease in growth rate. These breeds cannot be used for meat production. They are bred for show, for the laboratory and as pets.

Local populations and strains

Pure-bred animals are usually raised in small groups and their selection for breeding characters is in its infancy. These breeds could therefore constitute interesting potential gene pools for improving local populations.

Most rabbits raised for commercial meat production belong to populations which may resemble one breed or another (a question of appearance only, as they do not meet the criteria for that particular breed in terms of origin and standards) and sometimes resemble no breed at all. These are "common" rabbits, grey, spotted or white, the outcome of various unplanned crosses. They may belong to local populations. Some examples of local populations in developing countries are the Baladi rabbit of the Sudan *(baladi* means native or local in Arabic), the Maltese rabbit of Tunisia and the Creole rabbit of Guadeloupe. Developing countries planning to develop rabbit production should first identify existing local populations and establish their biological and breeding traits and adaptability before designing selection programmes and improved production systems.

Many countries where rabbit production is recent, dating back only a few decades, have no clearly defined local populations. The populations are highly polymorphic and come from a great many unplanned crosses with imported pure-bred animals. Often these populations are of limited potential and not locally adapted. Even so, they should be studied before deciding to eliminate them.

Finally, there are rabbit strains. The strain is a genetically closed group, small in number, with no outbreeding for several generations. Characteristics of a strain are the number of breeding animals, the year and way the group was constituted, and possibly the mating programme (selection or no selection). These strains can be found in research laboratories which keep them to study their biological and breeding characteristics in order to make the best use of them in selection. The INRA centre in Toulouse conducts selection experiments on strains (Table 28).

Private breeders have fairly recently begun selecting rabbit strains, along the lines of the poultry selection that has been practised since 1930. But some breeders or small groups of breeders, at village level for instance, may also have created strains without realizing it.

Some research laboratories, such as the Jackson Laboratory at Bar Harbor, Maine, United States, keep inbred rabbit strains or lines for use solely as laboratory animals.

Breeders in traditional rabbit-breeding regions use local populations. The genetic patrimony of the population is shaped by the ecology of the region, the characteristic production system and breeders' interventions. Slowly, the population evolves. Barring specific instances, the population is open to bordering populations. This slows the trend towards uniformity and offers new genetic variability for natural and/or artificial selection.

The next stage of evolution is the breed. Here the breeder is more important and defines a standard and looks for animals which conform to it. The ecology of the region and the characteristic production system is less influential than for populations and breeds are usually more homogenous. Selection for confirmation to a standard can lead to excesses. Breeders may be looking only for external characters, neglecting production characters. They may breed close relatives to increase the visual impression of homogeneity. The last evolutionary stage is the strain. There are fewer founders (a few dozen for each sex) and few genes are exchanged with neighbouring populations. A strain is usually artificially selected for a few traits. Strains are often more genetically homogenous than breeds.

Breeding characters

The expression of breeding characters depends on environment and the breeder. A comparison of results from several different environments and geographical locations can reveal general characteristics of the breeds or species. Fecundity, growth rate and tissue development in young rabbits are three sets of basic breeding characters.

Fecundity. Fecundity is defined as the product of fertility (number of kindlings per doe per unit of time) and prolificacy (number of young per kindling).

Prolificacy varies significantly according to several factors which may be inherent in the animal. Litter size increases by 10 to 20 percent from the first to the second litter and then again, but by less, from the second to the third, with no change from the third to the fourth. After the fourth the size may decrease. Inbreeding may reduce prolificacy.

TABLE 28 Characteristics of selected INRA experimental strains

Strain and origin	Selection criteria	Selection methods	Population size	No. of generations
1077	Litter size	Index	33 males	18

	at weaning			
New Zealand White			121 females	
9077	Field strain		22 males	12
Same origin as 1077			44 females	
2066	Litter size at birth	Index	24 males	18
Californian and Large Himalayan			64 females	

Prolificacy also depends on the season and the reproductive rate imposed on the doe. In healthy does receiving normal feed and 12 to 14 hours of light, prolificacy seems to be linked to adult size.

Ovulation potential increases, on average, with size. The first factor affecting prolificacy is the ovulation rate (number of eggs) followed by the viability of blastocysts and embryos before birth.

In 1932, Gregory showed that litter size depends on the number of eggs produced after mating and this number depends on the body size of the breed: 3.97 for Polish does and 12.88 for Flemish Giant. The corresponding litter sizes at birth are 3.24 and 10.17. Small light breeds are generally less prolific than medium and large breeds. Elamin (1978) gives the following average figures from the Sudan for the Baladi, Californian and New Zealand White breeds:

	Baladi	**Californian**	**New Zealand White**
Total litter size	4.7	7.10	7.49
Live births per litter	3.5	6.67	6.94

Matheron and Dolet (1986) analyse the results from 682 females in ten rabbitries in Guadeloupe. Their first category is small-size Creole females. These are hard to find and so breeders buy them in France and cross-breed them many times. They then distinguish between New Zealand White and "other" females on which more specific data are lacking. In these complex crosses, breeders have used Argenté de Champagne, Fauve de Bourgogne, Bouscat White, Papillon, etc. in addition to the above two strains. Table 29 shows that New Zealand females are more fertile and more prolific. This is a confirmation of the high adaptability of this breed to local conditions of high temperatures and humidity. Birth-to-weaning mortality is still high, indicating a need for further progress. Creole females are less prolific but more viable than the "other" females. The difference of -0.78 at birth is only -0.12 at weaning. The poor birth-to-weaning viability of young from "other" females is surprising. The literature indicates that these half-breed females often benefit from the effect of heterosis and complementarity, but the performance here shows that this is not always the case. It is also possible that the choice of breeds and crosses was poor.

Paez Campos *et al.* (1980) give the breeding parameters of New Zealand White, Californian, Chinchilla and Rex breeds raised at the National Rabbit Breeding Centre at Irapuato in Mexico, a tropical zone tempered by the 1 800 m altitude (Table 30).

TABLE 29 Performance of females of three genetic types in Guadeloupe rabbitries

Litter size	**Breeds**					**Mortality (%)**		
	Number	**Pregnancy rate *(%)***	**Total births**	**Total live births**	**Weaned**	**Birth**	**Birth-to-weaning**	**Total**
Others	2159	75	7.33	6.72	4.54	8	32	38
Creole	78	71	6.55	6.21	4.42	5	29	32
New Zealand White	291	80	7.44	6.71	5.14	10	23	31
Total	2528	76	7.32	6.70	4.60	8	31	37
Significance of the breed effect		**	NS	NS	*	NS	**	**
Standard deviation			2.78	2.86	3.00			

Source: Matheron and Dolet, 1986.

TABLE 30 Average breeding parameters of four breeds raised at the Irapuato National Rabbit Breeding Centre, Mexico

Strains	Litter size	Live births per litter	Rabbits weaned per litter	Age at first mating (days)	Weight at first mating (kg)	Number of litters examined	Number of does
New Zealand	8.5	8.0	6.5	1.44	3.49	3723	600
Californian	8.0	7.2	5.8	140	3.50	1090	200
Chinchilla	8.7	8.1	6.0	132	3.39	562	140
Rex	6.8	6.3	5.1	153	3.02	554	120

TABLE 31 Litter size observations in Cuba for four rabbit breeds

	Total births per	Total live births per

	litter	**litter**
Semi-giant White	9.3	8.2
Californian	7.8	6.6
New Zealand White	7.0	6.2
Chinchilla	7.6	6.4

Source: Ponce de Léon, 1977.

Ponce de Léon (1977) obtained the results in Table 31 from four breeds researched in Cuba, in a wet tropical climate. The characters of these breeds and this rabbitry are defined in greater detail further on in the chapter. The high rate of stillbirths (11.6 percent) is explained by rearing conditions in the rabbitry.

The development of technical and economic management systems in France and Spain provides series of results describing performance trends in rabbit production units. For the sample regularly followed in France by the *Institut technique de* *l'aviculture,* litter size (number of live births) rose from 7.2 in 1974 to 7.8 in 1986, reaching 8.6 in 1992.

Table 32 summarizes other findings comparing breeds reared under rural or southern country conditions. The numerous European and United States comparisons of medium-sized breeds such as New Zealand White and Californian rabbits, for which Rochambeau's (1988) summary might be consulted, have been deliberately omitted. The table stresses the importance of studies in India and Egypt. Regrettably, there are few studies on local populations. The New Zealand White and Californian rabbits are used by many authors, but they are very different strains. Since most authors rarely specify the origin of their animals, it is difficult to compare them and these various populations of white rabbits may well have only the phenotype of colouring in common. This table also shows the importance of specific "giant" populations found in India and Egypt, but without knowing the adult size of these populations it is impossible to know whether they really belong to giant breeds. Other populations such as the Russian Chinchilla or the Sandy also deserve attention.

Biological components of prolificacy. The description of biological traits in local populations and breeds provides useful pointers for better utilization strategies. The procedure is to count the numbers of corpus luteum to estimate the rate of ovulation. The number of implantation sites and the number of living and dead embryos are then counted to determine embryo viability. Litter size at birth completes the estimation of foetal viability. Observing the female tractus after embryo implantation (seven days after kindling and before the 15th day of pregnancy), both the rate of ovulation and embryo viability can be estimated. The simplest method is laparotomy, to observe the ovaries and uterus. As this usually requires slaughter of the doe, the technique of choice today is the laparoscopy. The effect on the doe is considerably reduced by the use of an endoscope which allows a normal productive life after the operation, and several observations on the same female. Tables 33 and 34 show that strains differ. The way the strains are classified varies between ovulation and birth, i.e. strain 2066 is penalized by poor pre-implantation viability (Table 33).

Weight gain and anatomical composition. The growth rates of young rabbits are strongly correlated with adult size and weight where there has been no marked dietary deficiency. Table 35 gives average weights of young rabbits at successive ages, from 28 to 78 days, as well as carcass weights at 78 days, for the Small Himalayan and New Zealand White. The table clearly shows the growth rate of young Small Himalayan rabbits (adult weight 2.5 kg) to be slower than that of the New Zealand White breed (adult weight 4 kg). Moreover, at 78 days the New Zealand White is more mature than the Small Himalayan, when its live weight is 63 percent of adult weight against 59 percent for the Small Himalayan. The variation coefficients, the ratio of the standard phenotype deviation from the mean, are typical of the intrabreed variability of these characters for a given feeding system. Variability is greater in young New Zealand White rabbits than in Small Himalayan. Medium breeds slaughtered at the same age also vary in growth performance and carcass composition. Table 36 gives data for young Fauve de Bourgogne, Argenté de Champagne and Large Himalayan rabbits slaughtered at 84 days. Argenté de Champagne has excellent growth, muscle tissue and fat development for meat production. Fauve de Bourgogne is a close second.

TABLE 32 Summary of selected breed comparisons for individual weight at weaning, individual weight at x weeks, litter size at birth and at weaning

TABLE 33 Litter size components in three experimental INRA strains

	Strain		
	2066	**1077**	**9077**
Ovulation rate	14.5	13.8	13.0
Number of embryos implanted	11.1	12.0	11.0
Number of live embryos at 15 days	9.8	10,4	9.7
Number of live + dead young at birth	8.0	8.2	8.4

Source: Bolet *at al.*, 1990.

TABLE 34 Litter size components in a sample of 233 V-strain females at the University of Valencia

	Average	**Standard deviation**
Ovulation rate	15.0	2.1
Number of embryos implanted	12.9	2.6
Number of live embryos at 12 days	12.6	2.6
Number of live + dead young at birth	10.0	2.8

Source: Santagreu, 1992.

Weight gain and the growth rate of the main tissues depend on the breed's biological characteristics and on production factors such as feeding. So the criterion for describing a breed in a particular production environment should probably be maturity in terms of weight, defined as weight at a given age divided by adult weight.

The most interesting breeds from the production point of view are those with the best ratio of weight gain to adult weight, which arrive early at the proper live weight for market. Lightweight breeds could be utilized as pure-breds or, better, crossed with medium-weight breeds for a light carcass with good muscle development and quality meat (sufficient fat) where there is consumer demand.

Genetics of breeding characters

The genetic improvement of breeding characters relevant to the production environment depends on the specific genetic variability expressed in that environment. This variability is expressed in animals of the same breed or local population as well as in different breeds and populations and in interpopulation crosses. Variability is an expression of genetic differences which selection and crossing try to exploit.

The question here is how genetic variability can be exploited in small-scale production, preferably using local resources. Upgrading the potential of a species depends on its biological characteristics, mastery of its reproduction and calculating the genetic parameters for selection.

Biological characters

Controlled breeding. One breeding operation requiring much care and time on the breeder's part is to get the first and successive litters from the doe. In cage breeding the doe should be serviced in the buck's cage. Once sexually mature the doe can theoretically be presented to the buck at any time except during gestation, but in practice she does not always accept the male. Acceptance of the male and subsequent mating produce litters only 70 percent of the time. This figure varies with physiological conditions, season, breed and environment. Figure 17 summarizes the respective genetic roles of the buck and the doe in litter size at weaning.

TABLE 35 Variability in weights of young rabbits from 28 to 78 days, and carcass weights, for two breeds

	Small Himalayan		**New Zealand White**	
	x	**v (%)**	**x**	**v (%)**
Age *(days)*	Live weight *(g)*			
28	428	8	599	26

31	485	12	761	16
38	582	8	1013	14
45	770	9	1248	13
52	933	9	1568	15
59	1105	10	1860	14
66	1245	10	2066	11
73	1387	10	2300	10
78	1476	10	2503	10
	Carcass weight *(g)*			
78	911	9	1364	7

Note: Animals bred at INRA (Toulouse Centre). Rational production; weaning at 28 days. Carcasses with head and paws. x = average; v = variation coefficient.

TABLE 36 Average live weight at 84 days, carcass weight, muscle weight/bone weight ratio, weight of fatty tissue in

carcass, for three breeds

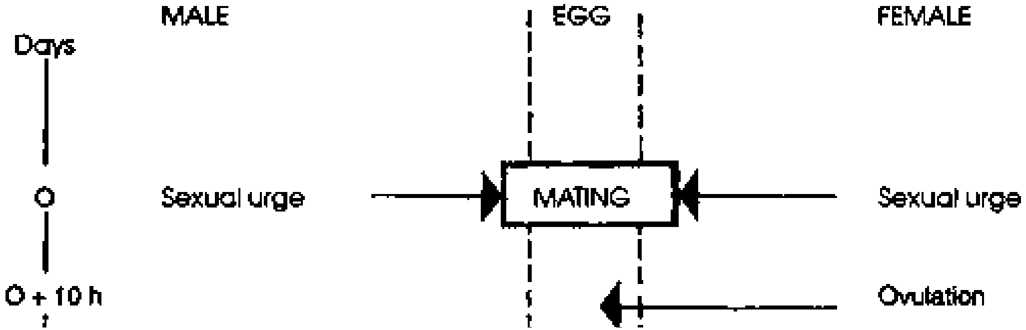
	Fauve de Bourgogne	Argenté de Champagne	Large Himalayan
Live weight at 84 days *(g)*	2143	2460	2055
Carcass weight *(g)*	1305	1588	1287
Muscle weight/bone weight ratio *(%)*	4.3	4.5	4.0
Weight of fatty tissue in carcass *(g)*	86	107	73

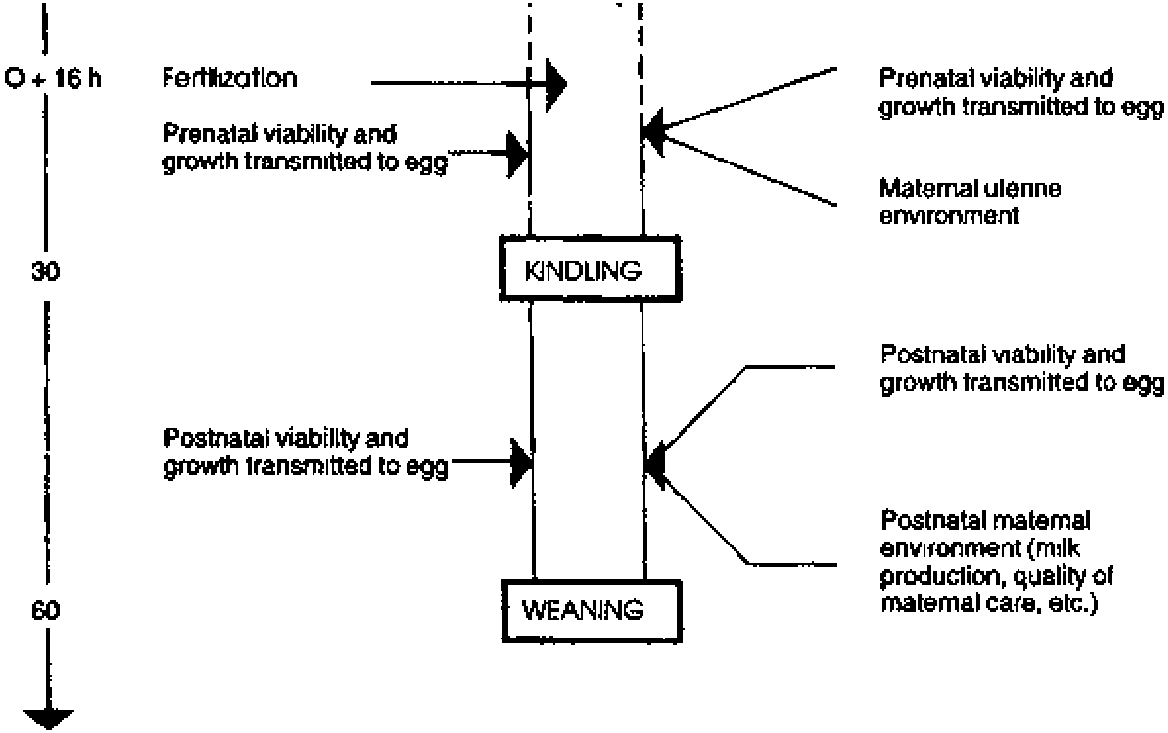
Source: Rouvier, 1970.

The breeder is dependent on the sexual urges of the buck and doe for the first essential step, mating. Little is known about the biological basis of rabbit sexuality. The urge drops with high temperatures (28° to 30°C). In the hot season the doe must be presented to the buck early in the morning, from 0600 onwards, when the sexual urge is greatest.

Fertility is affected by ovulation, which depends on the doe and takes place ten hours after mating, and by fecundation of the egg, which depends on the buck and occurs 16 hours after mating. The genes of both the buck and the doe equally affect prenatal growth and the viability of the egg. Crossing can improve the viability of the egg, blastocyst and embryo. The doe has more influence in the uterine environment, notably on embryo nourishment. The buck therefore has an influence on litter size.

FIGURE 17 Respective genetic roles of male and female rabbits in determining litter size at weaning





Source: Matheron and Mauléon, 1979.

Doe prolificacy is a breed characteristic, but with substantial individual variations (one to 18 young per litter). Once the doe has kindled, the litter must be safely raised to weaning. The breeder affects litter size at weaning by protecting the young and by the feed provided for the nursing doe. The viability of the baby rabbits, maternal behaviour and milk production are also important. Kindling-weaning viability in the litter depends on the number of live births, which varies from breed to breed, as shown in Table 37.

This viability remains fairly constant for the number of live births in litters of three to nine. Small litters (one or two live births) do not offer a favourable environment for the survival of the young. Live young at weaning peak at 8.60 for litters of 12 or more. This suggests practical rules for fostering to increase the total production of young rabbits weaned. The fostered rabbits may come from small (one or two), or more commonly from large (over ten) litters. However, fostering implies both a sufficient number of does in the rabbitry and the breeder's familiarity with their maternal behaviour. After birth and once the young rabbit has suckled, it can be separated from the mother for 24 hours, allowing for easy travel and transfer to a foster mother.

TABLE 37 Birth-weaning viability of young rabbits by litter size at birth

No. Of litters	No. of live births per litter	No. weaned per litter	Birth-weaning viability (%)
171	1	0.35	35
321	2	1.37	68
487	3	2.43	81
634	4	3.23	81
1035	5	4.06	81
1784	6	5.05	84
2741	7	5.80	83
3837	8	6.68	83
3753	9	7.34	82
2857	10	7.82	78
1343	11	8.21	75
676	12	8.57	71

221	13	8.59	66
63	14	8.60	61
Average	8.01	6.41	80

Note: Data from a rational rabbit production unit in the Midi-Pyrénées region of France.
Source: Roustan, Matheron and Duzert, 1980.

The biological characteristics of the female rabbit- ovulation induced by mating, acceptance of the male from the day of kindling, no lactation anoestrus, no marked seasonal anoestrus - are such as to afford a wide range of theoretical reproduction rates. As an example, Table 38 compares three different rates of reproduction at a commercial rabbit breeding centre in Mexico.

Both does and bucks have a very high reproduction potential, as confirmed by the latest research. Potential reproduction per doe per year can be evaluated at 150 young. Achieving this, however, will require many more years of research as well as the mastery of environmental factors. For breeding in developing countries it is best at present to aim at using local populations and longer reproductive periods. The best technique is to start by upgrading traditional production techniques and (where they exist) local populations.

Tissue growth. *As* demonstrated by Cantier *et al.* (1969), bone tissue in rabbits develops first, followed by muscle and then fat. In a population of common rabbits of average adult weight (4 kg) the skeleton develops rapidly up to a live weight of 900 g. Growth then continues more slowly up to 4 kg. Muscle tissue gains very quickly in weight up to a live weight of 2.3 to 2.6 kg, when the curve falls abruptly. Adipose tissue develops at a fast rate after 2.1 kg. To allow for the differences in the speed of overall weight gain due to breed or feeding, rabbits should be slaughtered at 50 to 60 percent of the normal adult weight for their breed or population. This is the right stage for the best anatomical composition of the carcass and the most efficient utilization of feed.

TABLE 38 Comparison of three reproduction rates

Breeding characteristics	**Rates**		
	1	**2**	**3**
Breeding does	75	75	75
Age at weaning *(days)*	28	35	42
Presentation of doe to buck after kindling *(days)*	3	10	17
Rate of acceptance of male *(%)*	85	84	87
Gestation rate *(%)*	61	84	87
Theoretical number of litters/doe/year	9.0	8.0	6.95
Estimate of litters/mother-cage/year	7.9	7.5	6.6
Number born per litter	7.6	7.6	7.7
Live births per litter	6.8	6.9	7.0
Number weaned per litter	5.7	5.9	5,8
Average weight at weaning *(g)*	520	760	990

Source: Irapuato National Rabbit Breeding Centre, Mexico.

Poor feed slows down overall weight gain and lowers conversion efficiency - the amount of feed necessary to produce a 1 kg weight gain. This might not be a drawback in a breeding system using local resources for feeding the growing rabbits, but the fastest growing animals in a population have the best carcass composition (muscle/bone ratio, fat percentage) at slaughter age or weight. Young rabbit meat is naturally lean; there is no excess fat. The best slaughter age and weight must be worked out in terms of market demand, the production system and the type of feed used.

Genes and the environment

Most quantitative breeding characters - fertility, viability, growth, etc. - are poly-genetically determined, but they are also subject to the effects of the environment. Phenotype is the outcome of the impact of genotype and environment on a character. The genotype is the outcome of the effects of genes at several loci. The environment is made up of a number of components: climate, habitat, the animals' microclimate, temperature, humidity, air speed, rabbitry equipment, breeding techniques and feeding practices, and the human factor-the breeder. The genetic determination of character variations is of dual interest to the selector and breeder: first, to exploit the genetic variability of animals of the same breed or population; and second, by crossing, to exploit the genetic variability between breeds and populations.

Individual genotypic values are not directly observable, only performance (phenotypes) can be measured. The conventional model of quantitative genetics assumes phenotypic value to be the sum of genetic value and environmental factors. This model assumes genotype and environment to be independent. According to this model, genetic value is partly the result of additive genetic value and partly of gene interaction on the same locus (dominance) or different loci (epistasis). Using a regression coefficient, the additive genetic value of an individual is estimated for the performance of this individual and its relatives. A selection programme tries to create genetic progress, i.e. to increase the average additive genetic value of the population.

TABLE 39 Allometric coefficients of the main organs and

tissues and indication of critical body weights (less digestive content) observed in male rabbits

Heritability and genetic correlations. The amount of genetic progress depends primarily on how much of the variance is of additive genetic origin. This coefficient is called heritability and it is calculated as the ratio of additive genetic variance to total variance. Heritability therefore varies from zero to one. Heritability is also the regression coefficient of an individual's additive genetic value over his/her own performance. Heritability varies with the character, the population studied and environment. It particularly varies with gene frequencies and thus changes in a selected population.

Figure 18 shows the heritability of the principal characters of interest to breeders. Heritability is read clockwise from the left. Female fertility is near zero in terms of heritability. Then, moving clockwise, heritability increases. The heritability of litter size is about 0.10. The highest heritability is for weight at a standard age (0.2 to 0.3) and this increases as the animal grows and maternal influence wanes. Postweaning growth rate and feed efficiency in collective cages are between 0.3 and 0.4. Above 0.4 lie characters such as carcass weight, muscle/bone ratio, intake in a group cage and slaughter yield.

FIGURE 18 Heritability and genetic correlation of production characters in rabbits

These estimates are relative: the problem of estimating a variance ratio with the available data is compounded by variations of heritability in place and time. Rochambeau's 1988 review is an instructive illustration of this: heritability for the number of live-born young varies from 0.0 to 0.4 when the upper quarter and lower quarter estimates are removed. The variation for individual weight at 14 weeks is 0.2 and 0.8 under the same conditions.

Genetic variability among breeds and populations. Local breeds or populations could be compared with improved breeds in other countries and under different production systems. Breed differences are primarily exploited through cross-breeding. Interbreed comparisons in rabbitries are therefore very useful.

Local breeds and populations can be compared with improved breeds in other countries and breeds produced in different conditions. Interbreed differences are basically exploited through crosses. Not all crosses are advantageous, however; they must be tested. The main advantages of cross-breeding are heterosis and interbreed nicking ability.

Heterosis may be defined as better breeding performances of crossed animals than that obtainable with the average of the two pure parent breeds. Heterosis may apply to the young rabbit (its viability, for example), the crossed doe (fertility, milk production) or the crossed buck (vigour, sexual urge, fertility). Characters subject to dominance, such as reproduction characters, are those most likely to benefit from heterosis.

Heterosis may occur where the populations crossed differ genetically, which is not always revealed by a phenotypic study of the pure breeds or populations. The crossed animals are always more heterotic than the animals of the two parent populations and this implies greater adaptability to variable and difficult environmental conditions. Crossing can therefore be useful in improving rabbit breeding in developing countries, but crossing trials must be planned. Where local populations exist their use is recommended.

Cross-breeding makes possible the optimum use of the nicking ability of the breeds or populations crossed. Nicking ability concerns the two groups of characters from the mother and her young which contribute to the quantity of rabbit meat produced by the doe. In cross-breeding this ability is aimed at bringing together either the overall characters relative to the mother and the offspring, or a favourable combination of additive effects on the components of an overall character.

In the first instance, bucks of a breed with high growth potential are crossed with does of another breed or population that exhibit good prolificacy, maternal performance and tolerance of the production environment. The second instance concerns traits making up an overall character. Thus, ovulation rate and egg and embryo viability are components of litter size at birth (prolificacy).

Prolificacy and birth-weaning viability are components of litter size at weaning. Crosses can therefore be sought which combine a high ovulation rate and strong embryo viability in the crossed doe. These characters may well be antagonistic on an intrapopulation basis.

The effects of heterosis and nicking ability are not systematic. Crossing programmes are needed to bring out these effects clearly. Let us consider population *A* and population *B.* It is recommended that two pure-bred *(A × A)* and (B × B) be compared with two reciprocal crosses *(A × B*) and (*B × A),* to highlight the effects of the maternal and grandmaternal generations.

As an intuitive illustration of the maternal effect, let us assume that breed *A* has an adult weight of 6 kg and breed B an adult weight of 3 kg. We cross an *A* male with a B female and a B male with an *A* female, and compare the weight of the young at weaning. The young *AB* rabbits have the same genetic heritage on average as the young *BA* rabbits, as they share half of the paternal and half of the maternal genes. The young have a different maternal environment, however: *A* females have a larger uterus and produce more milk so the young weigh more at weaning. Thus, even with the same genetic heritage, *BA* rabbits are heavier at weaning than *AB* rabbits because of the favourable maternal effect. A more precise definition is given in Matheron and Mauléon (1979). It is recommended that two successive generations of crosses be studied to bring out the direct effect of heterosis on rabbit characters and on the maternal effects, as expressed in the female characters. The first generation includes crosses *(A × A), (B × B*), *(A × B*) and (*B × A);* the second consists of mating pure *AA* and *BB* females and half-breed *AB* and *BA* females with, for example, males of a third C strain. If more than two populations are studied, the number of genotypes to compare at the second generation increases with the square of the number of populations.

One example is provided by an INRA experiment at the Toulouse Centre in 1987 to 1989. This three-stage experiment used strains 1077, 9077 and 2066, as shown in Table 28. The first stage involves a factorial mating between males and females of three strains: males of each genotype (1077, 9077 and 2066) are crossed with females of each genotype (1077, 9077 and 2066) to obtain litters with nine genotypes (three pure and six cross-bred). At stage two, females from these nine genotypes were mated with males of three pure genotypes. At the last stage, the same females were mated with males belonging to two strains of terminal crossing of different origin. The first three litters of the female were checked at each stage. The females were then slaughtered during their fourth pregnancy and litter size components studied.

Table 40 compares the performances of pure and cross-bred females. Cross-bred females were superior on the whole, the number rising from ovulation to weaning at a rate of one to 13 percent. There are also differences between the pure strains and cross-bred females. The following analyses attempt to explain these differences for further use. 2066 females have a better ovulation rate but this advantage disappears at the next stage. The performances of 2066 and 1077 are fairly close. The 9077 strain performs less well.

Cross-bred genotypes with 2066 genes also have a higher ovulation rate: an advantage maintained up to weaning, where the genotypes 2066 × 1077 and 1077 × 2066 confirm their superiority. Litter size is considerably increased by the use of cross-bred females.

Table 41 analyses the same findings in terms of genetic effect. For direct genetic effect, 2066 has a negative effect on the number of implantation sites and 9077 has a positive impact on litter size at birth. The maternal effect of 9077 on the number of implantation sites contrasts with the positive effect of 1077 on litter size at weaning. While the effect of direct heterosis is weak, maternal heterosis has a major effect on the number of implantation sites and is maintained until weaning, achieving 16 percent for 1077 and 2066.

The results of crossing experiments, of particular interest in selecting an optimum animal utilization strategy, are specific to the animal population studied and cannot be generalized for all animals in a breed. However, they can describe local populations or strains, thus selecting the best way to use them in cross-breeding or pure-breeding.

Cross-breeding in tropical countries. The biological bases for superior crosses should be sought among the available animal populations bred in various environments. Several large-scale studies of interbreed crosses in tropical countries have been made: there follows one from Cuba, and then a synthesis of experimental work in Egypt.

These studies were made on animals from imported acclimatized breeds, not on local rabbit populations. Meat production was improved by using the best crosses. In 1969 to 1971 the Cuban *Instituto de Ciencia Animal* crossed four breeds on a rotational basis: Semi-giant White, Californian, New Zealand White and Chinchilla. The characters analysed were litter size at birth and weaning, and litter weight at weaning. The experiment was conducted during the dry season (November to April, mean temperature 22.2°C, humidity 75.2 percent) and the rainy season (mean temperature 26.1°C, humidity 77.7 percent). Some of the experimental animals from these four breeds had recently been imported from Canada, others had been in Cuba for some time. Adult weights are given in Table 42.

TABLE 40 Average female performance in nine genotypes: litter size components measured at different stages

Female genotypes*	Number of corpus luteum	Number of implantation sites	Litter size at birth	Litter size at weaning
9077 × 9077	13.0	11.0	7.8	6.9
2066 × 2066	14.5	11,1	8.5	7.2
1077 × 1077	13.8	12.0	8.6	7.5
Average	13.8	11.4	8.6	7.5
2066 × 1077	15.2	13.4	9.9	8.7

1077 × 2066	15.3	13.1	9.9	8.8
1077 × 9077	12.4	10.9	8.5	7.4
9077 × 1077	12.7	11.0	8.8	7.8
9077 × 2066	13.5	11.9	8.7	7.9
2066 × 9077	15.0	12.5	9.4	8.3
Average	14.0 (+1%)	12.1 (+6%)	9.2 (+11%)	8.1 (+13%)

* Paternal genotype followed by maternal.
Source: Brun, Bolet and Ouhayoun, 1992.

TABLE 41 Genetic parameters of litter size measured at different stages between ovulation and weaning

Parameters	**Genotypes**	**Implantation sites**	**Litter size at birth**	**Litter size at weaning**
Direct genetic effects	9077	0.8	0.4	0.3
	2066	-1.2	-0.4	-0.2
	1077	0.4	0.0	-0.1
Maternal effects	9077	-0.9	-0.8	-0.4
	2066	0.5	0.5	0.0
	1077	0.4	0.3	0.4
Direct heterosis	2066 × 1077	3	5	0
	1077 × 9077	-1	1	0
	9077 × 2066	-1	3	6
Maternal heterosis	2066 × 1077	15	15	16
	1077 × 9077	-4	7	7

	9077 × 2066	10	9	15

Source: Brun, Bolet and Ouhayoun, 1992.

The animals were raised in hutches identical to those used for rabbit breeding in southern California. These are wire cages with wooden nesting boxes arranged in single decks in two rows, in a roofed building open on all four sides. This habitat protects the rabbits from direct sun but in a wet tropical climate cannot protect against rain and wind, which explains the high mortality rate of the rabbits before weaning.

An extensive system of reproduction was used, with weaning at 45 days, followed by mating. The average figures on litter size show a normal prolificacy for breeds of this adult size (7.45 total births per litter); slightly higher than normal stillbirth rate (over 10 percent); and, above all, a high birth-to-weaning mortality (2.5 rabbits weaned per litter). This was caused by inadequate protection of the nests from wind and rain and inadequate feeding of the lactating does. It is interesting to know the positive contribution of cross-breeding in such difficult production conditions.

A comparison among the pure breeds revealed that the Semi-giant White loses fewer young between kindling and weaning than the others, and the weaning weight is better. For simple crosses the highest averages for number of young weaned and lowest total rabbit mortality figures were recorded by New Zealand White × Semi-giant White. Numerical productivity can also be increased by crossing the female progeny of this cross with Californian males. The most productive cross is Semi-giant White does × Chinchilla bucks.

Afifi and Khalil (1992) summarized the findings of nine Egyptian experiments published between 1971 and 1990. They compared pure and cross-bred animals from local or imported populations. There is a long list of breeds used: Bouscat, Chinchilla, Giza White, Baladi White, Red and Yellow, Grey Flemish Giant, White Flemish Giant, New Zealand White and Californian. The trial designs include many simple crosses but, unfortunately, few cross-bred females.

The authors of the summary conclude that local breeds (Giza White, Baladi) are superior for characters expressed before birth and the imported breeds (New Zealand White, Californian, Bouscat) better for postnatal characters. The review includes a great many estimations of the effects of direct heterosis, here summarized in Table 43. In these experimental environments, the direct effects of heterosis proved weak for the characters studied. Apart from an average value of 15 percent for litter weight at birth and 7 percent for litter size at weaning, all other values were below 5 percent. They are close to zero for individual weight at four and 12 weeks and for postweaning viability. The effects of maternal heterosis are stronger, even though the low number of experimental results does preclude a categorical statement.

Genetic improvement: Selection and crossing

France, Italy and Spain in southwestern Europe are developing genetic improvement programmes to meet the needs of intensive production in a temperate climate. Animals selected in Western Europe are not necessarily the best for small unit production (five to 60 does) in different production conditions. Local rabbit breeds and stock bred locally using various imported populations should be used for genetic improvement.

Efficient genetic improvement should be a group effort with scientific and technical support from the country's research and development organizations. The improvement programme could focus on a village (or preferably a group of villages), on all the rabbitries in a province, or on the whole country. Genetic improvement is a costly operation: the group needs to be big enough to bear the cost and to mobilize the necessary skills.

Genetic improvement demands technical specialization. There should therefore be breeder-selectors and breeder-users, perhaps with breeder-multipliers between the two. While the pyramidal schemes used in Western Europe are efficient in their special context, they are not universally applicable. It is up to the individual to conceptualize networks tailored to the sociospecifics of the country's breeders (although the networks must be genetically efficient). The selectors should also be excellent breeders, making use of production systems, feed resources, housing and other materials adapted to the environment. Sophisticated selection facilities should be avoided, as the objective is to match the best local systems. Health care and sanitation, in particular, must be exemplary.

TABLE 42 Adult live weight of four breeds in a Cuban cross-breeding experiment, 1969 to 1971

Breed	**Weight of females**	**Weight of males**
	(kg)	*(kg)*
Semi-giant White	4.05	3.95
Californian	4.05	3.87
New Zealand	3.80	3.90
Chinchilla	3.98	4.20

TABLE 43 Distribution of the effects of direct and maternal heterosis in a series of cross-breeding experiments in Egypt

A selection unit must be effective on two levels: breeding and production. The extra costs entailed in the technical side of the selection work should be borne by the group of breeders benefiting from the genetic improvement. The cost of research devoted to a genetic improvement programme for the whole country should be shared by a larger group. There are several conceivable types of organization. With French assistance, Mexico experimented with a pyramidal system (1976 to 1982) with a state-supervised national breeding station and regional multiplication stations. Development agencies distributed breeding animals to family-scale rabbitries.

Research and development agencies should focus on: first, the real efficiency of selection methods and creating new genetic material to improve rabbit production in the country; and second, the best strategies for utilizing local and exogenous animal populations, making breed comparison studies, doing cross-breeding experiments and testing strains.

The object of selection is to upgrade performance by enhancing an animal's genetic value where husbandry and feeding techniques permit expression of genetic value. In fact, breeding and feeding techniques must be improved at the same time as the genetic value. Selection and crossbreeding should increase the annual output per doe and speed the growth rate for earlier slaughter and better carcass and meat quality.

The definition of a selection trial design requires both the choice of a method and the review of its theoretical efficiency. The crossing is a supplementary benefit to intrapopulation selection. But genetic progress from cross-breeding is not cumulative from one generation to the next, as is progress from selection, except where selection is used to improve crossing. The following are examined below: selection methods, cross-breeding strategies and organizing genetic improvement.

Selection methods

Characters and criteria for selection. A major objective of selection is to improve annual fecundity per doe. This global character depends on the breeder, the animal and the environment. The breeder establishes the theoretical reproduction rate of the does. For backyard rabbitries, it is assumed that weaning takes place at 42 days, servicing at 24 days after kindling, and the average conception rate is 70 percent. This gives an average of six litters per doe per year.

A culled doe is immediately replaced by a young doe ready for mating. If the stock renewal rate is 100 percent per year, the annual numbers of litters per doe will be roughly 5.5. If an average six young per litter are weaned and 5.5 reach slaughter or reproduction age, the objective is then 30 rabbits per doe annually.

This modest goal is realistic for backyard rabbitries not based exclusively on pelleted feed. If necessary, the weaning age can be extended by delaying presentation of the doe for servicing beyond day 24. The theoretical reproduction rate can be stepped up if the goal is too easily achieved or too modest in terms of the potential of the stock and environment. The doe could be brought for servicing at day 17 after kindling with weaning at 35 or 42 days. This would give an additional litter per doe, raising the annual goal to 35 rabbits per doe. A more intensive breeding objective could produce 40 to 50. For many countries, however, this would not be a realistic goal.

Whatever reproduction rate is adopted, it is important to have fertile does which accept the buck and can produce many large litters with good kindling-to-weaning survival rates. This implies a whole range of characters: acceptance of the buck, gestation, fertility, viability of young, milk production and longevity. These characters and performances can be summed up by the selection criterion: average number of weaned per litter from the first three litters obtained within a predetermined period. There is a close correlation between performance during the first three litters and the doe's total output. In practice, the following principle could be followed:

- after the second litter, calculate the selection index of the doe based on the average young weaned per litter;

- divide this index by the number of days between the first kindling and the nth kindling (for index for *n* litters). This gives an index of numerical productivity;

- compare does with the same numbers of litters against this index.

As weaning age is variable, the number of rabbits weaned can be calculated on litter size at 28 days so the doe's genetic value can be estimated more rapidly.

Chapter 9 describes an even simpler system of choosing breeding stock, which can be done directly in the rabbitry.

The other group of characters for selection has to do with weight gain. One selection criterion is average daily weight gain from weaning to slaughter age, say at day 70. The difference between individual weight at day 70 and individual weight at weaning is divided by the number of days elapsed between these two dates. The idea is to speed up postweaning growth. There is no need to measure the quantity of feed consumed, except for experimental purposes or to compare genetic types for selection for feed utilization.

It is not easy to measure the quantity of feed or dry matter eaten by the animals, and when they are given different feeds and local forage feed conversion efficiency is difficult to calculate. Speeding up postweaning growth indirectly reduces the amount of dry matter needed for every kilogram of live-weight gain.

Slaughter yield, carcass quality (meat/bone ratio, fat) and organoleptic qualities of meat are complex characters to select for because they can only be measured in carefully controlled slaughter conditions. Direct intrapopulation selection for these characters would be unrealistic. Breeders can check sample figures for these characters for the population they are using and if improvement is necessary crosses can be made with bucks from good meat breeds (described earlier in this chapter).

Performance control and technical data management. With stock being used for selection it is necessary to:

- identify each breeding animal individually;
- measure the breeding characters needed for genetic and breeding management of the stock;

- record these characters for later exploitation.

All rabbits are identified at weaning when separated from the dam by a numbered ear tag or a number tattooed in the ear. This might be the date of birth plus a day-of-year identity number. Depending on the size of the group an individual number might have four or five digits (up to 999 or 9 999 births a year) or even six if necessary. Another number indicating genetic type (breed or cross) could be added to the animal's cage card.

Troop management involves three types of record card: doe, buck and litter. The buck and doe cards identify the breeding animal, its number, date of birth and the number of its sire and dam; next, the animal's cage, for easier identification within the production system; then the date and cull rate.

On doe cards (see Figure 45) record:

- servicing dates (day, month and year);
- identification number of servicing buck;

- result of pregnancy test by abdominal palpation;

- kindling date and litter: parity of doe, number of live and stillborn young (found living or dead at first examination of nest after kindling) and number added or subtracted from litter 36 hours after kindling;

- weaning dates, number weaned per litter and weaned litter weight;

On buck cards (see Figure 46) record:

- date of servicing;
- number of does serviced;
- outcome of abdominal palpation;
- number of live and stillborn young.

While the buck card repeats some of the doe card data, it is very useful for following the pregnancies and prolificacy of does mated to that buck.

A litter card shows:

- litter birth date, number of dam and sire, weaning date per litter and per individual offspring;
- the young rabbit's number, weaning weight, and the preslaughter weighing date and weight.

A "remarks" column on each card allows the breeder to add observations (e.g. animal's health). These cards are designed for manual or computer processing and are used for daily breeding management, genetic management and, perhaps, experimentation.

There are software programs for desktop computers which collect this data on a daily basis and edit the breeder's workplans (particularly for mating, palpations, kindling and weaning). These can calculate the various balance sheets of the enterprise.

Choosing a selection system. Having chosen selection objectives and criteria, the next thing is to determine the selection system that will maximize genetic progress. This is dependent on three parameters: selection intensity, selection precision and the intergeneration gap.

Selection intensity depends on the percentage of individuals retained. Assume, for example, that 100 rabbits are weighed and ten chosen to breed. The rest are slaughtered and so the percentage is equal to 10 percent.

Selection precision depends on the heritability of the character, the number of measurements and the degree of related-ness between the selection candidate and the rabbit measured. For instance, in selecting for litter size, recording the data for the three first litters, not just the first, makes for greater precision. In selecting for slaughter yield, on the other hand, precision diminishes if the rabbits measured are five fraternal half-siblings of the candidate and not five full siblings.

The generation interval is the age of the parents at the birth of their average progeny and it increases if females are chosen after the third litter instead of after the first. There is a conflict between trying to be more precise and trying to reduce the generation interval.

In the end, genetic progress depends on the additive genetic variance of the character, a parameter assumed here to be constant.

There are four selection methods:

- mass or individual selection: measured on the selection candidate;
- pedigree selection: measured on the candidate's ancestors (parents, grandparents, etc.);
- sibling selection: measuring the candidate's siblings (full and half-siblings, etc.);
- progeny selection: measuring the candidate's progeny (young, etc.).

Table 44 illustrates the advantages and drawbacks of each method with respect to the three parameters of genetic progress.

These four methods are complementary: pedigree selection provides an initial sifting of selection candidates when the geneologies and performances of the sire and dam are known.

This choice is not very exact however. Mass selection is the simplest and most efficient method and as such is the method of choice. Sibling selection is more complex, but is useful for greater precision when the character selected for is not easily heritable, such as litter size, or when the candidate has to be slaughtered in order to measure the character. Progeny selection is not much in use for rabbits as it considerably increases the generation interval and is very expensive.

Table 45 summarizes the findings of selection experiments on rabbits. It shows that selection is an effective way of increasing litter size and postweaning growth rate, although there is usually almost no progress in litter size. Successful selection depends on full control of rabbit breeding, the collection and management of geneological data and performance, and the selection cycle.

TABLE 44 Four selection techniques compared for effectiveness

	Mass	Pedigree	Sibling	Progeny

	selection	**selection**	**selection**	**selection**
Intensity	Average	High	Average	Low
Precision	Average	Low	High to average	High
Generation interval	Average	Low	Average	High

In practice, a synthesis of various theoretical studies suggests the following recommendations.

To improve litter size, the selection criterion is litter size at birth or weaning, measured on the first three litters. For greater precision without increasing the generation interval, the performances of the candidate's full sisters and half-sisters are taken into account. Renewal with the progeny of the female's second or third litter is the next step. Rearing the rabbits in separate generations, as described below, increases selection efficiency but the rabbitry has to be much bigger. It is pointless to attempt selection without the necessary resources.

For a better postweaning growth rate, the selection criterion should be the speed of growth after weaning. This criterion can be measured on both sexes and heritability is average. Simple mass selection is therefore the technique of choice. In order not to reduce the strain's aptitude for reproduction, breeding animals are chosen in litters with at least one shared character and at least four or five births.

A breeder who renews the herd on the basis of the best does for litter size will choose the young rabbits from the litters of these females which weigh the most at slaughter time. In any case, unhealthy young rabbits are culled prior to selection.

Renewal of pure-bred stock and mating programmes*.* Here there are different cases to consider: first, a rabbitry practising combined selection based on litter size; second, mass selection based on the same character for a sizeable number of breeding does in the strain (200); and third, smaller groups.

Case 1. *Selection of a strain on the basis of litter size at weaning (INRA, Toulouse). Combined selection, separate generations.* The theoretical plan calls for raising the stock in separate breeding groups, each group constituting a generation. In each generation 196 does are bred with a batch of 42 males. Twenty-five percent of these does are selected according to the results of the first three litters, the theoretical reproduction rate permitting a generation interval of ten months. Each doe selected produces an average of four replacement female offspring, so the group is made up of families of full sisters and paternal half-sisters.

The mating programme is implemented in accordance with the composition of the breeding groups. Table 46 shows that the females of each of the 14 families are distributed among 14 breeding groups with three males (one and two alternates) and 14 females. One breeding female is chosen at random per family from among the 196 does.

This mating programme means the genetic value of each doe can be figured according to her performance and those of related females (family average). The plan can also be implemented with fewer than 14 families and 14 breeding groups (e.g. 10, or a total of 100 breeding females). The breeding groups system offers the practical advantage of matching a production lay out in which families are represented by mother cages. Here, the 14 doe cages and the three buck cages are arranged side by side in rows in the rabbitry.

TABLE 45 Findings of specific selection experiments on rabbits

Authors	Characters selected	Genetic progress per generation[1]	Strain size	No. of generations
Poujardieu *et al.* (1993, pers. comm.)	Litter size	+0.05	33 M and 121 F	18
Baselga *et al.* (1993)	*Idem*	+0.10	24 M and 120 F	11
		+0.03	24 M	8

		+0.03	and 120 F	8
Mgheni and Christensen (1985)	*Idem*	+0.35	20 M and 40 F	4
		- 0.43[2]	20 M and 40 F	4
Narayan, Rawat and Saxena (1985)	*Idem*	-0.05	22 M and 110F	6
Rochambeau *et al*. (1989)	Individual slaughter weight	+ 46 g and + 2.4%	12 M and 30 F	8
Mgheni and Christensen (1985)	*Idem*	+ 75 g and +3.4%	20 M and 20 F	4
		108 g and-	20 M and 20	4

		4.3%[2]	F	
Estany *et al.* (1992)	*Idem*	+ 27 g and 2.0%	15 M and 60 F	12
		+ 23 g and 1.6%	15 M and 60 F	8

Note: M = males; F = females.

[1] Expressed in gross and percentage of average.

[2] Selection to reduce value of characters selected.

Rearing the generations separately has a number of advantages: the animals compared are the same age and so it is easier to calculate selection indices and estimate genetic progress. It also makes it easier to create a gap between the generations for health purposes.

There are a number of drawbacks, however. If female fecundity is too low it is impossible to produce a new generation every two months. Optimal use of available cages is also impossible and the occupation rate is low. Many breeders therefore prefer a system of overlapping generations (Case 2), but the system does demand a strict adherence to management rules.

Case 2. *Selecting a strain for postweaning growth and female fecundity (IRTA, Barcelona, Spain), mass selection and overlapping generations.* The selected population includes six breeding groups composed of 16 does and five bucks. As in Case 1, the males remain in their breeding group and one sire is replaced by one male offspring. The females change group: the daughter of a doe is never in the same group as her dam.

Selection is in two stages: first the does are indexed by postlitter weaning weight of their litter. Only does in the first and second kindling category and does in the bottom 20 percent leave no progeny. Does with a negative index are culled as soon as a replacement female is available. All does are culled after the fifth kindling, as are males over the age of 13 months.

In the second selection stage, future breeders are chosen from the progeny of the does selected earlier. The final selection is for animals with the greatest daily weight gain between weaning and sale. Twenty-five percent of the does and 15 percent of the bucks of the weaned population of each lot are kept as replacements as needed.

TABLE 46 Formation of reproduction groups based on family origin

	♂ 1.1	♂ 2.1	♂ 3.1	♂ 14.1			
Family 1	♀ 1.1	♀ 1.2	♀ 1.3	♀ 1.14	♂ 1.1	♂ 1.2	♂ 1.3
Family 2	♀ 2.1	♀ 2.2	♀ 2.3	♀ 2.14	♀ 2.1	♂ 2.2	♂ 2.3
Family 3	♀ 3.1	♀ 3.2	♀ 3.3	♀ 3.14	♂ 3.1	♂ 3.2	♂ 3.3
Family 14	♀ 14.1	♀ 14.2	♀ 14.3	♀ 14.14	♂ 14.1	♂ 14.2	♂ 14.3
	G1	G2	G3	G14	Males	Replacement	

					used	males

Source: Matheron and Rouvier, 1977.

This set of rules governing the selection and culling of breeding animals is designed to maintain a population in demographic equilibrium and increase selection efficiency.

***Case* 3.** *Conservation of a numerically small strain.* It may be useful to conserve strains or populations that are few in number. Matheron and Chevalet (1977) proposed an appropriate management method (used to manage control strain 9077 at INRA).

The strain is composed of 11 breeding groups with one male and four females. From one generation to the next, each male leaves one male progeny and each doe one female progeny.

The male of group *i* is the offspring of the *i* male of the preceding generation. His dam is chosen at random from females in the breeding group. The four females making up group *i* in generation *n+1* are the daughters of four females who were, respectively, in groups *i-1, i-2, i-3* and *i-4* in generation *n.* This method is illustrated in Figure 19.

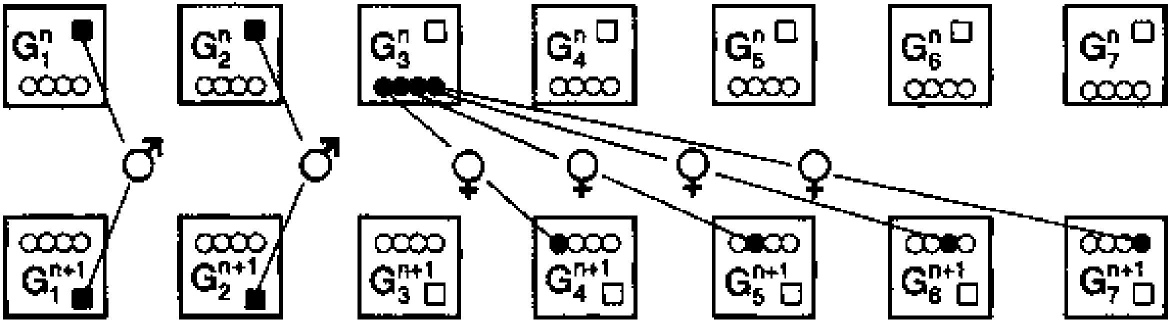
Once the breeding animals for herd renewal have been chosen, a mating programme -is the next step. Selection may be random, but mating between close relatives such as full brothers-sisters, half-brothers-half-sisters, mother-son or father-daughter must be avoided. A practical way to organize a servicing calendar is to assign breeding animals to cages by breeding groups, taking family origin into account (the family is the original breeding group). A breeding group consists of two or three cages of sires and 10 to 14 cages of dams, or proportionately fewer if the colony is numerically small.

Cross-breeding strategies

Three cross-breeding systems are:

Simple or two-breed crossing. Females of a local population, or breed A, will be crossed with males of breed C to improve the growth and muscular development of young meat rabbits and for a heterotic effect on the numerical productivity of does. Using this system the breeder can cross the pure breed *A* with part of his/her stock (perhaps 20 percent) for self-renewal of the female stock. The other females will be terminally crossed with C males, which can be obtained from another breeder. All the progeny of this cross are destined for the butcher.

FIGURE 19 Constitution of generation* n + 1 *groups, the progeny* of n *generation breeding groups

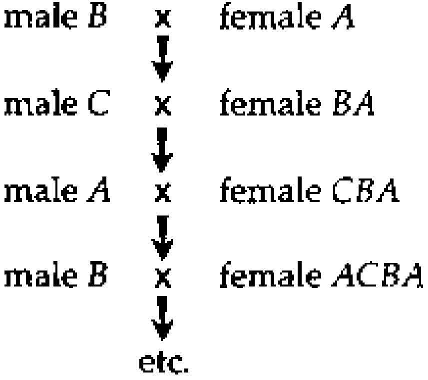


Two-stage or three-breed crossing. Breeding animals of two populations *(A* and *B*) will be crossed to get an *AB* crossed female for terminal crossing with males of breed *C*. The first crossing might be between B males of a good breed for size, fertility and maternal performance with females of a local *A* population. Using this system the breeder must rely on breeders or multipliers for female *AB* breeding animals and *C* sires, which demands careful timing and organization.

The system can be elaborated by the use of *C* sires which have themselves been crossed according to a system widely used in poultry breeding.

Table 47 compares the performance of three pure strains. *A, B* and *C*, simple strains *AB, BC* and *AC* and double crosses *D* × *AB, D* × *BC* and *D* × *AC.* It shows substantial production differences between the pure strains. Simple crossing improves overall performance. The best of the pure strains is still competitive, however. Crossing a male of a fourth strain, strain *D*, with cross-bred females *AB, BC* or *AC* further increases productivity. This is the most productive yet most complex system.

Rotating and alternative cross-breeding**.** Using several breeds and local populations for improvement, such as A, B and C, the breeder can apply the following system:



The advantage of this system is that it offers both heterosis and nicking ability and breeders can themselves produce their female replacement stock; only the male breeding animals need to be acquired elsewhere. When this system is used with only two breeds it is called alternative cross-breeding.

Systems one and three, in which breeders acquire male breeding animals for stock improvement but can select females from their own rabbitry, are well adapted to small-scale production.

TABLE 47 A four-strain cross-breeding experiment

Synthetic strains. Many countries have few or no local rabbit populations. Where they do exist, they are often the descendants of random imports dating back a few decades and crossed with no overall strategy. This population may have adapted somewhat to local conditions, but its initial genetic potential will be rather limited. For such countries, the creation of synthetic strains is an attractive alternative.

To create a synthetic strain, a male from strain C is mated with a cross-bred *AB* female to produce an F_1 generation which is crossed $F_1 \times F_1$ to produce F_2, followed by F_3 and so on. A synthetic strain can thus be constituted which enjoys the nicking ability of the two *A* and *B* populations and half the initial heterosis. A synthetic strain can also be established from a variable number of strains or breeds: here three but also two or four. The members of the F_1 generation are homogeneous but numerous genetic recombinations appear in F_2, F_3 etc. These recombinations reveal a new genetic variability which can be used to create a productive strain adapted to local conditions. In theory, to ensure that these recombinations appear fully, one would have to abstain from breeding for $2n$ generations, where n is the number of strains used. In these examples $2n = 8$. The number of strains will obviously rarely exceed three or four.

Parent animals from French, Italian or Spanish selection programmes can be chosen as the founder strains of these synthetic populations. This gives initial strains with good potential productivity and, through natural selection, the animals best adapted to local conditions. Two or three synthetic strains of this type can be created in a given country, in addition to any existing local strains. Cross-breeding experiments can then follow to compare these strains and choose a cross-breeding strategy for production.

Organizing genetic improvement: selection plans

This section uses an example to explain the organization of the technical components described throughout this chapter for a genetic improvement plan. France will be used as a case-study for the questions that need to be asked.

What is the initial situation? France has a long tradition of rabbit meat production and consumption. The breeders are organized into producers' groups and again into a national federation, the FENALAP. Producers constitute one link in the chain with other groups working in the field, particularly feed and equipment manufacturers, breeders and slaughterhouses. This is an organized market with standard national rabbit meat grades. INRA has collaborated for 30 years with the *Institut technique de l'aviculture et des animaux de basse-cour* (ITAVI) building expertise and furthering rational rabbit production. Technical, economic and individual management systems can supply data on production performance. France also has more than 40 pure rabbit breeds, the product of the breeders' art.

What kind of rabbit farming? French rabbit production is a rational system with breeders producing meat for sale to slaughterhouses. The "model" rabbitry has 200 or more does, one or more specialized rabbit houses with wire-mesh cages and an automatic drinking system. Balanced pelleted feed is used. The breeder also buys improved breeding animals and follows a hygiene and preventive health-care plan. The rate of reproduction is intensive with mating in the first 12 days after kindling and weaning at four to five weeks. The rabbits are slaughtered at a weight of 2.2 to 2.4 kg and mostly sold as whole carcasses.

What objectives? The objectives are the rational outcome of the foregoing. The ideal rabbits are those adapted to rational production systems, i.e. a female weaning a large number of fairly heavy young which reach commercial weight quite quickly and a male rabbit that transmits good growth potential and carcass quality to his progeny. This simplified presentation is confined to the principal objective, but there are secondary objectives for market diversification.

What kind of organization? France has chosen a pyramidal plan

(Figure 20) to create, accumulate and disseminate genetic progress, much as in poultry production. Private companies select strains that are cross-bred to produce meat rabbits. The "female" strains are selected for fecundity; the "male" strains are selected for postweaning growth and carcass quality.

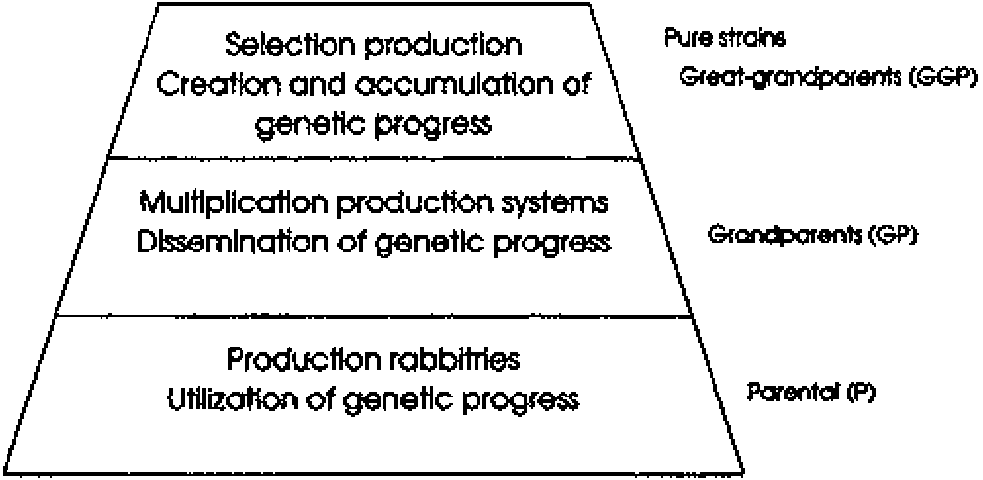
These private companies supervise multiplication networks which cross pure strains to produce the cross-bred female and the terminal-cross male, the parents of the meat rabbit.

Meat producers buy these improved breeding animals. Today, the "female" strain multiplication stage is often done in the production rabbitry. The breeder purchases the *B* grandparent male and the *C* grandparent female (Figure 21). Increasingly, one-day-old breeding animals are being purchased to be fostered by does with good maternal performance. These two techniques reduce the risk of transmitting health problems.

The main drawbacks are the health risk and the cumbersome organization. To obviate this risk, FENALAP and the breeders voluntarily adhere to a charter defining the rights and obligations of each partner. The main provisions of this charter include visits by a commission of experts every two years to selection and multiplication establishments and the utilization of technical and economic management by these enterprises, with FENALAP available to hear breeder complaints.

Within this pyramidal scheme, breeders create and build up genetic progress, which is then disseminated to and used by producers. A plan of this sort will not work unless the technical, economic and scientific organization described is in place.

FIGURE 20 Pyramidal scheme for creating and disseminating genetic progress in rabbits



A country or regional review of the problem

An initial hypothesis is that no approach can be transposed without prior reflection. The failures chalked up in recent years in various countries, not just for rabbits, are an illustration of this hypothesis. This review asks the following four questions:

What is the initial situation? Is there a rabbit production and/or consumption tradition? Are there rabbitries, local rabbit populations, imported populations? What are the techniques, rabbit housing and equipment and materials used by rabbit producers? What is the potential of existing populations? How should marketing be organized? Are there feed manufacturers, buildings and equipment, slaughterhouses, breeders and veterinarians with a background in rabbit production? Are there research, development and teaching organizations with an equal background? What is the government position on rabbit production? What role does it assign the rabbit in animal production?

What type of rabbit breeding? What is the breeder's objective: home consumption, export, sale to the local market? How big a rabbitry? What type of housing, equipment, feed, breeding animals, health care? Which rate of reproduction? Weight and age at slaughter? Organization and training for breeders?

Which selection objectives? The answer is simple: a rabbit adapted to the above constraints.

Which organization? Group organization is preferable because it is more efficient. The pyramidal scheme with private breeders is just one solution among many, e.g. collectively managed production units. There are other strategies that are less hierarchical, less rigid and better adapted to local constraints. This question raises a whole list of further questions: who creates genetic progress? Is there a buildup of genetic progress? Who disseminates it? What about cross-breeding? Who finances the cost of selection and dissemination? Who is responsible for checking the health, adaptability and production level of the animals produced?

Conclusions

Domestic rabbits are not as widespread as the other species of domestic mammals that are traditionally used to provide meat, milk, wool and skins. But rabbits are genetically very flexible, which makes them adaptable and productive in a wide range of production systems.

FIGURE 21 Use of different strains in a pyramidal scheme

Research on rabbit breeding behaviour and production development started only recently - less than 40 years ago -

although formal genetic research has a longer history. For production and selection this can be both an advantage and a drawback. The advantage is that there is less temptation for countries to import ready-made solutions without examining their own specific problems. A relative drawback is that the newness of this field of research calls for a new and appropriate genetic improvement pattern for each region or country. The major constraint here is dependence on the environment and a careful study of the production environment is essential.

The great genetic flexibility of the species arid its short life cycle are definite assets. This flexibility is a function of a genetic variability which can be traced to the recent domestication of the rabbit and the lack of intensive artificial selection. This has made possible the rapid emergence of breeds varying greatly in adult size and muscle development (adult weight varies at a ratio of 1:8). Doe prolificacy depends basically on the breed. In breeds of comparable mature size, average prolificacy is relatively independent of the environment. This character can be turned to good account in deciding how to use local populations.

Various breeds and populations are available for developing or modernizing production. A minimum of environmental factors must be mastered first; for the rest the rabbit will simply adjust to the physical and human constraints of its habitat.

In most developing countries, highly intensive production with complete control over technical and environmental detail is precisely the opposite of what is needed. What is needed are careful country profiles of the production environment (technical studies of local feed resources and genetic and sociological studies) and training for rabbit breeders. For genetic improvement, the first step could be a study of the breeding performance of pure and crossed local populations. Local populations are usually smaller in size and less prolific and appropriate crosses with local and imported breeds for better productivity could be worked out. Existing local populations should always be conserved and selected on an intrapopulation basis so they can be used to improve production in their own environment.

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