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Goat management and systems of production: Global framework and study cases in the Caribbean☆

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ABSTRACT

Animal output is a complex set of activities dependent upon interrelated abiotic, biotic and socio-economic factors. Increasing reproductive performances, reducing mortality rate, accelerating growth rate and improving carcass merit or milk quality are multiple and interdependent objectives. A multidisciplinary approach is necessary to characterise animals and systems for the different interrelated production traits. Setting priorities and implementing research within development projects are better accomplished through the farming system concept and holistic approach of interrelated factors of variation. This paper outlines the interest of the farming system approach and a general framework of the variable factors in goat performances. From these, guidelines are proposed for piloting the whole system through reproductive management, matching the system to available feed resources, implementing an integrated health control protocol, and adapting the breeding improvement approach to the local sector's characteristics. The second part of this paper presents case studies gathered from different experiences in countries of the Caribbean basin (*sensus largo*). These deal with climatic effects, the use of a male-effect, the use of forage trees and shrubs and integrated health control. The focus lies on both meat and goat milk production in the Caribbean basin.

1. Introduction

Goats are highly adaptable with good production potential in the tropics, as reviewed (Smith and Bosman, 1988). However their potential remains hugely unexploited (Ahuya et al., 2005) due to relatively less or wrong research and development approaches and attention that this sector has received and continues to receive. In their reference paper dealing with the role of goat in the society, Boyazoglu et al. (2005) highlighted many facts for goat production development in developing regions: Prospects for the development of goat farming appear to be positive, but technology transfer is difficult and there is a huge lack of training of goat farmers (and in the extension services sector). The authors recommended that goat production systems be studied with special reference to the parameters and discriminating factors of interest to the farmer, and to give farmers practical recommendations based on factual data for improving management and increasing production.

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This paper outlines the farming systems approach and presents a general framework of the various factors involved in goat performance in order to propose guidelines. In addition, it describes case studies from experiences in countries of the Caribbean basin (*sensus largo*). The intention is to allow the reader to form an own opinion applicable to a particular situation.

2. Global framework

Due to their high adaptive capacity (Silanikove, 2000) and level of fitness, goats are kept under a wide range of productions and farming systems throughout the tropics. A farming system is defined as a class of similarly structured farms that operate as a decision-making unit, inclusive of the farm house-hold, cropping and livestock operations, which produces crop and animal products for consumption and sale. Other functions (Peacock, 1996) could be added in this general framework, but these may be difficult to assess, such as for draught goats in Central-America (CATIE, 1987) or animals for "Hindu" and "Muslim" sacrifice in the Caribbean islands (Alexandre et al., 2008).

2.1. *Farming system approach*

Goats are usually associated with traditional, low technology production systems (Devendra and Burns, 1983; Wilson, 1998; Peacock, 1996). However, traditional and extensive do not signify an absence of management since nomadism and transhumance are adaptive responses to the shortage of resources. At the other extreme, high level of performances can be reached even with non-selected breeds as reported for the Creole breed on the semi-intensive grazing systems of the French West Indies (FWI) where the success was based on the use of available local resources, integrated health control and adapted management practices.

Setting priorities and implementing research within development projects are better accomplished through the farming system concept (Perevolotsky, 1990) and an holistic approach to interrelated factors of variation (Alexandre and Mandonnet, 2005). In a case study of goat herding in the dry tropical region of Peru, Perevolotsky (1990) established that although the ecological factors are important, the agro-ecosystem classification is not sufficient for a meaningful characterization of a production process. This author also stated that, "Only a multidisciplinary analysis including environmental (availability of herbaceous sources), economic (stability, alternative sources of income) and socio-political (land-tenure, control over resources) aspects enables us to define and distinguish between the various production units in the region studied". The combined effect of environmental, economic and socio-political factors on production and productivity features, management practice and marketing strategies was demonstrated quantitatively in this paper.

Therefore, it is critical to recognise animal output as a complex trait and that it is dependent upon numerous abiotic, biotic and socio-economic factors (Fig. 1). In addition, these factors are interrelated. Increasing reproductive performances, reducing mortality rate, accelerating growth

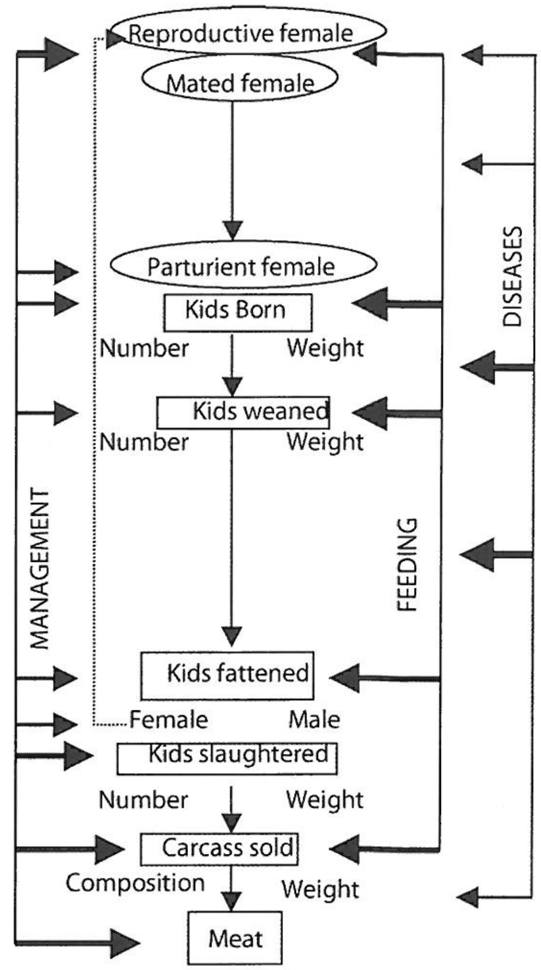

Fig. 1. Representation of physiological events, performances and factors of variation involved in meat production under the tropical goat production system for meat production.

rate and improving carcass merit are multiple and interdependent objectives. Thus, characterization of animals and systems, together with their different combined factors of variation, must be carried out for the different interrelated animal traits contributing to production. That means that a multidisciplinary approach is necessary as argued by Alexandre and Mandonnet (2005) and demonstrated in the case of the Creole goat of Guadeloupe. Studying the case of goat production in Venezuela, Pariacote (2000) recommended taking into account the extrinsic factors (market actions, institutions and enterprises) and also the cultural environment (with man's integral part).

2.2. *Factors of variation*

It is well known (LeGal and Planchenault, 1993; Galal et al., 2000; Shrestha and Fahmy, 2007) that animal performance (AP) is determined by two major components: genetic (G) and environmental (E) effects and the concomitant interactions between genotype and environment (G × E).

$$AP = G + E + G \times E.$$

AP is the animal performance (i.e., reproduction, lactation, growth) and capacities (i.e., resistance traits, mortality rate). G is the genetic effect with direct and maternal calculations of heritability (Shrestha and Fahmy, 2007). E is the environmental effect (*sensus largo*) including agroecological, physical environment, socio-economic conditions and all the techniques of management. G × E is the interaction which is commonly encountered in the tropics (Menendez-Buxadera and Mandonnet, 2006).

From the factors that are inimical to livestock production in the tropics, the most important, as classified by Baker and Rege (1994), are high ambient temperatures, high relative humidity, and erratic and/or low rainfall regimes. These have concomitant effects on quality and quantity of available feeds, a wide variety of diseases and low levels of animal productivity. Many ways can be underlined in order to mitigate these environmental effects: (i) limiting or avoiding stress by appropriate flock management and/or (ii) increasing animal resistance to harsh environment through genetic adaptation. Before describing the way these actions will be involved, let us recall the main factors of variation and the parameters of AP in a global approach are presented in Fig. 1.

2.3. Main environmental factors of variation

Climatic conditions have direct and indirect effects via biotic parameters (feed resources level and quality, pathogen occurrence and pathogenicity). Silanikove (2000) considered heat a major constraint on animal productivity in the tropical belt, arid areas and also subtropical Mediterranean zones. Growth, milk production and reproduction are impaired under heat stress conditions as a result of the drastic changes in biological functions caused by physiological changes to cope with heat stress (Ewing et al., 1999).

Feeding goats well is of fundamental importance to the success of the whole goat enterprise. Feeding conditions (both quantity and quality) determine overall nutritional status of the flock and are deciding factors for animal survival and meeting nutrient needs for maintenance, reproduction, lactation and growth potential (Fig. 1). Feeding and nutrition related factors also interfere in and often determines the individual vulnerability to potential diseases or climatic constraints. The main interactions in this regard have been reviewed by Alexandre and Mandonnet (2005) for goat rearing under harsh conditions. The feeding conditions and effects are well documented since the work of Morand-Fehr (1991) and many case studies around the tropical regions.

The occurrence of diseases and the prevalence of parasites considerably affect both animal survival and levels of performance (Fig. 1). Maintaining goats in good healthy state is obviously of great importance for the economic results and flock maintenance. Ticks and gastro-intestinal nematodes are recognised as two of the main issues that determine health in small ruminant (SR) farming throughout the tropics and, particularly, in the West Indies. The tropical bont tick (TBT) *Amblyomma variegatum*, originally from Africa, can cause severe injuries to goats, especially damage caused between toes (causing severe morbidity affecting animal mobility). Moreover, it is a vector for *Ehrlichia ruminantium* which cause the cowdriosis or heartwater disease and severe losses in goat farming (Camus et al., 1993). This TBT is also associated with clinically severe and often fatal forms of *Dermatophus congolensis* disease in all ruminant species (Barré, 1997). The *A. variegatum* first appeared in Guadeloupe and Antigua, but probably spread to the neighbouring Caribbean islands (Fig. 2) as a larval stage borne by cattle egrets. There is a high risk of spreading *A. variegatum* and its associated diseases to the Greater Antilles and the America main land (Corn et al., 1996). Gastro-intestinal nematodes (GIN), especially *Haemonchus contortus* and *Trichostrongylus colubriformis*, represent one of the main threats to the small ruminant industry in the French West Indies (Aumont et al., 1997) and other Caribbean islands (Arece-García et al., 2007). These internal parasites are much more prevalent in small ruminants than in other herbivores. Aumont et al. (1997) observed an in farm average of 45% kid death rate at weaning, which was attributed to GIN infection.

Animal factors such as age, bodyweight and number of lactation for does, as well as sex, litter size at birth or at weaning and birth weight of kids influence overall performance and productivity. General husbandry conditions such as reproduction control techniques, feeding supplies, age or live weight at weaning, prophylactic measures and pasture management are also known to be of paramount importance (Fig. 1). In addition, there are multiple interactions between the different functions of the animal, biotic and abiotic elements and between feeding, sanitary and technical conditions (Fig. 1).

Apart from feeding level and prophylaxis measures, animal husbandry *per se* is directly responsible for successes or failures in the goat production process. Frequently, farmers do not interact with the vital cycle of their animals: i.e., reproductive control, frequency of mating, culling and weaning strategies. Animal husbandry, including stocking rate, housing and fattening conditions are often not controlled. In the Caribbean, it is evident that there is a lack of essential technical support and infrastructure for an efficient collective organisation and for appropriate extension services in the sector (Pariacote, 2001). As an example, the off-take rate can be high and consequently prices are not based upon carcass quality. On the other hand, in practice animals are informally slaughtered and cut by the same farmers or intermediaries at farm and/or community levels. Sanitary rules and meat technology patterns are frequently not adhered to or simply poorly taken into account (Vokaty and Torres, 1997; Alexandre et al., 2008).

2.3.1. Main genetic variation

LeGal and Planchenault (1993) outlined the genetic and environment factors that influence goat production in the tropics (Fig. 3). Frequently, it is referred to crossbreeding schemes in order to improve animal performance. In these cases, it is hypothesised that the genes of the local population will be diluted and adaptability will decrease (Fig. 3) in terms of tolerance to diseases, resistance to climatic events, suitability to adverse environments, fitness and reproductive performances. On the other hand, productivity will increase (Fig. 3) and the local genotype will be up-graded in terms of higher milk production, faster growth rate or

Not infested, Provisionally free, Low level of infestation, Infested, Infested and Ehrlichia ruminantium present (CAP web site http://www.caribvet.net/index.php).

Fig. 2. Map of the Caribbean countries infested with Amblyoma variegatum: ( ) not infested, ( ) provisionally free, ( ) low level of infestation, ( ) infested, and ( ) infested and *Ehrlichia ruminantium* present (CAP web site http://www.caribvet.net/index.php).

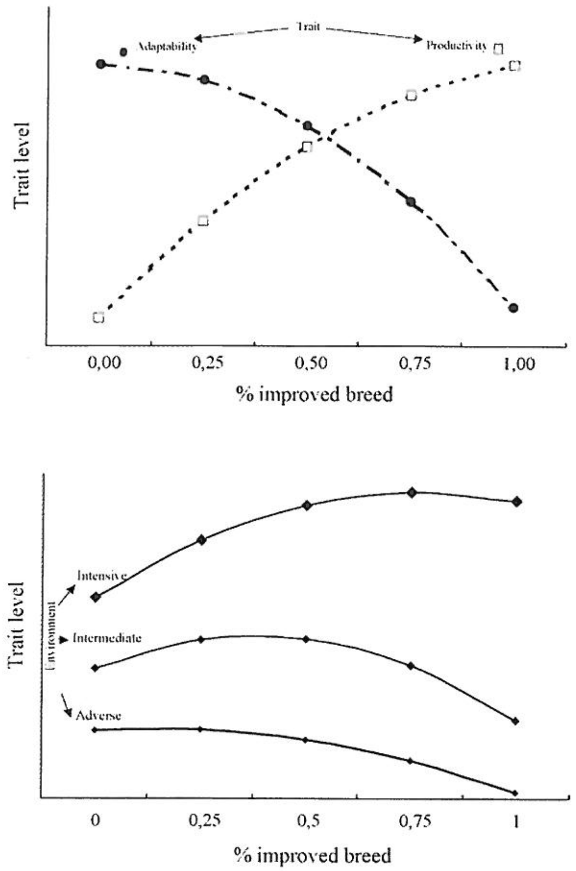

Fig. 3. Animal performances according to genotype and environment (source: LeGal and Planchenault, 1993); (a) evolution of adaptability and productivity traits with % of crossbreeding (0 = indigenous breed, 1 = exotic breed); (b) animal performances in different environments: adverse, intermediate and intensive.

heavier carcass. However, the actual animal performances will result from not only the genetic potential but also from the effects of all the interrelated factors of production. Fig. 3 provides the theoretical approach and the production levels in three different conditions, from adverse and intermediate to intensive environments. Alexandre and Mandonnet (2005) have shown that there is scope for improvement owing to a combination of improved nutritional management and breeding of adapted genotypes. In such review, the values of improved management in traditional systems or under un-supplemented feeding conditions show improvements ranging from 21 to 127% at birth and 71 to 172% at weaning. Similar trends were reported for growth, fattening and carcass characteristics, with improvements in average daily gain and carcass weight of 61–141% and 34–79%, respectively.

2.4. Set of rules

The future of animal husbandry in our regions rests on two contradictory requirements for increasing productivity: (i) intensified use of surface area, utilisation of locally available resources, improving animal output, and at the same time (ii) adopting techniques that guarantee sustainability. Therefore, production systems must be based on a fixed set of rules aimed at improving productivity and quality, adaptability and sustainability; in that sense we propose some principles which could be underlined as strong recommendations:

- Structuring the whole system via adapted reproductive techniques thereby allowing high levels of productivity.
- Matching systems of production to locally available feed resources and optimising the intensive use of pastures.
- Choosing the breeds in relation to the main constraints, animal production systems of the region and to general economical conditions; create balance between adaptive and productive traits and between reproductive fitness, growth and meat production abilities.
- Integrated disease control for external and internal parasites rather than eliminating risks.

2.4.1. Reproduction management determining the whole system

In the small ruminant sector, the profitability of enterprises depends primarily on the efficiency of offspring production and the most important factor affecting flock efficiency is reproduction (Devendra and Burns, 1983; Chemineau et al., 1991; Bosman et al., 1997). It is important that goat keepers would be able to manage the reproduction of their goats according to their own objectives, the availability of feeds and market demand (Peacock, 1996). Gibon et al. (1999) explained how reproduction is a key point for piloting the whole farming system (Fig. 4). This scheme shows that once the mating period and the kidding frequency is chosen together with such reproductive level objectives, then the system would tend to balance, on one hand the resources management (based on the territory and the biophysical environment) and on the other hand the flock management. Subsequently the approach at territory level, the breed choices and the off-take rate are all of deep interest and interdependent for the successful achievement of goals (and functions).

2.4.2. Feeding management and supplementation strategies

As argued by Peacock (1996), the approach of feeding management should imply that farmers in the tropics are keen to follow a supply-driven feeding management rather than demand-driven recommendations. Farmers must be helped to make more efficient use of the available local feeds, such as local roughages or non-conventional feed resources. This message was recommended by Preston and Leng (1987) 22 years ago for matching livestock system with available resources. Its efficiency has been clearly demonstrated, and is even more relevant today. More accurately, we need to assess the animal performances relative to the biomass available under the tropics. There are many feed resources on offer (Preston, 1995). The biomass can be classified in four groups (Table 1), high, low or medium quality and non-conventional feedstuffs.

Industrial products are expensive; low cost available sources of protein for ruminants remain in the great range of forage legumes, protein trees and/or shrubs

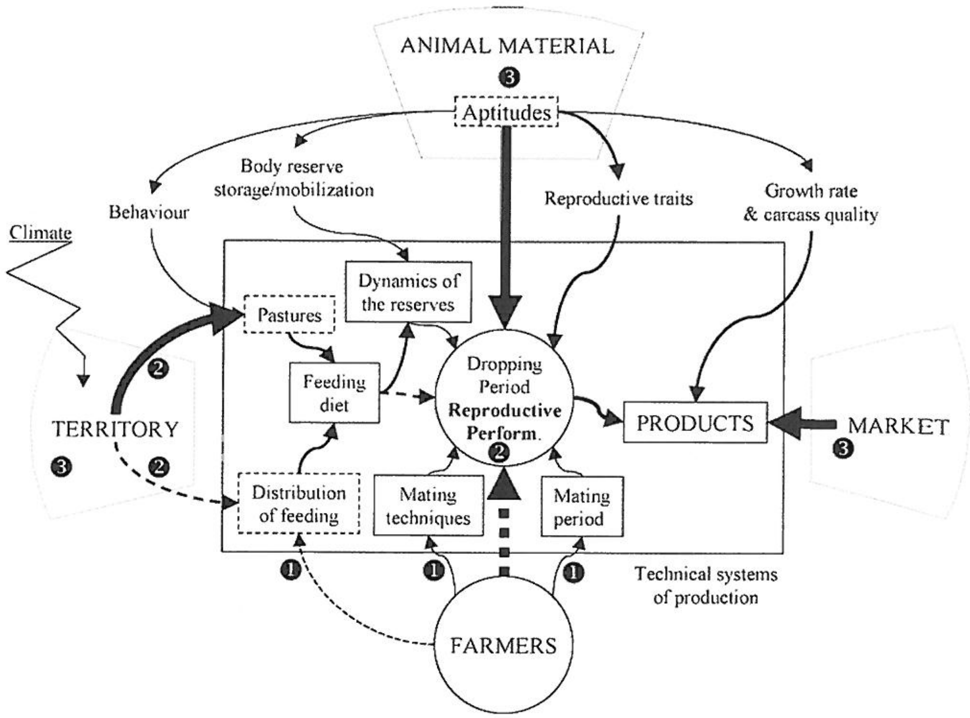

Fig. 4. How the reproduction management in livestock farming system (LFS) pilot the whole production system (Gibon et al., 1999).

species (Ramirez, 1999) with fill units similar to that of grasses. They are characterised by a relatively high level of acceptability, voluntary intake, digestibility and animal performance, depending on the specie or variety and respective concentration in secondary compounds like tannins and saponins, which at the same time may serve as 'CP protectors' from ruminal degradation, enhancing CP by-pass levels and animal productivity.

Except for the high quality feed value roughages, for obtaining high animal performances, it is necessary to mix ingredients and associate roughage sources with non-conventional feed resources. The main constraint of such diets is their high fill unit values and consequently relatively low nutritional density in energy and nitrogen. It is necessary to have a good blend between animal potential and feed resource characteristics to increase the economical component and the opportunities for the sustainability of the livestock production system. In fact, a handicap to rearing exotic goats while using local feed resources is often encountered. Taking into account the theoretical requirements of dairy exotic does (INRA, 1988) and the fill units of most tropical feed resources, the nutrient density of the diet must vary between 1.0–1.2 UF/kg DM intake and 70–120 PDI/kg DM intake. Growing exotic goat diet density may vary between 0.8–1.0 UF/kg DM intake and 70–110 PDI/kg DM intake, but its difficult to obtain these levels of nutrient density with most tropical feed resources available on farms. An attempt was made in Guyana to develop a complete pelleted diet for crossbred goats based largely on by-product feedstuffs (Lallo, 1996). To maximise the exotic animal's potential genetic expression, it is normal practice to introduce a commercial concentrate (based on imported cereals and grains) in the diet, thus increasing the feeding and overall production costs.

Table 1
Classification of the main tropical feed resources on offer.

Group	Nature of feeds	Feed value	Animal results
High quality	Young grass or legume/forage tree or shrubs/crop leaves (sweet potato, peanut cassava)	>0.65 UF CP > 12% (DM)	High productivity: 3 mating/2 years; ~50 g post-weaning ADG
Low quality	Old grass (>60 days)/crop by-products (sugar cane top, cereal straws, banana pseudo-stem)	<0.5 UF CP < 5% (DM)	Meets maintenance requirement
Medium quality	Tropical grass of 45–60 days/banana leaves/whole chopped sugar cane (WCSC but rich in energy)	<0.60 UF 5% < CP < 7% (DM)	If WCSC + urea medium performance
Non-conventional feedstuffs	Banana fruits/roots/tubers/bread fruit	~high in energy (>1.0 UF) poor in CP (<0.3 UF) high fill unit relatively to cereals	Substitutes to cereals for supplementation

2.4.3. Intra-breed selection and/or crossbreeding?

In harsh tropical environments, local breed improvement within is an appropriate strategy when management can only be improved marginally and when crossbred goats are unlikely to perform well (Peacock, 1996). This is the option supported by INRA (Alexandre and Mandonnet, 2005) for the improvement of Creole goats where high levels of genetic variability have been shown in productive (Mandonnet et al., 2002; Menendez-Buxadera et al., 2003) and in adaptation traits (Mandonnet et al., 2001, 2006). This can be considered a first step in genetic upgrading. The improved local does can further be used in crossbreeding, with improver bucks in the best managed farms. An alternative policy is to postulate that no organisational selection is viable under traditional environments in the tropics and that genetic improvement can only be introduced via improver sires as reported under the Venezuelan conditions (Juvenal-Castillo and Omar-García, 2001). However, crossbreeding with breeds from temperate regions has been unsuccessful or unsustainable due to incompatibility of these genotypes with the breeding objectives and low-input management systems in this area (Kosgey et al., 2006). Emphasis has to be put on adaptive traits (Baker and Rege, 1994; Mandonnet et al., 2006), on fitness, maternal abilities (lowering kid mortality) and early growth of kids (Alexandre et al., 1999; Menendez-Buxadera et al., 2003) rather than rapid increase in mature size and growth rate. Finally, selection must take place under the environment and the production systems prevailing in a specific region (Cunnigham, 1981; Galal et al., 2000) in order to avoid genetic–environment interaction, which are commonly encountered in the tropics (Menendez-Buxadera and Mandonnet, 2006). As an example, the famous meat breed Boer goat may have a higher proportion of muscle in the carcass than other goat breeds, but data in relation to this is far from conclusive (Warmington and Kirton, 1990). Recently, Almeida et al. (2006) outlined that extensive conditions, which are very common in tropical regions, markedly reduced the productive performances and carcass characteristics in the Boer male goat. In another sense, this classical trend to use exotic genes in order to upgrade the local ones (as it is argued) can be very hazardous, when implemented in an anarchic way, and can generate losses in biodiversity, as observed in the Leeward Caribbean islands and in Martinique (Alexandre et al., 2009).

3. Case studies

3.1. Evaluation of the climatic effects (Trinidad–Cuba)

There is a scarcity of information on effects of direct heat on tropical goats. However, in the hottest conditions prevailing in Guadeloupe, Creole bucks are heat-tolerant (Berbigier, 1988). This induces a great adaptability to water deprivations and in many cases watering is not undertaken in extensive production systems. The performance of native breeds is known to be better than those of temperate milk breeds when subjected to heat stress conditions. Thus, it is important to evaluate the general behaviour of imported exotic breeds for milk production (purebred or crossbreds).

In an attempt to improve the level of production and productivity in local goats, exotic stock was imported from the United Kingdom to Trinidad (Paul et al., submitted for publication). The objective of this study was to evaluate whether the animals were thermo-regulating normally under housing conditions provided, and to evaluate and compare the degree of heat tolerance of Anglo Nubian (AN) and Saanen (SA) purebred parent stock (PS) and their F1 generation. Trinidad lies in the humid tropics (11° North latitude and 61° West longitude). The mean daily temperature was 28.4 °C indoors and 28.7 °C outdoors during such study. The differences between maximum and minimum air temperatures were 9.2 and 5.6 °C during the dry and wet seasons, respectively. The AM rectal temperature irrespective of breed or season ranged from 38.5 to 38.7 °C, whereas PM values ranged from 38.8 to 39.0 °C. After 2 h exposure outdoors without shade, the respiration rates of the parent stock were significantly higher ($P < 0.001$) than those of their corresponding F1 counterparts (Fig. 5). The rectal temperature varied according to genotypes and location in the day but did not follow the same trend as the respiration breathing. Based on these results and reproductive traits (see milk production in the Caribbean), the authors concluded that, the Anglo Nubian goats appear to be more suitable for the tropical humid environment in Trinidad.

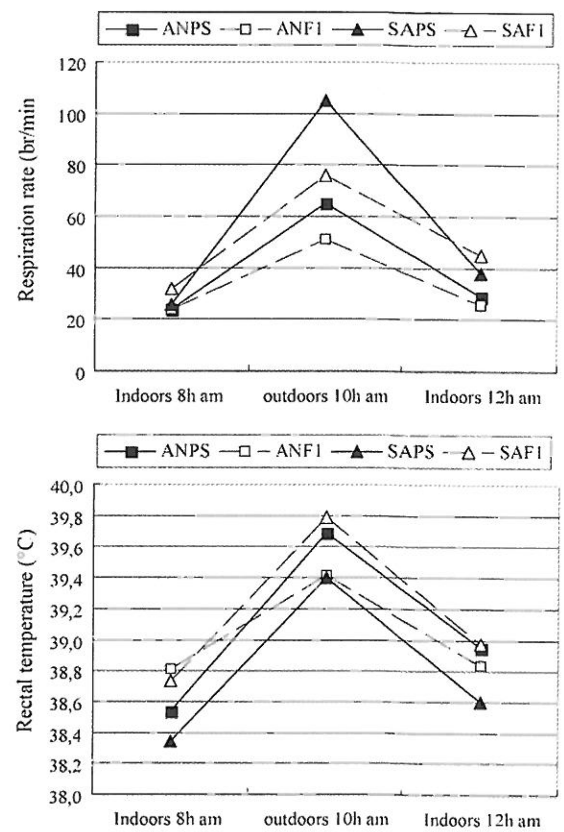

Fig. 5. Respiration rates (resp/min) and rectal temperatures (°C) for exotic dairy goats reared indoors and (8 h a.m.) after 2 h exposure outdoors without shade (8–10 h a.m.) according to breeds (parent stock, PS, and their F1 generation) SA = Saanen; AN = Anglo Nubian.
Source: Paul et al. (unpublished data).

Under intensive grazing systems in the Havana province of Cuba (23°08′N, 82°23′E) four European breeds were compared (González-García, 1997) for their suitability for milk production: SA, AN, Toggenburg (TB) and French Alpine (FA). Only TB showed well distributed estrus during the year without peaks, similar to the native genotype; the rest of the breeds concentrated breeding season mostly at the end of spring/summer with shorter days, showing high sensibility to light fluctuation rate.

3.2. Reproduction control and mating management (Guadeloupe)

Under tropical latitudes of the Caribbean and Central-America, Delgadillo et al. (1997) explained that a repeatable seasonal influence, presumably through photoperiodic signals, is found in European imported breeds and also in the local goats of some subtropical areas. The use of the male-effect allows to induce oestrus and ovulations during periods of reproductive inactivity and to increase overall fertility. The work of Chemineau (1987) explored this reproduction control technique which has been implemented very successfully in Guadeloupe (Alexandre et al., 1999; Mahieu et al., 2008) and in México, coupled when necessary with photoperiodic manipulations (Delgadillo et al., 2003; Mellado et al., 2006). It is important to highlight that this allows achieving productivity while preserving sustainability by the way of natural oestrus synchronisation without any exogenous hormonal treatments (Chemineau et al., 1991).

In Guadeloupe, reproduction is managed in order to obtain three parturitions within 2 years. The mating period is completed by systematically using the buck effect. Three 30-day mating periods, each one involving half the flock, are planned every year in mid-January, mid-May and mid-September in order to achieve an 8-month dropping interval. The corresponding kidding periods occur during the intermediate season (IS: mid-June to mid-July), rainy season (RS: mid-October to mid-November) and dry season (DS: mid-February to mid-March). The mating periods are chosen for matching periods of high meat demand in the market and work force availability. The offspring are weaned between 10 and 12 weeks of age, and the dams mated immediately after weaning. Since 1984, the reproductive performances (Alexandre et al., 1999) and thus, the results of productivity are high (Mahieu et al., 2008). The mating rate, calculated as the ratio of the number mating to the number joining, is reported to be high (93.5–95.5%). The number of services per kidding, defined as the total mating number between two successive kidding, necessary to induce a kidding, is approximately equal to 1 (1.06–1.09), thus showing how efficient the male is. The kidding interval stabilised between 245 and 250 days. The fertility rate and the prolificacy were 1.93 kids/doe. The duration of the kidding period was lower than 30 days in 97% of cases and 83–89% of does gave birth to their kid(s) within the first 21 days of each kidding period.

Based on this systematic use of the buck effect at Gardel Agricultural Experimental Station, (INRA) the mating management, aiming at an intra-breed genetic policy is as follows: the flock is made up of 250 Creole does and the management requires 12 families according to the principles of minimising inbreeding rates in small populations of domestic species (De Rochambeau and Chevalet, 1985). The other conditions are that an animal belongs to the family of its father, family sizes are uniform, and the rate of turnover of bucks and does is maximised (around 20%). Bucks are culled after three mating seasons (three per year), and does after two successive kidding failures, health problem or poor body condition. Since 1990, a rigorous breeding policy has been applied to replacement bucks and does. Breeders are born in litters of 2 kids or more (except for litters of primiparous does where single kids were also considered). Birth weight of males are chosen above 1.9 kg and for females ones above 1.7 kg. Growth rate during fattening and pasture periods are no less than 40 and 30 g/d, respectively. Finally, the family is also taken into consideration for bucks. This mass selection on prolificacy, birth weight and growth rate has had beneficial effect on flock productivity. When analysed, the flock performance database revealed a positive trend (Mandonnet et al., 2010) in the four live weight measurements commonly used by breeders (10, 30 and 70 days after birth). During this 25-year period, there was a 3.12 kg phenotypic increase in the 70-day liveweight, from which 0.51 kg was due to a genetic component. The evolution of the mean breeding value for all animals born in each season is shown in Fig. 6, from foundation animals to 2003 cohorts. During the first 10 years progress was null. After 1990 a positive and intense genetic progress on the direct genetic component occurred. However, as progress on maternal genetic component was negative, about 50% of the direct genetic progress was masked by the antagonism with the maternal genetic component. Even though the absolute magnitude of the breeding progress represents 16% of the total phenotypic progress at 70 days of age, it demonstrates the possibilities of the mass selection within a production flock.

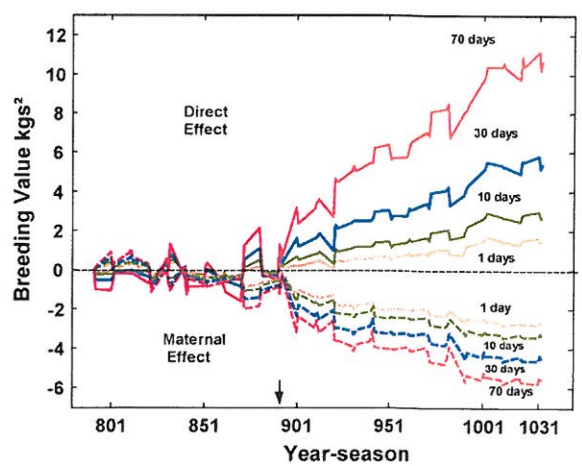

Fig. 6. Genetic progress in live weight at different ages in Creole goat for genetic direct and maternal effect (801 years 1980 season 1, 1031 years 2003 season 1), corresponding to three mating seasons per year in mid-January (season 1), mid-May (season 2) and mid-September (season 3) in order to achieve an 8-month dropping interval; years are codified 80, 85, 90, 95, 100, and 103 for years 1980, 1985, 1995, 1990, 2000 and 2003, respectively (Mandonnet et al., 2010).

Table 2
Dry matter intake and average daily gain (ADG, g) of crossbred kids in Cuba according to level of inclusion (% of LW, on a DM basis) of mulberry in the diet (González-García et al., 2001).

Item	Total DM intake		Average daily gain
	g/day	g/kg $LW^{0.75}$	
Control	392	67.7	38.0^a
0.5% mulberry	456	74.8	44.8^a
1.5% mulberry	545	86.5	76.2^b
2.5% mulberry	380	49.7	86.2^b

[a,b]Means within the same column with different superscripts differ significantly ($P < 0.05$).

3.3. Use of tree-forages (Cuba)

The use of forage trees and shrubs has been a key practice for the last two decades in Cuba in their aim to overcome national economic crisis by enhancing animal production systems with efficient use of natural and local resources. This kind of projects has also been strongly developed in small ruminants sectors, and especially in goat farming. An example is the study conducted by (González-García et al., 2001) with the objective of evaluating the level of inclusion of mulberry forage (*Morus alba*) as supplement in the rations of weaned kids and dairy goats. In the growth experiment, kids (20 weaned crossed animals of 10.2 kg of BW and 3 months old) were reared under confinement. The animals were distributed in a totally randomised design with four groups, according to the treatments: (A) control (*Panicum maximum* forage + dehydrated citrus husk), (B) 0.5% (*P. maximum* + mulberry at 0.5% of BW, DM basis), (C) 1.5% (*P. maximum* + mulberry at 1.5% of BW, DM basis) and (D) 2.5% (*P. maximum* + mulberry at 2.5% of BW, DM basis). The milk production experiment goats, under grazing conditions of *Cynodon nemfluensis*, were used to evaluate supplementation with mulberry provided *ad libitum* on milk production potential. The voluntary feed intake and ADG of growing kids as well as the milk production potential of goats was significantly improved by the level of inclusion of fresh and chopped mulberry forage in the diet. In kids, the increase of mulberry levels lead to increase in nutrient ingestion until the 1.5% inclusion (highest DMI, nutrient intake and growth rate; Table 2). In Saanen does the use of mulberry allowed a mean daily milk production up to 2.3 kg that can be compared to 2.5 kg obtained with 1.0–1.5 kg of commercial concentrate per animal daily. These studies argued the positive potential of mulberry as supplement in forage basal diets, which has been evaluated in other successive experiments with either mulberry or other woody forage species like *Leucaena leucocephala*, *Eryhtrina verteroana* or *poeppigiana*, *Albizia lebbeck* or *Bahuinia* spp. or *Malvabiscus arboreus*.

3.4. Integrated health control (Guadeloupe–Mexico)

In order to face the two main health problems in the Caribbean regions two major issues are noted: a coordinated collective inter-regional action against TBT and an integrated approach of GIN. As for the tropical bont tick (TBT) *Amblyomma variegatum*, the Caribbean Amblyomma Program (CAP), founded mainly by the USDA for the English speaking islands, and the POSEIDOM-Vétérinaire for the French West Indies, was launched in 1995 to eradicate *A. variegatum* from the Caribbean. CAP provides the stock farmers with acaricide and 'know-how' so they can successfully deal with this problem. Economical losses and associated diseases due to *A. variegatum* should be currently negligible.

In the particular cases of GIN, integrated control methods are needed to achieve sustainable goat farming (Torres-Acosta and Hoste, 2008). This means combining different actions (Fig. 7) on different stages of the life history of the parasite in order to maintain the losses due to its population under an acceptable threshold. First, one can act on the free larval stages, so that the infective larvae (L3) population is decreased when the animals graze. Epidemiological studies have assessed the variations of L3 density on the pastures, according to parasite egg contamination, and microclimate in the West Indies (Aumont and Gruner, 1989). The first L3's appear in the grass about 1 week after the egg deposition, the L3 density peaks about 2 weeks later and then decreases very sharply to undetectable levels 7–8 weeks after the egg deposition. Given that the feeding value of the pasture also decreases with ageing (Archimède et al., 2000), a compromise between these two constraints leads to the recommendation of a 5–6 paddock grazing design, each one grazed for 1 week and rested for 4–5 weeks. Trapping nematophagous fungi such as *Duddingtonia flagrans* could also be used for decreasing the L3 population (González-Garduno et al., 2005; Ojeda-Robertos et al., 2005), provided the required amounts of fungus elements are regularly supplied to animals. This is not possible at present in most of the Caribbean islands. Cattle (especially *Bos indicus*) are very resistant to SR *H. contortus* and *T. colubriformis*. Grazing cattle and small ruminants together results in diluting the pasture contamination by sheep or goat GIN. For example, the average faecal egg count of 4-month-old male lambs grazing with cattle (ratio, w/w, 1/3 sheep 2/3 cattle) was 10-fold lower than in control lambs, and their ADG increased by some 16%, without negative effect on cattle growth (Mahieu et al., 1997). Such results are currently obtained in ongoing studies of goat–cattle associations. Reducing the pasture contamination is the first step in GIN control. The second aim is strengthening the animal reaction against the parasite. Providing adequate feeding level should allow animals to cope more efficiently with GIN (Bambou et al., 2008). Ortiz de Montellano et al. (2007) reported the interest of combining copper dioxide needles and supplementary feeding for the GIN control in browsing goats in México. As for Hoste et al. (2005), they reviewed the positive effects of appropriate complementation of goats with energy, proteins, and/or tanniferous forage. Moreover, genetic studies revealed that there is a high level of genetic variability between (Baker et al., 1998) and within breed (Mandonnet et al., 2001, 2006) in goat response to GIN infection, and this variability could be used in breeding programmes. However, even a resistant breed such as the Creole goat of Guadeloupe may need some drenching during the first 6 months (and especially at weaning), or during the periparturient period. The Famacha© method

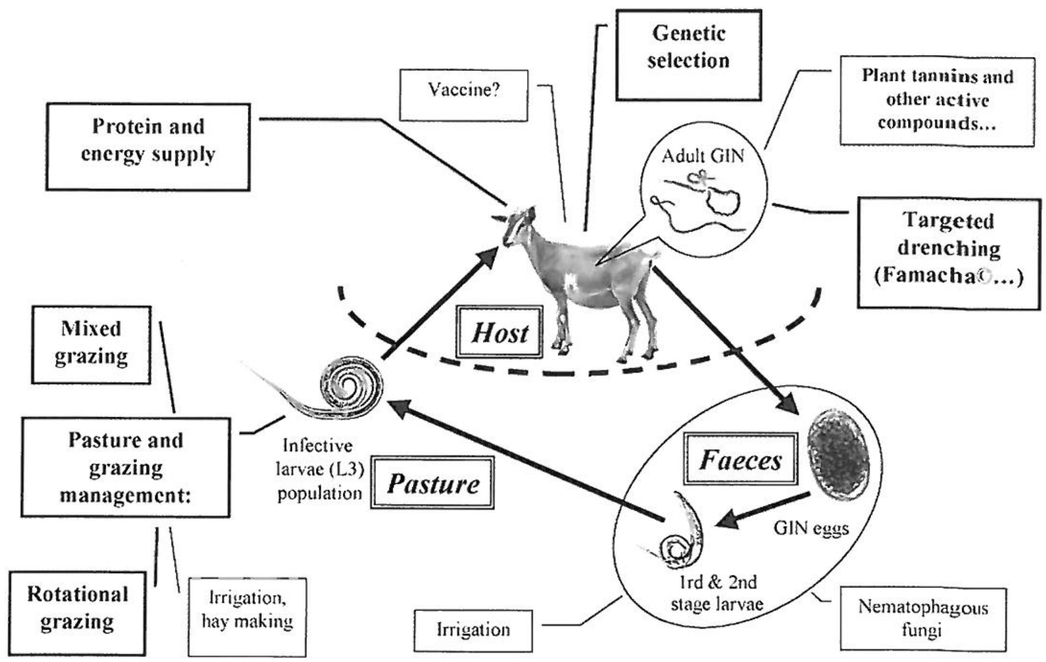

Fig. 7. Main interrelated actions included in the GIN integrated control as implemented at INRA Gardel station in the French West Indies (Mahieu et al., 2008).

has been applied to goats and allows for the survival of anthelmintic susceptible parasites in refugia by drenching only the goat unable to cope with GIN infection (Mahieu et al., 2007). Anthelmintic drenches were reduced by five times, thus providing a sound refugia since about 80% of the larval population of the pasture was the progeny of unchallenged worms (Table 3). This method is easy to run in well managed breeding flocks, and should result in delaying the spread of anthelmintic resistance in GIN population. However, young animals are much more susceptible to GIN than adults, so using the Famacha© method is somewhat hazardous and may result in large economic losses. It is probably preferable to continue systematic drenching in kids. Thus, weaned kids must share the same parasite population than the nursing dams to preserve the benefits of the Famacha© method (refugia and anthelmintic resistance delaying). That means the weaned animals must be infected by the same L3 population, so they must graze on the same pastures that the adults do. This objective could be achieved by an alternate or a leader-follower grazing design.

3.5. The case of milk production in the Caribbean basin countries (Venezuela–Mexico–Barbados)

In the Caribbean, as in many other tropical countries, goats are mainly raised for meat production (Devendra and Burns, 1983; Vokaty and Torres, 1997; Alexandre et al., 1999). However, many cases of milk production have been reported in Venezuela (González-Stagnaro, 1983; Pariacote, 1995), English Caribbean (Knights and Garcia, 1997; Paul et al., unpublished data; Thomas et al., 2008), México (Montaldo and Meza, 1999) and Cuba (González-García, 1997). In fact, goat milk is famous for its nutritive value and dairy breeds for being very efficient (Haenlein, 2004; Morand-Fehr et al., 2007), but favourable husbandry conditions are required which are not very common in the Tropics (Knights and Garcia, 1997).

According to Montaldo and Meza (1999) there are two main regions for milk production in the northern States of Coahuila and Durango and in the State of Guanajuato in central México. In both regions there are plenty of crop residues available for supplementation with the feeding

Table 3
Effects of the Famacha© method applied to a suckling Creole goat flock in Guadeloupe (Mahieu et al., 2007).

Percentage of does drenched	Famacha© group		Control group
	Doses per doe drenched	Doses per doe present	Doses per doe present
37.3 [31.3; 42.9]	1.54 [1.37; 1.70]	0.57 [0.47; 0.68]	3

Egg deposition per day per ha (×10^6)	Famacha© group Refugia (%)	Control group Egg deposition (no refugia) per day per ha (×10^6)
58.3 [52.0; 64.8]	79 [73; 85]	24.7 [20.5; 29.0]

Table 4
Milk production in Caribbean basin countries according to different goat genotypes.

Genotype	Alpine	Granadina	Local	Nubian	Saanen	Toggenburg
In Mexico (Montaldo and Meza, 1999)						
Litter size at birth	1.36	1.42		1.53	1.28	1.58
Mortality 0–90 days (%)	33.5	24.1		37.2	33.9	45.6
Milk production total (kg)	470	371	299	338	513	450
Metabolic weight (MW) (kg)	17.4	17.1	16.8	18.2	17.7	16.8
Total (kg/MW)	27.0	21.7	17.8	18.6	29.0	26.8
In Venezuela (Dickson Urdaneta et al., 2000)						
Milk production total (kg)	262			137		
Duration of production (days)	272			210		
Mean milk production (kg/day)	0.95			0.65		
In Cuba (González-García et al., 2001) (mean milk per day)						
Litter size at birth	1.37			1.45	1.33	1.48
Mean milk production (kg/day)	0.85			0.80	1.00	1.10
In Barbados (Thomas et al., 2008; 200 days of lactation; Alpine is British Alpine)						
Fertility rate (%)	80				92	80
Milk production total (kg)	343				317	332

based on pasture. Most milk producers use some crossbreeding involving French Alpine (FA), SA, TB and to a lesser extent, AN and Granadina goat. Intensive systems are developing in central Mexico with high grade or purebreed SA, FA and TB goats. There appeared to be a high environmental effect in this study. Alpine does observed an increase of 329% for milk production and 121% for prolificacy when comparing the grazing system to stall fed one. Corresponding values for WDB were 304% and 111%, respectively. The FA and SA goats exhibited better performances, even when survival rate was considered, while the Granadina and AN goat had a shorter kidding interval and were less seasonal than the breeds of Alpine origin.

In Barbados (Thomas et al., 2008) during the mid 1990s goat milk became a popular product among health conscious populace. Three goat breeds were imported from the United Kingdom, namely, British Alpine (BA), SA and TB. The goats were grazed on improved pastures consisting of *Cynodon* spp. *Digitaria decumbens* and the legume *Macroptilium atropurpureum* and offered an 18% crude protein dairy ration. The TB breed significantly out-performed the other breeds in milk production (Table 4) and quality, and on this basis should be the breed of choice for local conditions. In Cuba González-García (1997) reported better milk production and prolificacy for TB compared to FA, SA and AN (Table 4). Thus, comparisons did not follow the same trend in breed classification and probably depended on biophysical and feeding conditions, but also on the genetic merit of the animals imported from different origins (country, farm, pedigree).

Taking into account reproductive parameters and mortality rates, comparisons can be inconclusive. In a Montaldo and Meza (1999) study, high levels of kid mortality were reported (from 24 to 45%). In Barbados (Thomas et al., 2008) approximately 30% of Anglo Nubian and 40% of all Saanen kids died in the pre-weaned period, with no genetic or sex effects. In Venezuela, González-Stagnaro (1983) established that mortality can reach up to 60% for the pure FA and AN, and 30–40% for their counterparts crossed with Criollo goats. Pariacote (1995) demonstrated that although there is a considerable genetic distance between native and improved breeds, regarding milk production traits, such a distance tends to cancel out as the animal become older (from first to third lactation). This would be associated to lower reproductive performances of the improved breeds under the new environmental conditions to which they are exposed. The F1 crossbreed criollo-exotic surpassed the best of the pure breed due to the well known F1 heterosis (Table 5). It has also been shown how the F2 crossbreds exhibited the lowest values for reproduction and milk production due to the heterosis loss. This underlined very relevantly how important it is to maintain the maternal lineage at the country level, before implementing a crossbreeding program. In Venezuela, contrary to the initial hypothesis, the continuous introduction of specialized germplasm, far from improving, has significantly eroded the Creole gene pool. In most cases the Creole has been absorbed by the new breeds. Rotational and backcrossing to Creole is not common. Nevertheless, the Creole genes continue to be the most abundant ones, but are diluted in crossbred populations. The pure population of Creole would be threatened to risk of extinction unless special attention was paid to its interest for the region.

Table 5
Relative value of the Creole (CC), Nubian (NN) and Alpine (AA) breeds, and of their crosses for milk and meat production and reproduction (Pariacote, 2007).

Breed group	First lactation yield	Six months LW of kids	Kids weaned per doe/year
Pure breeds			
CC	1.00	1.00	1.00
NN	1.93	1.40	0.42
AA	3.13	1.71	0.50
F1 crosses			
NC	1.39	1.57	0.76
AC	2.51	1.60	1.08
F2 crosses			
3N1C	1.41	1.39	0.58
3A1C	1.70	1.73	0.43

3.6. The case of Creole goat in the Caribbean basin countries (Guadeloupe–Venezuela–Trinidad)

In Latin America, most livestock were brought in by Columbus and colonizers, and the descendants of those animals have been commonly grouped in the literature as Creole goat in Trinidad, "chèvre Créole" in Guadeloupe or "cabra Criolla" in Venezuela. The commercial exploitation of the Creole goat began once the colonizers were settled (Patiño, 1970; Naves et al., 2000). Large range-management herds arose, where the number of animals was probably the key factor for profitability of the system. The natural resources were abundant and carelessly exploited, and the Creole goat was raised without any breeding criteria or commercial approach in particular. The exploitation, for a long time, seemed to have been for the skin and the manure rather than for the meat and the milk. Under such a condition, the natural selection might have favoured adaptive traits in damage of productive ones; that will explain some how the current low and high genetic capacities of the Creole goat for those traits, respectively. The current exploitation of the Creole goat in many Latin American countries ranged from the only specie specifically raised for meat in large herds in areas with abundant pastures, to a complementary or integral part of the systems species, in small agricultural units, particularly in the mountain or cropping areas (Pariacote, 2001, 2007). The rationality of the exploitation varies among regions, but in any case seems to be neither a breeding criterion nor a commercial raising approach definition for selection. The current variation among subpopulations together with the size of the population are indicators of the potentiality of the "cabra Criolla" for the region (Pariacote et al., 2004; Pariacote, 2007). However, such a variation has not been well managed. Although some breeds have arisen from the Creole population (Mariante and Cavalcante, 2000; Naves et al., 2000), breeding is not a common practice, and programs for the conservation and improvement of this indigenous breed are almost nonexistent.

In contrast, in the small island of Guadeloupe there is an ongoing breeding plan with the local Creole goat that has been described elsewhere (Alexandre and Mandonnet, 2005; Mandonnet et al., 2008). Through different activities explained by Naves et al. (2008), combining *in situ* and *ex situ* methods for research and breeding purpose, INRA-Guadeloupe is highly committed to the characterization, preservation and improvement of local genetic resources valuable for the humid tropics. Keeping this INRA approach in mind, researchers in Trinidad are now beginning a study of the description and characterization of the Creole goat of Trinidad (Borely, 2009) with a long term objective of promoting dual-purpose animals which would probably be best suited for the local sector, as demonstrated elsewhere in the Tropics (Ahuya et al., 2005).

4. Conclusion

To be successful, initiatives to improve farmer's goat production should directly address the needs and objectives of the keepers while promoting rational use of local feed resources and indigenous breeds. The difficulty arises because a large number of factors of diverse nature are intricately linked to the system. This paper argued that goat production, like other animal farming systems, must be thought about as a function of the genetic resource, the biophysical environment, the cultural environment or technology acting as man's integral part, the extrinsic environment as global and local economic and socio-political regulations, and their interactions. From this conception, it seems that: (i) the model is multifactor and can be demonstrated not to be an additive one, therefore the challenge should be to combine, in a harmonic way, factors from the different components that optimises the response; (ii) the response can be adjusted, in a given biophysical and extrinsic environment, by searching the animal genetic resources to be used and the technology to be applied; (iii) the ideal combination of factors can vary from one situation to another, due to interactions; (iv) the success of the system will always depend on the local knowledge available about each component; (v) a minimum understanding of those components is required to be able to evaluate or build coherent and successful development plans; (vi) any action should be evaluated in a multidisciplinary way which helps us understand how, with others factors fixed, the action affects the response; (vii) a full comprehension of the system requires knowledge from several disciplines, making it very unlikely to be done by a single professional alone. The model evaluates the sustainable evolution of any livestock production system. However, what is favourable or desirable is not a constant; in fact, it will naturally depend on the local strengths, the link of the chain at which the decision is being taken, and more fundamentally on the policy makers.

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