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Review: Towards the agroecological management of ruminants, pigs and poultry through the development of sustainable breeding programmes. II. Breeding strategies

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Agroecology uses ecological processes and local resources rather than chemical inputs to develop productive and resilient livestock and crop production systems. In this context, breeding innovations are necessary to obtain animals that are both productive and adapted to a broad range of local contexts and diversity of systems. Breeding strategies to promote agroecological systems are similar for different animal species. However, current practices differ regarding the breeding of ruminants, pigs and poultry. Ruminant breeding is still an open system where farmers continue to choose their own breeds and strategies. Conversely, pig and poultry breeding is more or less the exclusive domain of international breeding companies which supply farmers with hybrid animals. Innovations in breeding strategies must therefore be adapted to the different species. In developed countries, reorienting current breeding programmes seems to be more effective than developing programmes dedicated to agroecological systems that will struggle to be really effective because of the small size of the populations currently concerned by such systems. Particular attention needs to be paid to determining the respective usefulness of cross-breeding v. *straight breeding strategies of well-adapted local breeds. While cross-breeding may offer some immediate benefits in terms of improving certain traits that enable the animals to adapt well to local environmental conditions, it may be difficult to sustain these benefits in the longer term and could also induce an important loss of genetic diversity if the initial pure-bred populations are no longer produced. As well as supporting the value of within-breed diversity, we must preserve between-breed diversity in order to maintain numerous options for adaptation to a variety of production environments and contexts. This may involve specific public policies to maintain and characterize local breeds (in terms of both phenotypes and genotypes), which could be used more effectively if they benefited from the scientific and technical resources currently available for more common breeds. Last but not least, public policies need to enable improved information concerning the genetic resources and breeding tools available for the agroecological management of livestock production systems, and facilitate its assimilation by farmers and farm technicians.*

Keywords: agroecology, livestock, cross-breeding, local breed, breeding scheme

Implications

To promote transition towards agroecological systems, a major concern is the need to develop breeding strategies that will ensure sufficient diversity within and across breeds and encourage the use of breeds with characteristics that are well adapted to local and sustainable animal production. Breeding programmes in all livestock sectors need to evolve so that larger numbers of diverse and complementary genotypes become available to fit the full range of environmental conditions and production systems. In addition, the performance of animals from local breeds and cross-bred populations in contrasted environments needs to be better characterized.

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Introduction

Traditionally, farmers use breeding stock from a single selection programme, or in other words animals bred for high added value in a conventional production environment (Nauta *et al.*, 2001). This so-called 'conventional' environment qualifies the production system most frequently encountered in a livestock sector, and differs between monogastrics and ruminants. In particular, intensive production in closed containment buildings is the conventional method of production for pigs and poultry, while ruminants are mainly grazed or fed with farm crops and fodder, which maintains a direct connection with the land. A land-based approach in poultry and pigs means that animals have access to outdoor runs. The development of production systems with both high economic and environmental performance requires the selection of genetic resources that are capable of ensuring relatively stable production in a variety of less controlled environments (Dumont *et al.*, 2014). To develop agroecological production systems, breeders may wish to choose stock with performance characteristics which differ slightly from those targeted in conventional breeding. In a companion review paper (Phocas *et al.*, 2016), we emphasized that the traits of major interest to any breeder relate to the robustness of animals; particularly their health and ability to reproduce under fluctuating environmental conditions, and their feed efficiency on forages or local feed resources. Although the literature on the breeding goals and genetic resources demanded by farmers engaged in non-conventional production systems is very scant, we argue that there is no single animal type but animals with various profiles that meet the expectations of agroecology. We also discussed new genetic selection criteria (Phocas *et al.*, 2016) that may contribute to the implementation of agroecological principles in livestock farming systems (*sensu* Dumont *et al.*, 2013). These were related mainly to the integrated management of animal health by placing emphasis on the adaptability of animals in order to minimize drug inputs, and the efficient use of limited resources by minimizing food/feed competition and the polluting emissions that result from animal waste.

The aim of the present paper is to offer a vision of how animal breeding, in terms of developing appropriate breeding strategies, could promote the development of agroecological production systems based on the last two agroecological principles proposed by Dumont *et al.* (2013): (i) to strengthen the resilience of systems by enhancing the diversity of plant and animal resources and their complementarity and interactions within systems; and (ii) to preserve biodiversity in agroecosystems, including domestic biodiversity. From an agroecological standpoint, the scope of breeding programmes needs to be related to locally available resources, and particularly local breeds and environmental conditions. We have limited the scope of this review to the environmental conditions encountered in developed (mostly temperate) countries.

Designing appropriate breeding strategies involves both the selection and mating strategies of parents and their dissemination from the selection to the production tier. The aim is to improve animal efficiency and adaptability to local and fluctuating environments linked with changes to the climate and system inputs over the seasons. The FAO's highly generic description of five main breeding strategies (2010) can be applied to promote agroecological breeding strategies in temperate and developed countries, although the description initially focussed on the implementation of breeding strategies in developing countries.

1. using local pure-bred animals and improving the production traits of local breeds that are well adapted to their environment;
2. using international or exotic breeds assumed to have the appropriate characteristics for the local environment;
3. mating seedstocks from different breeds to play on the complementarity of parental breeds and the level of heterosis in cross-bred animals;
4. creating a new synthetic (composite) breed;
5. improving, by gene introgression, the adaptation traits of international breeds or the production traits of local breeds.

The choice of breeding method is one of the most important decisions to be made when designing a breeding programme. The first key decision is to choose between straight breeding or cross-breeding strategies and to define the parental genotypes (breeds or lines). The choice of the best strategy depends on breed complementarity and the level of heterosis effects in cross-bred animals for traits of major interest, by comparison with parental pure-bred populations. The choice of the best strategy is therefore linked to relevant characterization of the genetic resources available. It is also strongly dependent on a long-term capacity to maintain a suitable level of 'upgrading' in the population or the initial pure-bred parental populations for future use in cross-breeding. It is important to remember that even when a cross-breeding design is opted for, a parallel programme of genetic improvement in parental breeds must be pursued.

In this paper, we will first of all comment on the choice of the genotypes (pure-bred or cross-bred animals, homogeneous or heterogeneous herds) that would best fit the goals of agroecological systems. Then, assuming the parental breeds/lines thus defined, we will discuss how current breeding programmes could evolve to support the transition towards agroecological livestock production systems.

Which genotypes are suitable for agroecological farming systems?

One of the five agroecological principles proposed by Dumont *et al.* (2013) is to enhance diversity within each animal production system to benefit from the complementary skills of the different kind of animals. As underlined by Tixier-Boichard *et al.* (2015), 'biodiversity in livestock production systems may be considered at all scales, from individuals and breeds to species and ecosystems. (…). At the population scale, one possibility is to increase the

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number of breeds in use, or to produce new composite populations. At the local scale (i.e. the farm), the increase of biodiversity may be obtained by intermixing breeds, by using cross-breeding but also by monitoring individual genetic diversity within a group'. Here, the population scale matches the global scale of a livestock sector.

Use of local breeds

To solve the frequently mentioned antagonism between improving production performance and the adaptation of animals to less controlled production conditions, it is advocated that local breeds should be well suited to agroecological systems as they require fewer inputs than breeds highly selected for yield. Among the possible alternatives, traditional local breeds can be found almost anywhere. Indeed, numerous generations of natural selection and human-controlled selective breeding in a broad range of production environments have generated considerable genetic diversity among the world's livestock. Around 1000 breeds are currently registered worldwide in each chicken, cattle and sheep species. Some 10% of these breeds are qualified as 'international' because they are present in different parts of the world (FAO, 2007). The numbers are smaller for pigs and goats, but there are still about 40 international breeds among the 500 breeds registered in each species worldwide (FAO, 2007). Even at a national scale, the number of breeds present in each species may be considerable. For instance, about 140 pure chicken lines, 59 sheep breeds, 52 cattle breeds, 37 pure pig lines and 11 goat breeds are currently registered in France; 47, 47, 29, 7 and 10 of which, respectively, are local breeds (Phocas *et al.*, 2015).

However, local breeds usually display poor productivity when compared with commercial and international breeds, unless an efficient breeding programme can be applied, as is the case for the Lacaune and Manech dairy sheep breeds whose milk is used to make Roquefort and Osso-Iraty cheeses, respectively. In poultry, a poorer performance of international fast-growing genotypes is often observed in terms of the production, reproduction, and survival of animals in outdoors systems or with suboptimal diets when compared with breeds that have a lower genetic potential for growth, such as Label Rouge chickens or crosses between local and commercial lines. These crosses and Label Rouge chickens have therefore been recommended for use in organic and extensive production systems in Norway (Brunberg *et al.*, 2014).

As stated by the FAO (2015), 'locally adapted animals remain essential to many livestock-keeping livelihoods. As climate change progresses, and new environmental challenges emerge, some of the adaptive characteristics of these animals are likely to become more widely important'. If demand for climate-adapted breeds does increase, it will be important to ensure that these breeds, and the knowledge associated with their management, can be accessed fairly and equitably by those who need to use them. Even more fundamental – both for international exchanges and for adaptation at a more local scale – will be the need to preserve these breeds and document their characteristics in the environment where they are productive, although to date this does not appear to have been the general case, as pointed out by Marshall (2014). For example, Browning *et al.* (2011) compared reproductive and health traits among three different meat goat breeds under humid subtropical pasture conditions in the south-eastern United States. They showed that Boer goats (originating from South Africa) were not well adapted despite general agreement in the literature as to their general hardiness in diverse environments. Such an overstatement reflects insufficient observations of the breed under the full range of possible production conditions, particularly those that are harsh.

As a consequence, the only recommendation that can be made so far – in the event that a new breed might be of interest – is to implement trials before initiating the large-scale importation of new breeds into a given agroecosystem. From a practical perspective, no general database is currently operational which can register both animal performance traits (such as production, fertility or longevity) and environmental conditions (nutrition, breeding, climate and housing conditions), although the FAO and some countries have been trying for a long time to set up such a database. However, it seems rather that overlaying a performance database with environmental databases through a shared geographical information system could be a promising means of opening the way towards landscape genetics.

Another alternative is the introgression of new variants in a given breed so as to better adapt it to targeted environments. Selection schemes designed to introgress genetic material from a donor into a recipient line can be performed by repeated back-crossing programmes combined with selection in order to preserve favourable characteristics in the donor population. Genomic introgression can preserve targeted quantitative trait locus through the back-crossing phase and accelerate retrieval of the recipient genetic background (Odegard *et al.*, 2009). For example, it would be useful to introgress genes involved in heat stress tolerance (Phocas *et al.*, 2016) in international or temperate local breeds in order to maintain production and reproduction when local temperatures remain above 25°C and the animals are reared outdoors. Until now, use of the FecB (Booroola) gene in sheep is one of the few examples where genomic technologies have been shown to clearly benefit practical breeding programmes (Marshall *et al.*, 2011). Before the development of DNA technologies, the FecB gene spread from the Booroola Merino to some 40 breeds of sheep worldwide through classic back-crossing programmes in order to increase ewe fecundity. Classic introgression was efficient because FecB is a major gene. Today, genomics offers accurate tools that can be used to manage animal genetic resources in an agroecological context through the tailored monitoring of targeted regions in the genome (Tixier-Boichard *et al.*, 2015).

Use of cross-bred animals

The literature is very conclusive in saying that cross-breeding is certainly an interesting strategy to address complementary

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characteristics across breeds, and also the heterosis of offspring. However, as mentioned above, our current lack of knowledge makes it difficult to develop new cross-breeding programmes in all livestock sectors. Cross-breeding is applied systematically in pig and poultry production (three or four-way crosses) so as to overcome unfavourable genetic correlations between production and reproduction. This system offers the possibility to change just one of the three or four pure lines in order to adapt the product to specific conditions. In ruminant sectors, cross-breeding (two or three-way) is widely practised in meat sheep breeds around the world in order to exploit the potential of prolific breeds as maternal lines and others with good growth and carcass value as paternal lines (Bittante *et al.*, 1996). This practice helps to enhance productivity by increasing the number of weaned lambs in the flock, which is the key economic driver for sheep meat production. For the same reason, cross-breeding is also very common in most countries that rear large beef cattle herds (Australia, Brazil, North America). It is used either to create maternal lines or for terminal crossing to improve the growth and conformation of products (Golden *et al.*, 2009). Continental cattle breeds (Blonde d'Aquitaine, Charolais, Limousin, Piemontese, etc.) are frequently used as paternal lines for terminal crossing on cross-bred or pure-bred females (Angus, Hereford, Zebu). By contrast, although France is the principal European country for beef cattle production, it does not generally apply beef cow cross-breeding. Besides the terminal crossing that is mainly employed by dairy farmers with beef bulls, French cattle farmers overwhelmingly choose to breed pure-bred cows (>90% of beef and dairy cows) because of the historical links between a breed and a specific region, and the small average size of cattle herds in France (40–50 cows on average) that impairs the simple management of cross-breeding due to the need for keeping some pure-bred females. In dairy sectors, pure-breeding is the most frequent practice in temperate countries, while crossing is more widely used in the tropics (Leroy *et al.*, 2016). In a recent study of the suitability of cross-bred cows for organic dairy farms, de Haas *et al.* (2013) indicated that cross-breeding Holstein dairy cows with other dairy breeds (such as Brown Swiss, Jersiaise or Montbéliarde) reduced milk production, although a clear heterosis effect was seen in the F1 crosses; cross-breeding improved fertility in all the crosses, but udder health was only improved in some crosses. Another study (Dezetter *et al.*, 2015) indicated that some F1 crosses could even be as good as Holstein pure-bred cows in terms of milk production.

Intermixing genotypes within the herd

Another strategy that has been suggested to improve the resilience of production systems under fluctuating environmental conditions is the intermixing of animal species/genetic profiles within production systems. One example of its potential benefits concerns the management of animal health at the farm level: the spread of infections and its devastating effects on animal health can be limited by the diversity of hosts, thus preventing the specialization of a highly pathogenic agent (Springbett *et al.*, 2003). For instance, it is well known that mixing different herbivore species at pasture can procure performance benefits for farmers because of the complementarity of herbivore feeding niches (d'Alexis *et al.*, 2014), and reduce the parasite burden of each species by clearing pastures of parasites using a non-susceptible species (Alexandre *et al.*, 2010). Furthermore, it has been assumed that an individual variability of animal responses might be a key factor affecting herd sensitivity to fluctuating feed availability or changing environments. Modelling studies accounting for a diversity of female functional profiles have provided some conceptual evidence that individual variability may help to maintain the production and ecological efficiency of ruminant farms (Tichit *et al.*, 2011; Blanc *et al.,* 2013). The diversity of individual trade-offs between functions has been quantified in herds of dairy cows (Ollion *et al.,* 2016), suckler cows (de la Torre *et al.*, 2015) and dairy goats (Puillet *et al.,* 2010). Such a diversity of trade-off profiles does not increase herd milk production but enables performance stability under fluctuating environmental conditions (Blanc *et al.,* 2013), leading to more consistent economic margins for farmers. Nevertheless, when interviewing farmers in different livestock sectors (Phocas *et al.*, 2015), it was found that most of them felt that exploiting within-herd heterogeneity was not an appealing strategy. Intra-livestock genetic diversity is not favoured by markets which demand standardized products. In addition, most farmers associated intra-herd variability with a greater complexity of livestock management, causing extra work and more tedious procedures. For some, the beauty of a homogeneous herd was also important. This point of view was shared by farmers from all livestock sectors, but a few dairy cattle farmers were less negative towards this strategy, although they felt that they had insufficient knowledge to decide whether it might be an interesting option for their herd. By contrast, there was consensus among the farmers regarding the maintenance of high genetic variability between farms, so as to preserve the genetic diversity of the breed in the long term.

In brief, numerous genotypes are available as alternatives to highly disseminated international genotypes in each livestock sector and they may eventually be well adapted to certain specific agroecological farming systems. Nevertheless, while there remain numerous livestock breeds or lines within and across countries, there is also a real lack of knowledge regarding their performance characteristics, thus hampering their appropriate exploitation from an agroecological point of view. While both research scientists and breeders agree on the necessity to maintain long-term genetic diversity at the population scale, opinions differ regarding the potential usefulness of managing a broad diversity of animal performance profiles within a herd. While adaptive management may offer opportunities to benefit from inter-individual variability within herds (Dumont *et al.,* 2014), further experimental work is necessary to provide practical evidence of the value of increasing genetic and phenotypic variability at the farm level before relevant

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breeding strategies can be developed. Nevertheless, as has long been promoted for crops (Altieri *et al.*, 2015), it is now recommended that livestock genetic diversity should be sustained or restored at a local level by maintaining groups of herds that host different genotypes, so as to provide a buffer against the risk of pathogen dissemination.

Which breeding strategies that are best suited to agroecology could be adopted by collective breeders?

In all sectors, three major approaches can be envisioned in terms of strategy selection and use of breeding stock adapted to agroecological systems.

The first option is simply to use animals selected by current breeding programmes. In different livestock sectors, this option has been shown to meet the needs of many farmers committed to agroecology (Phocas *et al.*, 2016).

The second option is to choose different breeding stocks from the principal sources, considering all available candidates for selection under conventional breeding programmes. In this case, a specific synthetic selection index needs to be proposed to different breeders so that they can adopt the most appropriate ranking of animals to fit their specific needs. Such a strategy could be developed through advanced web questionnaires attached to a selection index similar to that proposed by Ahlman *et al.* (2014) for Swedish dairy producers.

Such a strategy would help to maintain genetic diversity across farms. In addition, existing $G \times E$ interactions should be included in genetic evaluation and the selection of animals should be based on their estimated breeding values in the targeted environment. However, this environment may be difficult to characterize. First of all, defining an environment involves numerous factors (feed and water resources, climatic conditions, soil quality, pathogen pressure, premises, social interactions, etc.) and little is usually known (meaning recorded in a database) of the precise environmental conditions with which the animals will have to cope. In addition, for each dimension of the environment, there are often as many diverse situations as the number of herd-year-season levels considered in commercial environments. Even though it is difficult to characterize a production environment, it is important to be aware that when the differences between environments become too marked, the breeding values estimated on performance in one environment will not also be valid in another.

The third option is to develop specific programmes for non-conventional farming systems. Two key issues may limit the implementation of this third strategy. The first concerns the technical efficiency of such programmes in terms of the size of population under selection and the availability of technical support for farmers participating in the breeding programmes. The second issue concerns their economic feasibility: is the market large enough for private companies to be able to afford the cost of an additional selection programme? How else can it be supported through public funding and policies in favour of participatory research and selection?

What about the development of ruminant breeding programmes that are best suited to agroecology?

Although there have been some marginal initiatives in Europe (Switzerland, the Netherlands) to develop specific dairy cattle breeding programmes for organic farming systems, ruminant breeding programmes are not usually specific to a given system. Genetic and genomic evaluations are based essentially on on-farm data relative to production (milk or meat traits) and functional traits (fertility, calving ease, longevity, udder health, etc.) that are collected from the acceding farms to dairy or beef recording system. National on-farm genetic evaluations provide objective criteria for the selection of replacement females with in a herd, and also for the choice of the best parents from other herds. The differences in environment encountered between farms are a guarantee of selecting sires most suited to the farming conditions that prevail in each country. As for small ruminants, it is worth mentioning that their conventional farming systems are among the most agroecological, especially with respect to sheep meat production systems. The genetic improvement of small ruminants can contribute to producing animals that are suitable for contrasting environmental conditions because a wide variety of breeds, and a great diversity of farming systems are considered in small ruminant breeding programmes. Moreover, because nematode infections are the most important problem affecting grazing sheep, resistance to these infections is now included in the breeding programmes for several breeds around the world (Hunt *et al.*, 2013). While genomic selection is only in its infancy in breeding programmes for small ruminants, selection for population improvement that includes the effects of major genes has been a widespread practice for almost 20 years. This selection is particularly interesting for traits that are difficult and expensive to measure, or only expressed in one sex or late in the animal's life. For instance, sheep prion diseases have been virtually eradicated by selecting rams carrying the ARR allele and selecting against the VRQ allele to the PRNP gene involved in resistance to scrapie (Sidani *et al.*, 2010). To increase the meat yield of sheep flocks, the major prolificity genes (Vinet *et al.*, 2012) have also been introgressed or selected in some sheep breeds worldwide.

In ruminants, it is complex and expensive to implement efficient selection programmes for populations of a small size (fewer than ten thousand breeding females), especially in cattle because of their high production cost, low fecundity and important generation intervals. Apart from major national and international breeds, many current breeding programmes are struggling to achieve a technical and economic balance, while a significant proportion of these operations is supported by public and collective funding. Furthermore, most of the farmers recently interviewed (Phocas *et al.*, 2015) were not opposed to existing breeding programmes, believing that they meet their needs, even if sometimes imperfectly.

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In this context it does not seem appropriate to propose the creation of specific breeding programmes for agroecology. Anyway, their outcomes would only be feasible for the largest breeds in a country and thus not help to promote small local breeds. However, it remains necessary to encourage change and the development of current breeding programmes. In recent years, developments in breeding programmes have increased the number of selection criteria available and balanced production and functional traits in the breeding goals designed to cope with various farming conditions. In the context of international dairy cattle selection, Miglior *et al.* (2005) analysed the index used in 2003 to select Holstein bulls in 15 countries throughout the world. Individual traits were grouped into three components: 'production', 'sustainability' and 'health and reproduction'. The 'sustainability' component mainly accounted for conformation traits such as body condition score, udder conformation or locomotion scores. In the total merit index, the average relative emphasis placed on production, durability, and health and reproduction, across all countries, was 59.5%, 28% and 12.5%, respectively. The index best balanced between the three components was the Danish index with 34% on production, 29% on sustainability and 37% on health and reproduction. It thus attached the greatest importance to the 'health and reproduction' component (37%), the next most targeted in this respect being the French index (25%). By comparing the relative emphasis placed on these three components in six European indices, Vanderick *et al.* (2011) showed that in all countries, greater importance was given in 2011 to the 'health and reproduction' component, with values ranging from 28% in Italy and Belgium to 54% in Nordic countries, with intermediate account being taken in France (37%), Germany (40%) and the Netherlands (45%).

In some countries, specific selection indices for organic dairy cattle have been developed, based on subjective scores determined by organic farmers for traits with a genetic evaluation; for example, the ecological breeding index in Switzerland in 2000 (Haas and Bapst, 2004) and the organic total merit selection index in Ontario in 2006 (Rozzi *et al.*, 2007). Initially, the relative balance between production and functional traits differed substantially from that of the corresponding national total merit indices (Rozzi *et al.*, 2007; Fric and Spengler Neff, 2014). However, in 2014, because of the greater weighting given to functional traits in the national selection index, the ecological selection index was abandoned for Swiss dairy cattle (Fric and Spengler Neff, 2014). In meat sheep, a comparison of the total merit indices for within-breed selection in New Zealand and Ireland (Santos *et al.*, 2015) revealed a relatively high correlation (0.86) between the two maternal indices, even though sheep farming practices are quite different in the two countries despite both production systems being pastoral and season-based. In New Zealand, the flocks are very large and under extensive management throughout the year (even around lambing) with exclusively forage-based diets for both ewes and lambs, whereas in Ireland most farmers tend to apply indoor lambing and the discretionary concentrate supplementation of ewes and lambs up to weaning. Because these two situations are quite representative of the broad range of meat sheep production systems, and both indices were based on economic considerations in each country, it can be anticipated that there would not be any benefits in designing an agroecological selection index for meat sheep breeding.

From an agroecological point of view, it is important to encourage these developments, particularly through the acquisition of references on new traits (roughage feed efficiency, resistance to pathogens, etc.) that are required by Global Change issues such as climate change, increases in human population, shifts in dietary preferences towards animal products in the developing world, or competition for arable land use (Dumont *et al.*, 2014). In addition, fine tuning of the use of genetic diversity among breeding stock is recommended in order to maintain this diversity across herds, thus enabling adaptation to a broad range of farming systems and local conditions. To achieve this, we recommend better support for farmers regarding the appropriate use of selection indexes and suggest tailor-made synthesis indexes that can be adapted to the specific objectives of each farmer and local environmental conditions. In addition, we recommend a further extension of genetic evaluations to integrate $G \times E$ interactions and include cross-bred animals, thus enabling a move towards multi-breed genetic and genomic evaluations. Training farmers in the use of selection indexes and the choice of breeding stocks suited to their own production systems must be considered at a regional or national scale, depending on the organization of agricultural sectors in each country.

What about the development of pig and poultry breeding programmes that are best suited to agroecology?

Pig and poultry breeding is mainly assured by a small number of multinational firms that recommend specific production conditions in order to achieve the optimum performance from their improved lines, whatever the country. Yet even in the case of poultry, where the production environment is said to be well standardized, there may be differences because of the raw materials used in the diet, housing systems or livestock management methods. Such differences are not always well characterized but have a real impact, which explains why breeding companies organize performance testing of their elite lines in different countries. Alongside the dominant industrial system, there are also some small national structures in certain countries (e.g. France) that compete with the larger firms or more frequently focus on specific lines, such as local breeds of pigs and poultry, or Label Rouge chickens in France. Although the principal purpose of these national structures is to meet the needs of producers at national level, there has been a significant development of their international business in recent years. One result of the standardization of production is that selection can be carried out efficiently in a limited number of breeds within each species. For instance, the pig breeds used in France are mainly

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Pietrain and, to a lesser extent, male Large White and Duroc for the sire lines. Maternal lines are generally Large White or Landrace, and to a lesser extent some composite varieties derived from crosses with Chinese breeds. Alternative farming systems use the same cross-bred genotypes as conventional production, although more frequent use of the Duroc breed can be noted regarding Label Rouge pork production. In the French pig industry, farmers engaged in organic production are aware that the market is insufficient (0.4% of domestic production) to cover the costs of developing genotypes adapted specifically to their system. They have recognized the fact that pigs adapted to conventional production systems are sufficiently flexible to meet the needs of organic farming. However, they underline the difficulty of obtaining sufficiently heavy piglets at birth to ensure satisfactory adaptation to the dietary constraints of organic production (Phocas *et al.*, 2015).

Because pig production for quality labels is limited in all countries (e.g. Label Rouge only accounts for 3.1% of French domestic production), breeding organizations do not invest in specific breeding programmes for non-conventional farming systems, for both technical reasons (population size) and in terms of economic balance. A wide-ranging study was recently conducted in several European countries on the sustainability of pig production systems, and covered traditional, organic and conventional farms (Bonneau *et al.*, 2014a and 2014b). Admittedly, breeding programmes are not really guided by the agroecological principles as presented by Dumont *et al.* (2014), even if some current efforts based on economic considerations may help to ensure the sustainability of the pig industry: the limitations on inputs are quantitative and do not specifically incorporate the use of local and variable resources that might be less well suited to the genetic potential of the animals; the preservation of biodiversity is restricted to the management of inbreeding in selected populations, particularly in the case of local breeds; waste reduction is seen as a simple, positive consequence of improved feed efficiency, and the diversification/coexistence of production modes is not envisaged at a large scale. Rydhmer *et al.* (2014) evaluated the sustainability of population management programmes for various husbandry systems, ranging from the traditional to the conventional and including organic farming systems. In their study, the latter appeared not to breed animals that were fully adapted to their system; it was either possible to have a suitable system that included management of a local breed, or to drive a breeding programme in line with the organic system. In France, a few local farms rely on raising local pig breeds linked to specific production systems that associated with typical products with high added value. France is the main 'reservoir' of swine genetic diversity at the European level, with the preservation of six local breeds (Laval *et al.*, 2000). These breeds are generally characterized by low prolificity, high adiposity and low growth, but much higher meat quality. A similar situation exists in the poultry sector where the low production level of local breeds has also restricted them to niche markets for high quality products.

The broad variety of local pig and poultry breeds available in France for the alternative production of Label Rouge type animals is a real asset to the French position regarding the development of agroecological livestock productions. Unlike conventional production, the breeds are raised under purebreeding conditions on commercial farms so as to ensure both the high added value of their products and the preservation of breeds that would be at a high risk of extinction otherwise. Furthermore, organizations that manage local breed conservation programmes focus their market strategy and communication policies so as to remain a niche market. They are reluctant to cross these local genetic resources with standard genotypes that would cause them to lose the distinctiveness of their products. In these breeds, the main objective of population management is to control inbreeding. There is therefore no breeding programme in the strict sense, apart from compliance with breed standards and, in the largest populations, the exclusion from reproduction of animals with an extremely low level of performance.

Although some important obstacles limit the implementation of specific breeding programmes for non-conventional farming systems, complementary strategies with respect to pig and poultry genetic resources offer a means of producing animals that may be well suited to agroecological systems.

First, the use of cross-breeding between three or four closed lines selected from a pool of available lines is almost systematic in these species. This type of system enables considerable flexibility to adapt to different production conditions by just changing one of the lines used in the cross. Increasing the number of lines will increase even further the number of cross-bred combinations, which is desirable for agroecology, but it will be necessary to compensate for the cost of maintaining a larger number of lines at some point in the food chain. Mention should also be made of the production of cross-bred animals between strains of laying hens and broilers, which aims to create a genotype where the females are good layers and the males can produce sufficient meat to prevent them from being sacrificed at hatching (Icken and Schmutz, 2013). This is one of the responses found by breeders to the welfare and ethical issues relative to laying hens. In addition, some existing lines are better adapted than standard genotypes to some agroecological systems. This is particularly the case of slow-growing broiler breeds such as 'Label Rouge'. These strains are less demanding than the very fast-growing strains used to produce standard broilers, so they are therefore more suited to extensive and less controlled environments. They nevertheless sustain a level of performance which, although lower than that of standard strains, is acceptable for production, as mentioned in Norwegian and US publications (Fanatico *et al.*, 2007; Brunberg *et al.*, 2014).

Second, in both the pig and poultry sectors, some breeding programmes have been set up by multinational companies to integrate performance from 'associated farms' located at several sites around the world in order to evaluate the adaptation of animals to varying local conditions, and

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therefore select parental lines and crosses that are well suited to different production systems. This strategy seems particularly effective with respect to heat resistance in both swine and poultry (Ansah, 2000).

Finally, one interesting option that deserves investigation in the pig sector is an approach more usually mentioned in ruminants as a system-dependent choice of breeding stock from the same pool of candidates for selection, as under a conventional breeding programme. There is indeed significant variability within breeds that could be better exploited if more information were available to better characterize the animals, particularly in terms of functional traits. In the same way, a different use of the breeds could be considered in order to increase the value of existing diversity in the context of innovative cross-breeding strategies to reconcile the benefits of cross-bred products, the possibility for the within-herd replacement of breeding females, and the improved adaptation of animals to the production system.

Consequences

We should first of all remember that agroecological livestock farming systems cannot be scaled up if the economic viability of farms and market and societal expectations are not taken into account. Therefore, in the context of the sustainable development of animal production, agroecological systems may be economically efficient either because they correspond to strong demand from society and a clear added value for animal products, or because grasslands and local resources are available and limit the use of external inputs for production. Agroecology is one of several potential routes for the development of sustainable livestock farming systems. A complementary route is industrial ecology that is based on the same management principles; applied to conventional systems, it can increase production yields and could thus play a key role in feeding the world's growing world while limiting the environmental footprint of animal production (Dumont *et al*., 2013).

In all livestock sectors, it seems desirable to change current breeding programmes so that they can better respond to a wide range of needs in terms of breeding stock profiles. Facilitating this overall change will allow the broader development of agroecological systems than proposing specific programmes that will struggle to become really effective because of the small size of the populations raised with agroecology as the primary concern. In addition, it is important to note that the idea of establishing a line or a breeding programme dedicated to agroecology involves reaching a consensus on the standardization of ideal animals and breeding conditions, which seems antithetical to the very principles of agroecology which aim to benefit from complementarities and interactions between available resources. Although cross-breeding may be an interesting strategy to target complementary performance traits across breeds, our important lack of knowledge of the characteristics of local breeds and cross-bred populations makes it difficult to implement new cross-breeding programmes. Special attention should be paid to the true value of cross-breeding *v.* straight breeding strategies that promote well-adapted local breeds. As well as supporting the value of within-breed diversity, we must ensure the preservation of between-breed diversity, which is one of the essential components for adaptation to a variety of production environments and contexts. This may involve specific public support for local breeds, which would also benefit from the sharing of scientific and technical tools with larger breeds in order to enhance the cost-efficiency of local breeding programmes.

Current advances in genomics indicate that data on genetic markers associated with adaptive traits may become useful in a medium/long-term perspective, either for the introgression of particular genes or to enable complete genomic selection. However, despite spectacular developments in our knowledge of the genome, there is a serious lack of knowledge on the expression of phenotypes, and obtaining this should enable a better response to the dual challenge of exploiting the variability of animal performance: (i) appropriate selection to improve the production efficiency and robustness of animals, and (ii) precision farming that places value on the individual variability of animals so as to increase efficiency and resilience within herds. The efficient exploitation of individual variability for selection purposes requires development and maintenance of the phenotyping and genotyping of a reference population containing several thousands to tens of thousands of animals, so as to ensure representative genetic diversity for a given candidate selection programme. This remains a major obstacle to the development of genomic selection in many breeds. Public funds could therefore be mobilized to constitute such populations in breeds where private financial resources for selection are non-existent or weak, as is often the case for local breeds. But first of all, to ensure the sustainability of local breeds, public support should primarily aim to characterize the phenotype of these populations and encourage their local development before any breeding programmes are initiated. Indeed, the main aim of genetic management is to limit any increase in inbreeding in these populations with small effective numbers.

Last but not least, there needs to be public support to improve information on the genetic resources and breeding tools available to enable the agroecological management of livestock production and facilitate their assimilation by farmers and farm technicians.

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