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Literature review

Small ruminant production systems in Mexico and their effect on productive sustainability

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ABSTRACT

In the small ruminant sector, there is a great interest in measuring and improving their production systems and their environmental performance, since its great adaptability and inhabits a wide variety of ecosystems, with a great biodiversity of food resources, grazing in turn, generates economic-productive and environmental benefits. However, unplanned management and overexploitation of the natural resources of these areas have caused erosion, water depletion and even desertification, in the same manner intensive production systems and intensive agriculture that feeds these farming systems. To compare scientific innovations in the sustainability of the different production systems of small ruminants a bibliometric analysis was carried out to describe the advantages and disadvantages of the management of extensive, semi-intensive and intensive-stable production systems in the sustainability of small ruminants. There is concern in society about the environmental impact of animal production systems and that these have been carried out in a sustainable way. This trend influences the production of sheep, goats, and white-tailed deer, which are develop in intensive, semi-extensive and extensive systems. Due to the pressure to increase the volume and efficiency of production and to cope with demand, intensive systems are best suited, but face greater environmental problems such emission of greenhouse gases (GHGs), which contribute to global warming and animal welfare problems. On the other hand, semi-extensive and extensive systems also emit GHGs, however are associated with greater animal welfare and cleaner production. However, are affected by seasonal variations for forage production to maintain production levels.

Keywords: Extensive; intensive; goats; semi-intensive; sheep; sustainable; white-tailed deer (*Fuente: CAB*).

RESUMEN

En el sector de los pequeños rumiantes existe un gran interés en medir y mejorar sus sistemas de producción y desempeño ambiental, pues poseen una gran adaptabilidad y habitan distintos ecosistemas, con una gran biodiversidad de recursos alimenticios, el pastoreo genera beneficios económico-productivos y medio ambientales. Pero, el manejo no planificado y la sobreexplotación de

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recursos naturales de estas zonas han ocasionado erosión, agotamiento del agua y desertificación, lo mismo ocurre con los sistemas intensivos de producción y la agricultura que alimenta estas explotaciones. Para comparar innovaciones científicas en la sustentabilidad de los diferentes sistemas de producción de pequeños rumiantes, se realizó un análisis bibliométrico para describir las ventajas y desventajas del manejo de los sistemas de producción extensivos, semi-intensivos e intensivos en la sustentabilidad de pequeños rumiantes. Existe una preocupación de la sociedad por el impacto ambiental de los sistemas de producción y que se realicen de manera sustentable. Esta tendencia influye en la producción de ovinos, cabras y venado cola blanca, que se desarrollan en sistemas intensivos, semi-extensivos y extensivos. Dada la presión para aumentar el volumen y la eficiencia de la producción, los sistemas intensivos son más adecuados, pero enfrentan mayores problemas ambientales como, la emisión gases de efecto invernadero (GEI) y de bienestar animal. Por otro lado, los sistemas semi-extensivos y extensivos también producen GEI, pero se asocian con mayor bienestar animal y producción más limpia, pero se ven afectados por las variaciones estacionales para la producción de forraje para mantener los niveles de producción.

Palabras clave: Caprinos; extensivo; intensivo; ovinos; semi-intensivo; sistemas de producción; sustentabilidad; venado cola blanca *(Fuente: CAB)*.

INTRODUCCIÓN

The production systems of small ruminants such as sheep, goats, and wild ruminants (mainly white-tailed deer), represent an important productive resource in many countries around the world. Furthermore, they produce benefit effects on the environment. Some of the interventions that they are being done in the sector to keep their exploitation profitable and sustainable. Its main products are wool, meat, and milk. While wool production is generally associated with extensive systems, meat production and especially milk production are associated with semi-intensive or intensive systems (1).

The small ruminant sector has global importance, sheep/goats are approximately 2,200 million heads (2). The world production of sheep and goats in 2018 was 15.7 million tons of meat and 29.3 million tons of milk (2). About 56%, 27% and 21% of the world's small ruminants are found in arid, temperate, and humid areas, respectively. Small ruminant production plays an important socio-economic role, helps in the management of ecosystems to conserve biodiversity and to provide niche products for each market (3).

In Mexico the production of sheep and goats is an economic option to face poverty in rural areas, due to the amount of income and the number of producers (4,5). In the case of sheep, the national inventory is 8.6 million heads (6), in 50,000 production unit. Around of 34% of the producers only income from sheep production. The temperate zones of the center of the country demands 85% of the sheep meat consumed at the national level (5). On the other hand, the national goat inventory is 8.7 million heads, this places Mexico in 13th place in the world and second in the American continent, after Brazil. The herds are located mainly in the states of Puebla, Oaxaca, San Luis Potosí, Coahuila, Guerrero, Zacatecas, Nuevo León, Guanajuato and Michoacán (4).

The white-tailed deer (*Odocoileus virginianus*), this is only distributed in the American continent, México benefits economically from the use within UMA's (Management Units for the Conservation of Wildlife, according to the General Law of wildlife) and its regulations (DOF 06-06-2012) is the legal framework where the regulation of the use of wild fauna is addressed. It establishes two types of exploitation: extractive and non-extractive; extractive include hunting, hatcheries, decoration, food, inputs for the industry, crafts, and exhibition, while the non-extractive ecotourism, research, environmental education, photography and video (7). The hunting exploitation of the white-tailed deer is the one that generates the highest economic income, including the subspecies *O. v. texanus, O. v. carminis* and *O. v. miquihuanensis* (8). With a high economic value (up to $ 5,000 US dollars/person), the white-tailed deer hunt is the deer harvesting system through the UMAs that has been successful in the northern states of México (7). Although, the use of genetic manipulation practices or the supply of growth promoters has also been reported, resulting in males with massive and deformed antlers that become an impediment to movement, destined for hunting, considered a controversial practice (7).

In addition, in Mexico there are 14 subspecies of deer and their exploitation has an impact on the native carnivorous fauna due to the use of non-validated management measures to reduce losses due predation, such as traps and poisons, mainly for coyotes (8).

Therefore, in the small-ruminant segment, there is great interest in measuring and improving their production systems and their environmental performance, since they have a wide variety of management and feeding systems (Table 1). These species have great adaptability and inhabit a wide variety of ecosystems, with a great biodiversity of feed resources and subjected to different fluctuations in environmental conditions (9). The grazing in turn, generates economic-productive and environmental benefits. Whereas, not planned management and overexploitation of natural resources in these areas led to erosion, water depletion and even desertification (10), in the same manner the intensive production systems and the use of intensive monoculture agriculture that feeds these stabled farms. The integral management of productive systems and ecological ordering are useful actions to face environmental problems and continue the production of goods of animal origin for society (11), through the application of sustainable development policies, prioritizing the value of water resources, the management of feed and manure, for the mitigation of greenhouse gases (GHG), that generate global warming (12). Therefore, the objective of this paper is to compare the management between the extensive, semi-intensive and intensive production systems of sheep, goats, and white-tailed deer, together with the environmental problems that affect or are attributed to them.

Intensive systems

In this system, the sheep/goats are housed, and the feeding must be balanced to achieve high levels of milk and/or meat production for specific markets (1). They are provided with accommodation, veterinary care and integral diets, added with vitamins and minerals, as well as cut pastures, ensiled or hayed, also the incorporation of legumes (18) and more soluble concentrates in the diet to favor the reduction of methane (CH_4) (19).

Generally, involves an increase in one or more inputs to increase total production (high-quality food, labor, and the veterinary stock supplies). According to Gallo and Tadich (20), in South America, the production of cattle and small ruminants are mainly characterized by grazing and an extensive system, while pig and poultry production are associated with intensive systems; they are also considered to cause more environmental problems such as inadequate management manure (generates nitrous oxide, N_2O), reduction in the air and water quality (deposition of nitrites and phosphates), soil degradation and loss of biodiversity (11), problems that decrease its sustainability.

The increase in animal density could be associated with problems in normal behavior patterns, increased risk of aggressive interaction between animals and transmission of infectious diseases. For these reasons, greater overall control of the facilities is required. Likewise, for the production of meat and milk this system requires the improvement of forages and a correct supplementation of grains to avoid nutritional imbalances (21).

The intensive small ruminant systems for dairy production are better known in Europe, increasingly in North America and New Zealand (1). According to Aréchiga et al (4), approximately 6% of the goat population located in developed countries produces 25% of the world production of goat milk, compared to Asia and Africa with the 85% of the world goat population produce 64% of the world production of milk, this difference is mainly due to the higher technological level, economic profitability and the implementation of sustained genetic improvement programs. However, intensive small ruminant milk production systems are randomly distributed in developing countries where there is a niche market. Also, Yusuf et al (22), indicated that surveyed sheep/goat producers in Nigeria, 44% use the semi-intensive system, 38% the intensive system, and only 18% the extensive system, associating this change with an improvement in production and profitability. In Mexico, intensive goat milk production systems are found in the region of La Laguna, El Bajío and the center of the country, where milk of optimum quality is produced with high production levels than extensive systems (23).

The case of deer, has been reported that the intensive rearing of fawns habituated to people can have excellent results to increase and reproduce populations of deer with excellent characteristics and consists of keeping individuals in enclosures where they are fed with milk formula, forages and concentrates depending on the state of maturity of the deer (17).

Table 1. Summary of different case studies of extensive, semi-intensive and intensive small ruminant systems.

Specie	Type of system	Additional handling	Productive parameter	Interaction with the environment	Observations	Author
Goat kids	Extensive	Milk and grass grazing	ADG= 113.5 g	Seasonal variation affects forage production	Recommended for good quality forage.	Herrera et al (13)
	Semi-extensive	Milk and alfalfa	ADG= 127.5 g			
	Intensive	Milk formula 3 d old, concentrate and alfalfa	ADG= 96.0 g		Recommended if the milk is to be transformed into a product of high additional value.	
Goats/ sheep	Extensive	Continuous grazing	Lower DM yield, 30 to 471 kg/ha	35% vegetal coverage	Animals put more grazing pressure to meet their requirements.	Echavarría-Chairez et al (14) con pequeños rumiantes. El estudio se realizó en agostadero (53 ha
	Extensive	Rotational grazing	Higher DM yield, 101 to 1,151 kg/ ha	60% vegetal coverage	Helps to maintain the botanical composition of the grassland.	
Sheep	Extensive (SPS)	Voisin grazing in Pangola (*D. eriantha*) associate with Guaje (*L. leucocephala*)	Higher annual yield with 25,000 trees (15,958 ± 1190 kg DM / ha), LCC (2.93 AU/ha).	The *L. leucocephala* takes advantage of seasonal rains to maintain growth and mitigates production of CH_4.	This management maintains the availability of forage throughout the year, even with a prolonged dry season.	Azuara-Morales et al (15)
Sheep	Semi-extensive	Festuca grass (*S. arundinaceus*) + 0.5 kg of wheat.	CP=16.8% Forage availability = 5,050± 80 kg/ha ADG= 880 g	Grassland expansion puts pressure on native forests and other ecosystems.	Festuca grass, suitable for a 6-week winter grazing	Pent and Fike (16)
	Extensive (SPS)	Festuca grass (*S. arundinaceus*) + (*G. triacanthos*), honeylocust pods.	CP=18.5% Forage availability =5,140 ± 90 kg/ ha ADG= 890 g	Trees facilitate infiltration of water, nutrients, carbon sequestration, forage, and shade.	*G. triacanthos* pods were more nutritious compared to supplementation of 0.5 kg of wheat, but require adaptation	
Fawns	Intensive	Milk formula 4 times at day for 4 weeks after that concentrate, water, and forage *ad libitum* were offer for 9 weeks.	ADG=130 g females	Improvement of wild populations and natural habitat.	No differences were observed with males raised on bred naturally.	Ramírez-Torres (17)
		Bred naturally with the mother	ADG= 150 g females			

ADG: Average daily gain, DM: dry matter, g: grams, kg: kilogram, Ha: hectare, CP: crude protein, SPS: Silvopastoral system, AU: animal unit, LCC: Livestock carrying capacity.

Semi-intensive systems

The sheep/goats graze and browse in pasturelands with natural or planted vegetation and when they return to the pens and facilities, they are supplemented with concentrates and forages (24). In white-tailed deer, this system includes zoos and hatcheries that operate in fenced areas, generally small. Many hatcheries, owned by cooperatives of communal Land holders or small producers, require in many cases better training in management (nutrition and health) and merchandising (7).

In Mexico, most of the goat inventory is located in arid zones, which cover more than 50% of the country's surface and more than half of the vegetation is xerophilous scrub. Most of the agricultural investment is found in arid zones, as well as extensive and semi-intensive livestock farming. Pasture-dominated areas have been devoted to producing calves for export. This development system produces a large amount of agricultural waste, creates rural unemployment, and leaves large tracts of land without means for irrigation, with bad weather, poor water sources and whose flora does not favor the development of extensive cattle ranching. The agricultural waste, available workforce and the shrubland, have been the bases for the persistence and sustainability of a type of semi-intensive goat cattle system (4).

As stated by Yusuf et al (22), the semi-intensive system is used by small Nigerian producers to produce meat and milk, in their herds some have both goats and sheep, they feed their animals through grazing and browsing, with supplementation (basic as the block of salt to multi-nutritional blocks). Also, the production system influenced the amount and composition of the milk in goats, with greater production being observed in semi-intensive silvopastoral production system, which can be attributed to a better selection of the forages by the ruminants (25).

Semi-intensive and intensive conditions can guarantee that requirements of the animals for feed and water are satisfied more easily or efficiently (in addition to being protected from extreme climates). Contrary to intensive systems, society considers that extensive or grazing systems, allow greater animal welfare, but, seasonal variation and the presence or absence of precipitation can lead to low forage production, and consequently, drastic reductions in production and body condition of the animals that graze in these pasturelands (20,25), a problem that, does not occur in an intensive system since the stall feeding aims to maintain high levels of production.

Extensive systems

In this system, goats and sheep graze and browse freely with or without supervision. The main advantage of these systems is that they convert fibrous plant material such as grass, leaves of trees and shrubs with forage potential into useful products for human and thus allow him to live in ecosystems that are not viable for agriculture like arid and semi-arid regions (26). Also, the white-tailed deer carried out from its natural habitat and the exploitation of the species is historically for hunting purposes (27).

Relying entirely on grasslands, in Africa, pastoralists move from one part to another in search of places with more vegetation (28). This migratory movement is of two types: Nomadism and Transhumance. Nomads move from one place to another with their herds, while transhumant are those with permanent settlements to which they return after spending long periods of time in other places with their herds searching for food and water. Extensive goat and sheep meat production systems that are fed on forages and pastures increase profitability for producers, despite, their sustainability and productivity vary due to seasonal and climatic changes along with the nutrient content of forage, as reported by Herrera et al (13), for the production of goat meat.

In countries where production systems are based on grazing and semi-intensive systems, such as New Zealand, livestock input to GHG emissions is considerably higher (29). In semi-arid regions, legume and non-legume species according to the season and fodder availability are used as feed by browsing (30), due to a content relatively high in nutrients throughout the year and because they contain satisfactory levels of proteins and minerals, while maintaining or improving grassland availability (31,32). However, legume trees and shrubs contain a greater variety of plant secondary metabolites (PSM), such as tannins, the presence of these compounds could present a challenge for their consumption as a feed resource (33). The negative effects of PSM may be due they can reduce feed intake and nutrient utilization, and as consequence of the productive performance of the herds, in general. A high content of PSM may affect the use of energy and metabolizable proteins (34), although it has been shown that moderate levels of PSM did not excessively affect the degradation of the foliage of tropical shrubs and trees by small ruminants (35).

It has been reported that the leaves of some trees and shrubs with forage potential show a low potential for methane (CH_4) production and could be used as alternative for GHG mitigation in semi-extensive and extensive systems of production of small ruminants in developing countries (36), and within the extensive system, the silvopastoral system (SPS) integrates high densities of forage trees and shrubs, to increase productivity and improve the nutritional quality of the forage, seeking to be productive throughout the year under appropriate management. Then it is inferred that the SPS offer a higher amount of forage and of better quality in relation to the usual extensive systems, even though there are variations in the availability of biomass during the year, the supply of forage is sufficient to cover the ruminants requirements (37).

Azuara-Morales et al (15), showed that the availability of forage increased in a case study of an SPS with two densities of Guaje (*Leucaena leucocephala*) associated with Pangola grass (*Digitaria eriantha*), and under a Voisin grazing system with sheep. The crude protein (CP) concentrations of both pastures (86–118 g kg^{-1} DM) and Guajes (234–247 g kg^{-1} DM) were in the range of their species, this management protocol maintains forage availability throughout the year, even with a prolonged dry season (although rain is an important factor for the recovery of the plant), contributing to the maintenance of forage biomass without the use of irrigation or chemical fertilizers and the use of Guaje has been associated with the reduction of emissions of CH_4 by cattle (38). Also, Pent and Fike (16) reported that browsing in temperate and cold weather under a SPS with *Gleditsia triacanthos* (which produces nutritious pods that could serve as supplementary forage), in a winter grazing of 6 weeks shown more CP, forage availability and daily weight gain (Table 1). Along with the above, SPS with *G. triacanthos*, incorporates ecosystem services (water infiltration, nutrient cycling, and carbon sequestration) and trees can provide shade, protection and browsing.

It has been reported that rotational grazing has a positive effect on the improvement of the water infiltration variables, better use of the soil and the vegetation benefits as it allows the accumulation of organic materials. The foregoing leads to the incorporation of grazing management, like adaptative rotational grazing with low stock densities to allow sustainability of forage production to maintain growth rates for ruminants, while still providing spatiotemporal variability and multiple ecosystem services (39), or Voisin grazing systems in a traditional extensive or SPS, as useful tool. The vegetation cover was 60% and 35% for rotational and continuous grazing, respectively (14). Likewise, to the extent that grasses are used with a higher density of trees and shrubs as a source of forage, they help to store carbon, symbiotic fixation of atmospheric nitrogen to the soil by legumes, increase animal welfare and production (29,40), in this way to improve the sustainability of the system. The intensification of agropastoral practices its seen as a way to reduce the pressure on native forests (41), caused by the increase in intensive agriculture that has incentives for further expansion of monoculture and induced grazing in forest frontiers. Under extensive production systems, animals are free to move, allows better physiological activities and behavioral functions. However, grazing can also negatively affect welfare, due to seasonal fluctuations in the quantity and quality of the forage source; consequently, grazing animals are generally subject to seasonal nutritional stress (21), poor nutrition results in low reproduction rates, high mortality rates, and low production of both meat, milk, and healthy offspring (42).

Quality of rangelands

Rangelands are natural extensions of land that function as a source of food for domestic or wild ruminants that involve the relationship of grasslands, shrubs and trees that are consumed while these graze these areas, grazing is an important tool in countries with large areas of rangeland like Australia according to McKeon et al (43), the productivity is based on the management and type of livestock, climatic conditions, soil type, elevation and topography. Associated with the concepts of semi-intensive and extensive systems, grazing is used to maximize or optimize biodiversity values in nature reserve management, while in grassland management, its objective is to maximize animal production (44).

Livestock carrying capacity

The range coefficient is an index that expresses the number of hectares (ha) necessary to maintain an animal unit for a determined period of permanence of the cattle in the range, which results in the livestock carrying capacity (LCC), according to Villarruel-Sahagún et al (10), with information from "Technical Advisory Committee for the Regional Determination of the Stocking Rates" of Mexico. But there is a need to know sustainability, maintaining a certain level of stability of the ecosystem, this is driven by pressure, composition and grazing regime, so there are other methods to determine the LCC (Table 2), such as suggested by Johnston et al (45), who defined "safe" animal carrying capacity.

The LCC calculation involves estimates of the production and safe level of forage utilization (43). The above model could be applied to grazing mainly in grassland areas, but with the capabilities of small ruminants to browse tree and shrub leaves, the model described by Holechek et al (46), considers the surface, the available biomass of trees, shrubs, herbaceous and grasslands, the average weight of the animal and the percentage of each species in the diet, therefore, it may be more successful in extensive systems with silvopastoral complement.

In a previous study by Ebrahimi et al (44), includes the impact of another correction factor such as the "palatability index" and its relationship with the "harvest coefficient", the result of the model shows a higher level of complexity, also included , other reduction coefficients such as bush obstacles, steep slopes and water supply distance. He determined that a high harvest coefficient, when the vegetation has a low palatability index, results in a low LCC. The use of these coefficients in models can help to the protection of palatable but vulnerable plant species, determined low LCC or reverse the invasion of grass or scrub, with grazing densities temporarily increased (47).

Table 2. Models for calculating livestock carrying capacity.

Model	Description	Observations	Author
LCC=D/(AU*t)	Where, LCC; livestock carrying capacity, D; Forage or biomass production in kg DM/Ha, AU; Animal unit, t; period of permanence of livestock in the rangeland.	AU is generally represented by a 450-500 kg cow with calf that consumes 3% of its BW in DM, in the case of goats/sheep, the equivalence of AU = 0.20 is used, and in adult white-tailed deer its AU = 0.15.	Azuara-Morales et al (15)
LCC "Safe" (AU/D) = [Amount of forage that can be safely eaten (kg/ha/year)/ VFI (kg/ha/year)] x rangeland size (ha)	Where, AU; animal unit, D; DM availability of land use system, Amount of forage that can be safely consumed (kg/ha/year) = [Safe level of forage utilization (%)/100] x Annual average of cultivated forage (kg/ha/year). VFI; voluntary feed intake.	Defined "safe" livestock carrying capacity as; the number of AU or its equivalent, which can support a long-term range or paddock without any decline in pasture condition and without accelerated soil erosion.	Johnston et al (45)
K = (D) (HC= 0.35) (A)/(BW)(VFI)(GC)	Where, K; corresponds to the value of load capacity, D; is the total DM availability, per plant stratum (kg/ha), HC; (harvest coefficient or forage utilization percentage) = 0.35, A; study area, BW; body weight of the animal, VFI; voluntary feed intake, GC; grazing cycle (365 days).	The "HC" is a factor that adds the appropriate use to the ruminant or correction for the condition of the habitat and the specific management objectives, in this case "0.35" is for white-tailed deer	Holechek et al (46)

Dry matter, Ha; hectare.

The incorporation of geography information systems, to determine distances, terrain orography, and even tree volume, can be useful tools (48). In any case, these are adaptations applied to a greater or lesser extent in the mentioned models, for a better knowledge of the ecosystem, the quality of species and a clear definition of the objectives that will lead to the determination of the appropriate LCC to maintain the sustainability of the production system.

Sustainability

The sustainability of a production system must be related to a pattern of use that preserves the natural environment and these needs can be satisfied not only in the present, but also in future generations (24). Intensive systems can maintain production, but their effect on the environment requires specific actions, on the other hand, extensive production systems also have real and potential limitations to respond to the demand imposed by the needs and perception of the consumer (21). Uncontrolled grazing, due to ignorance of the biomass production of the rangeland, can lead to the proliferation of species not consumed by ruminants, soil degradation and a loss of plant cover. Consequently, the LCC must be calculated based on updated environmental characterization and monitoring programs (10), which identify the growth periods, the preservation of consumed species, as well as avoid overgrazing and to take advantage of the biomass production levels adequately. The improvement of the grassland use system must include the recovery of plants and forage productivity beyond the rainy season (15).

As well as the management and care of natural areas, grazing, can avoid the predominance of trees and shrubs, this creates opportunities for phytocenosis associated with the ecosystem. The same forests benefit from grazing as reported by Ruiz-Mirazo and Robles (47), that grazing sheep reduced the plant biomass that could function as fuel in forest fires in Holm oak (*Quercus rotundifolia*) forests, although it increased the bare soil, due to a deficit of rain, this can be fixed with a correct estimate of the LCC and this hardly produced changes in the botanical composition and diversity of forage. Many landscapes are maintained through a combination of herding and direct human labor to maintain their livestock (11).

Grains and cereals are increasingly necessary for human nutrition and increase in the price for feeding animals (49). Small ruminants can be part of a sustainable system in the future, their production can be based on more fibrous feedstuffs inedible by humans, ensuring that they meet their nutritional requirements (50), for example, the diet of white-tailed deer, in different ecosystems are composed of 55% shrubs, 30% trees, 13% herbs and 2.0-1.0% grasses (51,52). Using and maintaining these resources and provide ecosystem services to cities and communities (16,40), and small ruminants can produce meat, milk, wool and even furs for society.

The global and web media are causing social change faster than at any time in history. The new generations aspire to the standard of living of the most developed countries and no longer want to live in rural communities. Although extensive goat and sheep systems can be ecological, their returns to work are low and they are not producing the income levels to sustain the next generation, leading to migration to large cities, abandonment of the native places and the disappearance of herds (24). The concern of some researchers for the future of rural systems in northern and southern Europe, also being a problem in rural areas of Mexico, where the herds of goats and sheep are found (4,5). Subsidies and technical advice will be necessary to preserve rural systems and lessen concerns about whether the next generation of goat and sheep farmers will be willing to continue this tradition in their native places.

Although, extensive and semi-intensive systems, especially SPS, a prototype of agroforestry with a livestock component, which can be categorized as clean production, since they provide a variety of goods and services to society, such as mitigating climate change (40,53). Intensive livestock production systems have been associated with important environmental problems derived from high animal densities, manure management, water quality problems and disease transmission, and intensive crop production systems to supply these productive units and society faces soil threats, surface or groundwater quality, loss of biodiversity due to monocultures, and other environmental problems (40).

Nevertheless, the increase in the human population and urbanization promote the reduction of the area available for grazing either in a traditional or silvopastoral production system, so the intensive system is gradually becoming the most viable option in the future to meet the needs of the population (42,54).

The production of GHG, another of the main environmental impacts attributed to livestock production, these contribute to global warming, which in turn, affects the production systems of small ruminants causing reduction of meat and milk production due to heat stress, metabolite imbalances (glucose and minerals) and transmission of emerging and parasitic diseases (3). The CH_4 and N_2O come from the enteric fermentation of carbohydrates and the handling of manure and CO_2 from respiration. In small ruminants, CH_4 emission is related to enteric fermentation and the accumulation of excreta, while N_2O seems to depend only on the production of feces (55). Agriculture and livestock contribute 47% of anthropogenic CH_4 emissions, with ruminants responsible for 39% of enteric methane emissions, which cattle contribute 77%, buffalo 13%, and small ruminants 10%. Wild ruminants are estimated to range between 2.5 and 7.7% of CH_4 and showed a global warming potential 25-34 times greater than CO_2 (56,57). For its part, N_2O has a warming potential 298 times greater than CO_2 over a time horizon of 100 years, but due to the lower amount produced, its effect is lower than CH_4, even so, it also depletes stratospheric ozone and is expected to continue into the century (12,57). Production systems can also affect GHG emissions, grazing (ruminants), semi-intensive (ruminants) and intensive (includes ruminants and monogastric) represent 30.5%, 67.29% and 5.51% for the total emission of CH_4 (from enteric fermentation and manure management) and 24.32%, 68.11% and 7.57% for N_2O, respectively (12). The carbon footprint is an increasingly important method to communicate the impacts of production on climate change (3).

In overall, cattle are the largest GHG emitters with around 5.0 gigatons of $CO_{2\text{-eq}}$, which represent 62% of all emissions. Beef and dairy cattle emit similar amounts of GHG. Pigs, poultry, buffaloes, and small ruminants have lower emission levels, accounting for between 7% and 11% of total emissions (9,58). Regarding the final product, bovine meat and milk are the largest emitters: 2.9 and 1.4 gigatons of $CO_{2\text{-eq}}$, respectively, pork (0.7 gigatons of $CO_{2\text{-eq}}$), meat and buffalo milk (0.6 gigatons of $CO_{2\text{-eq}}$), chicken meat and eggs (0.6 gigatons of $CO_{2\text{-eq}}$) and meat and milk from small ruminants (0.4 gigatons of $CO_{2\text{-eq}}$) (9,58), sheep and goat products are shown as the most efficient in the ratio kg of product/$CO_{2\text{-eq}}$. In general, the increased productivity and efficiency of small ruminants can be a promising tool to reduce the amount of $CO_{2\text{-eq}}$ per kg of milk or meat, but genetic improvement programs, the incorporation of more soluble concentrates, arboreal and shrub legumes or crops (such clover or alfalfa) that reduce the emission of GHG and other additives (free amino acids, fats and ionophores) to diets, must be taken into account as other alternatives to reduce GHG emissions (12,18,19,40).

Defining the climatic, geographical, and social properties gives the tools to determine if the intensive, semi-extensive or extensive system is the most suitable for the productive development of sheep, goats, and white-tailed deer according to their physiological characteristics and the consumption needs of each region. Focused on the basics, an intensive system must guarantee feed, water, space, rest, and shade, while maintaining productivity with an environmental and animal welfare perspective. The knowledge of the physical and chemical properties of forages, grasslands, tree leaves and shrubs, to develop better nutrition programs, for both intensive and extensive systems may help to increase the productivity and mitigate GHG production, which should always be an objective, even with the demonstrated productive efficiency of small ruminants. However, it is necessary to update rangeland coefficients for each region and thus be able to make sustainable use of the rangelands, manage the ecosystem and maximize production, from this perspective, the future of sustainable use of ruminants may be the implementation of SPS that involve the use of grasslands, shrub and tree species, in addition to providing ecosystem services such as improving soil fertility, water filtration and increased tree biomass that contributes to carbon sequestration and the sustainability of the productive systems of small ruminants.

Conflict of interest

The authors declare that they have no conflict of interests for the submission of this manuscript.

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