Revista CES Medicina Veterinaria y Zootecnia
ISSN: 1900-9607. Volumen 10 Número 2 julio - diciembre 2015
Artículo original

A study of tick infestation on cattle in the Abanico de Ibagué, Colombia using the complex systems approach¤

Estudio de infestación por garrapatas en ganado en el Abanico de Ibagué - Colombia usando el enfoque de sistemas complejos

Estudo de uma infestação recorrente em gado no Abanico de Ibagué, Colômbia, usando uma aproximação ao sistema complexo

Diana Nayibe Polanco-Echeverry[1*], Bacterióloga, MSc, cPhD; Lizeth Marelly Álvarez-Salas[2], Bióloga, Magíster, cPhD; Leonardo Alberto Rios-Osorio[3], Bacteriólogo, Esp, PhD.

**Autor para correspondencia: Diana Nayibe Polanco-Echeverry. Universidad de Antioquia, Colombia. diana.polanco@udea.edu.co*

[1] Investigadora y profesora en las áreas de microbiología veterinaria, nutrición animal, agroecología y desarrollo rural de la Universidad de Antioquia. Grupo de investigación Salud y Sustentabilidad; [2] Grupo de Investigación Medio Ambiente y Sociedad. SIU. Torre 1 Laboratorio 213. Universidad de Antioquia, Colombia;
[3] Profesor e investigador de la Universidad de Antioquia, Colombia. Grupo de Investigación Salud y Sustentibilidad.

(Recibido: 29 de mayo, 2015; aceptado: 16 de octubre, 2015)

Abstract

Cattle ranching systems have traditionally been studied based on Cartesian research models that break them down into each of their constitutive parts. For this reason, definition of biophysical and technical-productive parameters dominates knowledge in this area, but does not allow a complex vision of the production systems to be obtained. The emergence of agroecology and the implementation of new models of livestock rearing, such as silvopastoral systems (SPS), suggests that, in addition to studying the characteristics of the natural and technical-productive quantitative variables, sociocultural aspects should be incorporated to offer a more complex, transdisciplinary vision of agricultural systems and to allow new interpretations of agro-ecosystems, their components and interrelationships. The tick *Rhipicephalus microplus* has normally been considered a disruptor of the equilibrium of the ranching system, such that positivist research recommends its eradication. In this study, the structure and function of the system is related to a specific agricultural problem by describing the characteristics of a theoretical model to analyze tick infestation on cattle in the Abanico de Ibagué (Colombia), using the complex systems approach. Through development of this model, it was possible to postulate dynamic relationships between the SPS and conventional system components that can influence the behavior of the tick, demonstrating its presence in the system to be essential for achieving socioecological resilience.

¤Para citar este artículo: Polanco-Echeverry DN, Álvarez-Salas LM, Ríos-Osorio LA. A study of tick infestation on cattle in the Abanico de Ibagué, Colombia using the complex systems approach. Rev CES Med Zootec. 2015; Vol 10 (2): 95-110.

Keywords:

Agroecology, complex systems approach, silvopastoral systems, socioecological, theoretical model (Sources: DeCS, CAB, Agrovoc).

Resumen

Los sistemas de cría de ganado han sido tradicionalmente estudiados en base a modelos de investigación cartesiana que los dividen en cada una de sus partes constitutivas. Debido a esto la definición de los parámetros biofísicos y técnico-productivos domina el conocimiento en ésta área, pero no permite obtener una visión compleja del sistema de producción. La aparición de la agroecología y la implementación de nuevos modelos de cría de ganado, como los sistemas silvopastoriles (SPS), sugieren que además de estudiar las características de las variables componentes naturales de tipo cuantitativas y técnico-productivas, los aspectos socioculturales deben ser incorporados para ofrecer una visión compleja y transdisciplinaria de los sistemas agropecuarios y para permitir hacer nuevas interpretaciones de los agroecosistemas, sus componentes e interrelaciones. La garrapata *Rhipicephalus microplus* ha sido normalmente considerada como un disruptor del equilibrio de los sistemas de cría, tanto que la investigación positivista recomienda su erradicación. En este estudio, la estructura y función del sistema es relacionado a un problema agropecuario específico, al describir las características de un modelo teórico para analizar la infestación por garrapatas en Ganado del Abanico de Ibagué (Colombia), utilizando el enfoque de sistemas complejos. A través del desarrollo de éste modelo fue posible postular relaciones dinámicas entre componentes del SPS y los sistemas convencionales que influencian el comportamiento de la garrapata, demostrando que su presencia en el sistema es esencial para alcanzar adaptabilidad socioecológica.

Palabras clave:

Agroecología, enfoque de sistemas complejos, modelo teórico, relaciones, sistemas silvopastoriles, socioecología.

Resumo

Os sistemas de cria de gado tem sido tradicionalmente estudados em base a modelos de pesquisa cartesiana, os quais dividem-se em cada uma de suas partes constitutivas. Devido a isto, a definição dos parâmetros biofísicos e técnico-produtivos domina o conhecimento em esta área, mas não permite obter uma visão complexa do sistema de produção. A aparição da agroecologia e a implementação de novos modelos de cria de gado, com os sistemas silvopastoris (SPS), sugerem que além de estudar as características das variáveis componentes naturais de tipo quantitativas e técnico-produtivas, os aspectos socioculturais devem ser incorporados para oferecer uma maior visão: ampla, complexa e transdisciplinar dos sistemas agropecuários e para permitir fazer novas interpretações dos agroecossistemas, seus componentes e inter-relações. O carrapato Rhipicephalus microplus tem sido normalmente considerado como um disjuntor do equilíbrio dos sistemas de cria, tanto que a pesquisa positivista recomenda sua erradicação. Neste estudo, a estrutura e função do sistema é relacionado a um problema agropecuário especifico, ao descrever as características de um modelo teórico para analisar a infestação por carrapatos no gado do Abanico de Ibagué (Colômbia), utilizando o enfoque de sistemas complexos. A traves do desenvolvimento deste modelo, foi possível postular relações dinâmicas entre componentes do SPS e os sistemas convencionais que influenciam o comportamento do carrapato, demonstrando que sua presença no sistema é essencial para conseguir a adaptabilidade socio ecológica.

Palavras chave:

Agroecologia, enfoque de sistemas complexos, modelo teórico, relações, sistemas silvopastoris, socio-ecologia

Introduction

Colombian ranching is extensive, with a low level of technology and limited parameters of production and reproductibility. Ranching is the most prevalent activity in the Colombian countryside, representing 3.6% of the national GDP, 27% of the GDP for farming and 64% of that for livestock. According to the national farming survey [6] the total area of agricultural land in Colombia is 37.815.539 ha of which 30.362.366 ha are used for livestock rearing, 65% being dedicated to grass and fodder. In the Colombian *departamento* (state) of Tolima this corresponds to an area of 1,292,449 ha. The 2012 national cattle inventory recorded 2,406,899 cows and 8,025,241 bulls in 22 departamentos, the herd in Tolima for that year consisting of 517,137 cows and 316,776 bulls (4% of the national total). About half (49.6%) of the Colombian herd is raised for beef, 11.9% for milk and 38.5% for both purposes.

Despite these apparently healthy economic Fig.s, cattle production in Colombia has been criticised for its low productive efficiency and negative environmental impact. Tropical conditions manifest low availability and quality of feed, with pastures that are degraded or in the process of degradation [37]. That analyses of the chain of productivity should study cattle-raising processes and consider factors such as the pressure exerted on natural resources, low productivity and poor economic returns, lack of business vision and union organisation, deficiencies in marketing and commercialisation and decreased consumption of beef in Colombia [21]. Other processes, veterinary health problems associated with production limit competitivity of the chain of production [29]. Nevertheless, the solutions proposed for these problems remain one-off and short-term, contributing to the gradual weakening of this industry [21, 22, 35].

Research into these systems has traditionally been generated using a quantitative and technico-productive approach that permits information to be obtained on biophysical variables that is insufficient to explain the phenomena presented. The most common topics in this area of research include studies of biodiversity, use of agroforestry and management of silvopastoral systems (SPS) [41] and their efficiency in carbon sequestration [36]; animal integration to improve soil fertility [17]; and production yield [7].

With regard to cattle ranching production systems, the agronomic sciences have evaluated various aspects such as productive efficiency, economic factors, genetic improvement and animal health. Ticks are among the components that have been defined as perturbers altering the equilibrium of the system of production. The hard tick *Rhipicephalus microplus* (family Ixodidae) only requires a single host and has been recognised as an important ectoparasite. It infests 80% of the world's cattle[9] and is therefore considered to be one of the factors that limit ranching in the Tropics. This is the tick species that has the greatest economic impact in Mexico, Central America, South America and Australia [31], as well as being the most common species in the Caribbean biological corridor, especially in Colombia and Venezuela [14]. It is associated with economic losses due to direct damage to hides, trauma, intoxication and expropriation of nutrients, as well as indirect damages due to diminished production of beef and/or milk and retarded development of animals. Certain breeds have limited adaptability to parasitic infections, with a predisposition to acquire zoonotic diseases and transmit parasites such as *Babesia bovis, B. bigemina, Anaplasma marginale* and *Theileria parva*. This results in higher costs to control parasites, treat diseases and prevent reproductive problems in livestock [9, 29].

Agroecology provides an alternative means of understanding the relationships between socioecological components in agroecosystems. It represents a new scientific paradigm which focuses on complex systems to observe reality.

Epistemologically, the objective of this transdisciplinary science is to study socioecological resilience and understand the agroecosystem. Although the term "resilience" is constructed from ecological theory [18], in acroecology it is understood to mean the capacity to adapt to the ecological, social, cultural and environmental phenomena that disrupt production. It is thus the capacity of a system to absorb shocks and rearrange itself according to its new conditions with the aim of essentially conserving the same function, structure and identity[40]. At the same time, adaptability in a complex system is the capacity of the components to influence its resilience.

The object of knowledge is defined as the agroecosystem, which is both a physical place and a natural system/society, and for which a reciprocity exists between subjective and objective components [23]. For agroecology, the fundamental difference is that the agroecosystem exists beyond the biophysical limits of the plot of agricultural land [19]. The agroecology incorporates elements such as public policies, which affect and dynamize the agroecosystem without being part of it themselves [25]. The agroecosystem is therefore considered to be the spatial dimension where the dynamic relationships between the system's components are established. It is where these relationships fluctuate and are transformed according to the adaptive processes of the system, creating a unique history. Agroecosystems to be structurally and functionally complex, due to the interactions established between ecological and socioeconomic processes [15]. These interactions may engender new qualities that can only be explained by the interactions between the components described above.

The agroecosystems could be designed, rather than controlled systems, for which rules of operation have been established that direct their behaviour although their components are not manufactured [34]. Because of high degree of autonomy and behaviour of its components, their behaviour is partially controllable and consequently presents a wide range of possible behaviours.

In order to understand the dynamics of the socioecological relationships that define the behaviour of *R. microplus* in cattle in the Abanico de Ibagué, a theoretical model of this system was constructed from the methodological approach for the study of complex systems [2, 11.] This model is presented below.

Materials and Methods

Research approach

This research was developed under the complex systems for the study of open systems [27]. Agroecosystems are considered to be open systems where matter is transformed while energy and information flow continuously between the system and the ecosystem that acts as its matrix [4]. These systems present multiple ecological, social, cultural, economic, political and ethical dimensions [5].

Type of study

A study was designed under the systemic [2, 11]. This starts by defining the research question as 'What are the dynamic relationships between the different components of the silvopastoral and conventional ranching systems that influence the behaviour of ticks *R. microplus* as an essential attribute of each system, from an agroecological perspective? The central process of this question was then defined as 'Infestation by ticks on cattle in the Abanico de Ibagué'; the limits being set in terms of geographical locality and systems of production; the elements; the structure or relationships between the elements required for the system to be in equilibrium by means of a dynamic process; the levels of processes and of analysis; and the boundary conditions [11].

Data collection

Data collection was carried out in seven phases:

- Phase 1. Description of the phenomenon to be studied: this was described by means of a review of the literature dealing with agroecological indicators for SPS and conventional ranching systems.

- Phase 2. Elaboration of the research question and central process: this allowed a concept or initial central process to be established which could then be discussed with academic colleagues. This phase includes theoretical description of the central concept and construction of an initial theoretical model.

- Phase 3. Discussion of the central process with academic colleagues: the central process was discussed, requiring it to be reformulated from a systemic and transdisciplinary agroecological standpoint. This allowed the complexity of the agrosystem dynamics of interest to be understood.

- Phase 4. Reconstruction of the theoretical model: a new model of the system was proposed based on the research question and central process previously discussed with academic colleagues. In this phase the following methodological protocols were introduced, as proposed by Rolando García:

    1. Definition of the limits of the system to be investigated: since complex systems have no precise limits, the study evaluated the 'conditioners' or everything that affects a system. A first conditioner is the temporal scale of the analysis, where the findings of the fieldwork contrast with previous studies in the area and reliable local information from secondary sources. The second conditioner is the spatial scale, defined from the general research objective.

    2. Determination of the principal elements of the system and the structure within the complex system. Fundamental elements such as the history and conformation of the system; the dynamics in its transformation.

    3. Definition of the relationships or processes involved with the central process: the first level processes

that include those components that affect the central process directly and locally; the second level processes that directly affect the components of the first level and indirectly affect the central process and that are of regional or national order; lastly, the third level processes or aspects of international or global character that impact on both the first and second levels.

4. Classification of the subsystems that give rise to the processes and elements according to their ontological nature (economic, institutional, ecological, social).

- Phase 5. Validation of the theoretical model with different actors of the investigative process: the system defined in Phase 4 was discussed initially with a group of academic staff and students of the Agroecology doctoral programmes at the University of Antioquia and National University of Colombia (Medellín campus). Once the observations of this group had been incorporated, the system was presented by the researchers to a group of key regional stakeholders for discussion and validation within the community. The final model of the system allowed the observables and the field data required for these to be established.

Locality and geoclimatic conditions

The study was carried out in the municipalities of Alvarado (4º34'7" N; 74º57'24"W) and Piedras (4°32′36″N; 74°52′40″W) in the province of Ibagué, departamento of Tolima. Alvarado has an area of 353 km^2 and mean elevation of 400 masl, presenting an average temperature of 26 °C and mean annual precipitation of 1360 mm, while Piedras has an area of 355.15 km^2, a municipal centre at 403 masl and mean annual temperature and precipitation of 26 °C and 1250 mm respectively.

Unit of analysis. Cattle ranches were selected with different characteristics related to the type of production system, according to data supplied by the National Federation of Colombian Cattle Ranchers (FEDEGAN) in Tolima. The ranches selected could be divided into three different categories: system 1 (conventional cattle ranching system, naturalised pastures with grazing); system 2 (naturalised grasses with trees dispersed around pasture, fodder banks and supplementation with multinutritional blocks) and system 3 (naturalised grasses and trees dispersed in pasture, SPSi of *Leucaena leucocephala* and grass Panicum maximum, fodder banks and supplementation with silos of maize or grass).

Inclusion and exclusion criteria

Ranches were selected that were specifically orientated towards any of the production systems of interest to the study: SPS, conventional or other agroforestal livestock systems. Ranches where the systems were not managed directly by their proprietors were not included.

Analysis of results

The information collected by different methods allowed a theoretical model of the system to be constructed (Figure 1). The general problem of empirical study methodologies is the relationship that is established between the empirical data and conceptualisations made by the researcher[11]. Thus, the system is referred to as an empirical reality, and the elements that are 'abstracted' from it to be used by the researcher correspond to data conceptualisations of the observed reality. For this analysis the causal relationships and processes are also important, both being in agreement with the author's 'inferences' regarding the complex system. This theoretical construct of the system is the starting point to defining the observables and the required field data for each of them. The elements abstracted from the reality have relationships among themselves, this set of relationships forming the 'structure' of the system. The systems constructed have a particular structure as a function of the study's objectives, determined by the research question or questions.

Ethical aspects

In this study the academic and administrative norms and techniques for health research established by the Colombian Ministry of Health in resolution 008430 of 4th October 1993 were followed. The informed consent of the ranch proprietors was obtained, this being a mandatory requirement. Finally, this study was considered as being of minimal risk given that it did not involve any procedure that modified the biological, physiological, psychological or social variables of the participants[26].

Results

The complex systems methodology[11] was applied in this study with the aim of constructing a theoretical model of ranching production systems in the Abanico de Ibagué. The results obtained for each of the phases were as follows:

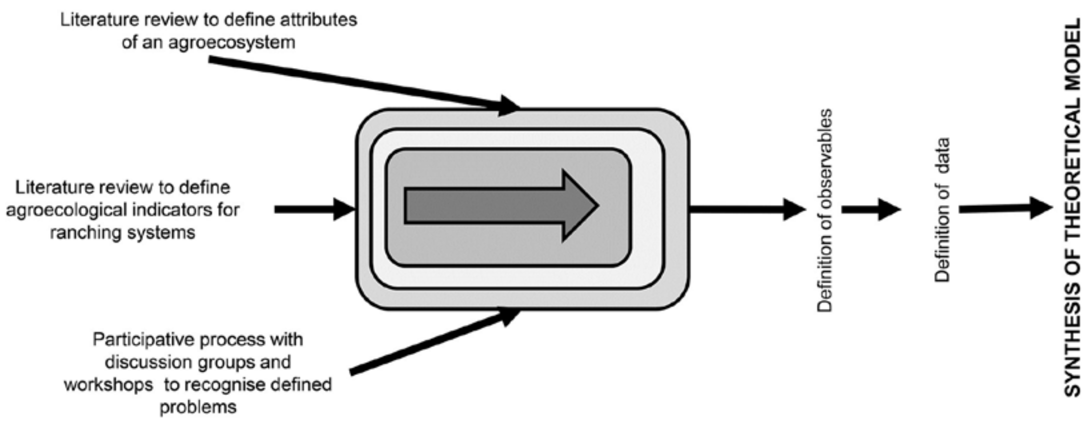

Figure 1. Analysis of results for construction of a theoretical model of the system to be investigated.

Phase 1. Description of the phenomenon to be studied

To characterise a cattle ranching agroecosystem from the agroecological perspective it is first necessary to identify its attributes. However, agroecosystem components and their attributes have been described by some authors without reaching a consensus. These attributes can be understood from biophysical, sociocultural, sociopolitical, socioeconomic, technological or productive perspectives[8,19]. Some authors even consider that agroecosystems, as 'sustainable systems' behave with attributes of sustainability such as productivity, production, resilience, self-management, equity and stability [1, 24]. In the same way, sustainability is an emergent property attributable to agroecosystems which does not exist at their lower levels [12]. This can be evaluated with a relatively small group of attributes such as productivity, stability, resilience, equity, autonomy and cultural adaptability[15]. Although the literature includes many theories proposing the characteristics of the components or attributes of farming production systems, agroecosystems and specifically of SPS, these are heterogeneous and unbalanced.

Although some authors [8], does not textually define the components and attributes of the systems of livestock production, he does present models or prototypes of ranches, components such as biodiversity, recycling of nutrients, energy and the production of assets and services of the systems, as well as their biophysical components such as soil, climate, and types of crop. Other components mentioned are size of the ranch, production intensity and type of management. These elements are cited as components of the systems and have permitted analysis of the production systems, tipification of the ranches and generation of prototypes. Another autor, proposes a simulation model of intensive cattle ranching, in which the demographics, biophysical, productive and economic components of ranching systems are analysed [13].

It is also proposed the description of an agroecological system shown in Figure 2, establishing hierarchical levels which define the characteristics of the system[19]. The first is the principal ecological structure of the landscape (PES), defined by as

> […] a set of natural and seminatural systems that have a localization, range, connections and state of health, ensuring the maintenance of biodiversity integrity and provision of environmental services (water, soil, resources biological and climate) as a means of guaranteeing that the inhabitants' basic needs are satisfied and life perpetuated […].

Furthermore, the PES includes the elements that apparently do not form part of the landscape but condition and define it, such as the laws, structure of territorial legislation, public policies and type of communities that establish their own dynamics in the management and use of resources.

The principal agroecological structure (PAS) is inserted in the PES of the major systems. This is defined as the internal spatial organisation of the major agroecosystem and the connectivity conferred by its sectors and patches or corridors of vegetation, or the production systems that govern the diversity dynamics of animals and plants, by providing them with shelter, habitat and food among other ecosystemic or cultural resources.

It also regulates the microclimate and affects the production and conservation of natural resources and

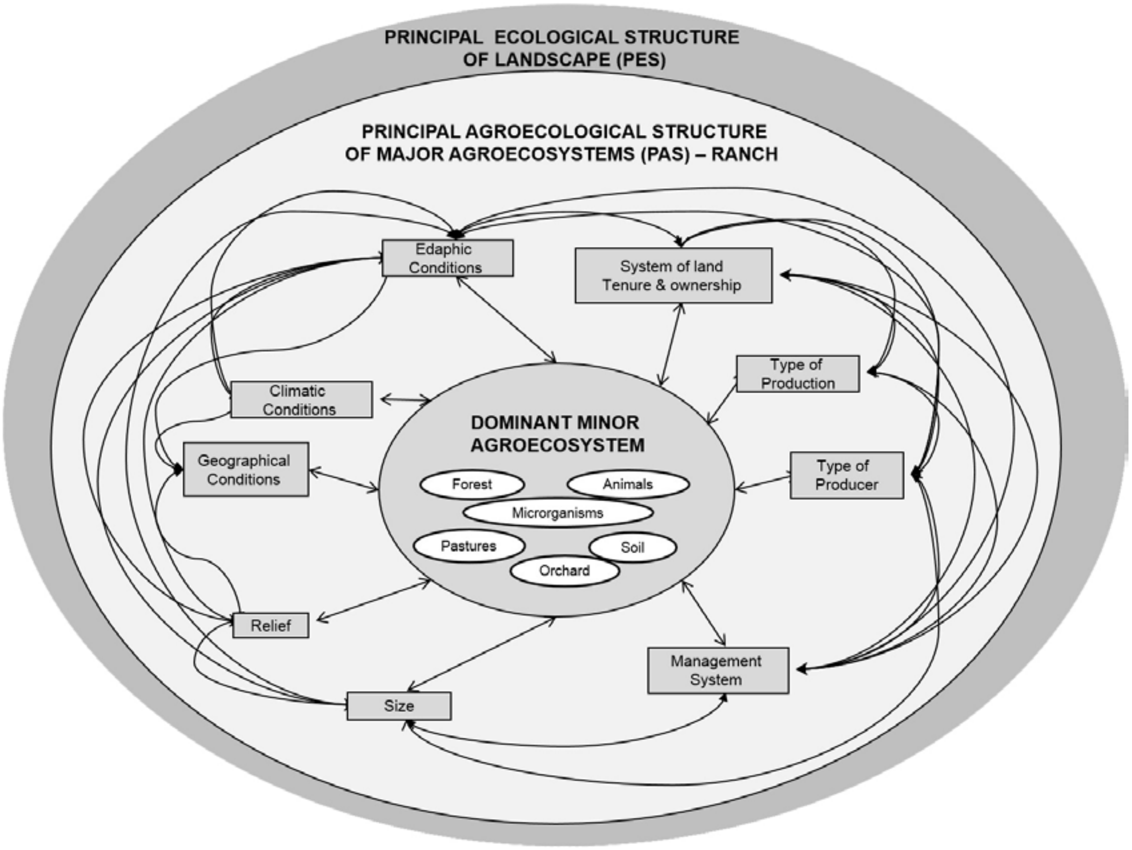

Figure 2. Principal ecological structure of the landscape, structure and principal agroecological structure of major and minor agroecosystems. Authors' adaptation, based on diagram by León (2012).

other associated sociocultural factors. Furthermore it incorporates the climatic and edaphic conditions, the physical and geographical characteristics, regimen of land tenancy, type of producer, type of production, management system and area[19]. For this author, these are essential characteristics of the ranch and may be constant or changeable within the ecosystemic, cultural, spatial and temporal spheres. This author also includes the dominant minor agroecosystem (defined as the principal production system of the ranch) in the PAS, whether this refers to a herd of cattle, polyculture or monoculture.

The entire system proposed by Leon is an interesting approximation of the inherent complexity of agroecosystems. An interpretative scale can be established for the state of the PAS, giving priority to five principal elements: i) Management of biodiversity, which can be productive, functional (whether introduced or specific to the system, not having been introduced by the producer), practical or auxiliary [39]. ii) Soil use and management. iii) Management of weeds. iv) Perception and awareness of the producer regarding the environmental factors that affect agroecosystem management. v) Level of commitment to action regarding strengthening of the PAS, taking into account factors such as: financial resources, local economy, family structure, social structure and technology. These are aspects that contribute to the concept of agroecosystem complexity.

The principal components specific to the SPS are the animals, grass, trees and soil [3,28,33]. However, these only refer to the biophysical components of the system, ignoring the dimensions of the unit or 'society' supra-system mentioned previously. This peculiarity may lead to an incomplete or even erroneous analysis of the phenomena of the system by ignoring components that are essential and determinant.

With regard to this issue, if for example one observes an estate or ranch that has intensive silvopastoral systems (SPSi), whether as the sole livestock production system or as one of several systems, the essential components can be defined as: the climatic and edaphic conditions, geography, topography, land tenure and ownership, public policies, type of production, type of producer, management system, size, types of economy, sociocultural aspects, biodiversity, purchase/sale of cattle, movement of animals and livestock immunity. The attributes of these components are described in Table 1. They can be monitored by means of indicators or describers that allow changes in the system to be measured and try to predict any phenomena that may occur, whether they be positive or negative. It is even possible to predict new characteristics or emergencies, understood from the general theory of systems as those that are not derived from the elements of the system, but rather from the 'complex', *i.e.*, relationships established between these components[10,32]. Thus these emergencies generate a new order with new characteristics, and may be said to cause changes in the equilibrium of a system that is always dynamic.

Phase 2: Elaboration of research question and central process

Theoretical definition of an agroecosystem's attributes permit understanding of the need to link matters of social, political, economic, and ecological orders. This situation requires an epistemological approach such as that of the complex systems which seek to explain these aspects and the socioecological relationships established between them. This is based on the fact that agroecology studies the socioecological resilience of agroecosystems and is thus a transdiciplinary science [2, 34]; quantitative or qualitative approaches are inadequate to tackle the complexity of the reality phenomena.

Starting with formulation of the research question: '¿What are the relationships between the elements of silvopastoral and conventional ranching systems that condition the presence and damage caused by *R. microplus*, from the agroecological perspective?' An initial theoretical model was put forward (Figure 3) reflecting the theoretical categories of the proposed system. This has a central process denominated as: 'Ticks of cattle in ranching systems' with nine principal components: management system, production type, animal immunity, biodiversity, movement of animals, purchase/sale of animals, public policies, climatic conditions and type of producer. Finally an attempt was made to present the relationships that could be established among the different components described previously.

Each component of the system involves characteristics that are unique and non-transferable to other ranching systems and allows systems or ranches to be typed.

The relationships established between components could explain their unique dynamics. Some of the relationships that can be observed in cattle ranging production systems are presented in Figure 2 and described below. The first of these has to do with the interactions that are established between the management system (control of ectoparasites) and the type of production, specifically referring to the breeds selected for each type of production. In this case the interaction between these two components follows the possible introduction of breeds more or less susceptible to being attacked by ticks. In the case of milk production systems, for example, the breeds selected (*Bos taurus taurus*) are more susceptible to attack by ticks, requiring the frequent use of acaricidal baths or some alternative control method more in keeping with the SPS. These management decisions regarding the type of production can result in several emergencies such as: i) the appearance of strains of ticks resistant to chemical treatments, resulting in their proliferation; ii) loss of enzootic stability in the herd, as the result of immunologically naive animals being introduced to meet new production targets and upsetting the bovine-tick-hemoparasite 'triad'; iii) on the other hand, the decision to introduce a type of natural or alternative control may have positive effects on the system by reducing the tick population without generating resistance and causing an imbalance.

Another possible interaction between components relates to the transportation of cattle from zones with more aggressive strains of ticks than those already present in the system and the public policies that regulate such movement. In this case it is important to clarify that in Colombia ticks are not a veterinary problem that has to be reported or for which state control programmes exist, according to Fedegan. This lack of regulatory norms for movement of cattle to and from zones where the ectoparasite occurs therefore affects the number of ticks entering the silvopastoral system.

It is important to take into account that the number of scenarios which may occur in such a complex system is infinite. They do not only involve interactions between two components but rather a conjunction of the relationships among many components and their feedback mechanisms. The qualitative model presented here attempts to explain this and possible emergencies in the cattle ranching production system, including: appearance of strains resistant to control treatments; introduction of new animals belong to susceptible breeds; microclimate modifications that favor the tick's biological cycle; changes in the herd's state of enzootic stability; illegal purchase or sale of materials; inaccesibility of control products; disappearance of natural enemies from the fauna associated with the system; and introduction of

Table 1. Components of a silvopastoral production system in which biophysical, socioeconomic, sociocultural and sociopolitical dimensions are included to analyse cattle infestation by ticks.

Component	*Qualities or describers**
Climatic conditions **	Temperature, relative humidity, solar radiation, precipitation.
Edaphic conditions **	Soil nutrients, organic matter, humidity, pH, microorganisms, water
Geographical conditions**	Classification by life zones, surface, localization at the regional or national level, hydrography
Topography**	Plateau, valley, massif, mountain range
Land tenure & ownership**	Soil nutrients, organic matter, humidity, pH, microorganisms, water
Edaphic conditions **	Property (communal, individual or cooperative) Tenancy (sharecropping, joint , rent)
Public policies	Laws and norms related to animal health, movement permits, veterinary health certifications, among others
Type of production**	Objective of production: milk, dual purpose or beef (breeding, fattening, raising or complete cycle)
Type of producer**	By number of animals: large, medium or small. By area of the production system of production in hectares
Management system **	By type of infrastructure: housed, semi-housed or grazing By degree of intensity of use of natural resources: intensive, extensive or semi-intensive By type of parasite control: chemical or alternative By feed type; By type of supplementation
Size**	Large, medium or small in terms of area in hectares and typing for the region
Types of economy	Family Collective Alternatives Sale of products Access routes
Socio-cultural aspects	Family and blood relationships between employees and employers, religion, education, Belief system, local knowledge, basic social organisations, communal action committees/groups (JAC)
Biodiversity***	Productive (Animals) Harmful (ticks and hemoparasites) Functional introduction (entomopathogenic fungi) Functional (natural enemies, soil microorganisms) Auxiliary (native biota with indirect effects, wild plants and draft animals)
Purchase/sale of animals	Cattle fairs Times of the year when purchase or sales are made Quarantine Control of new animals in herd
Movement of animals	Norms that regulate movement of live animals
Immunity animal	Degree of livestock immunity to ectoparasites or hemoparasites

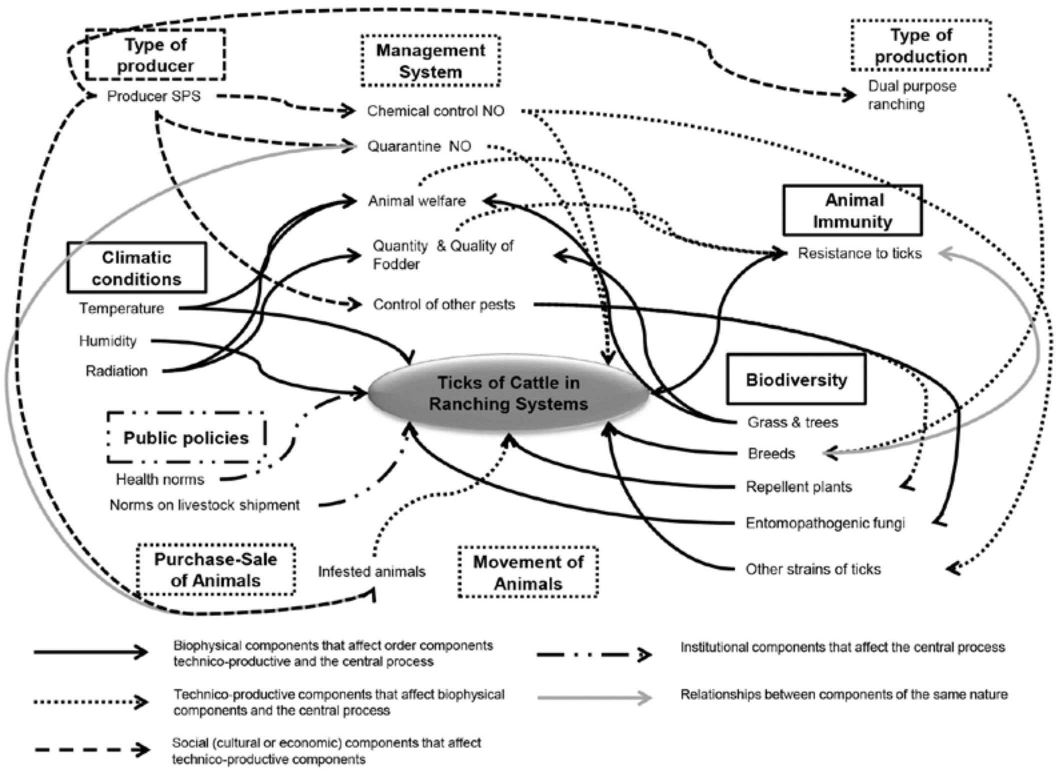

Figure 3. Theoretical model to explain the presence of ticks in cattle ranching systems.

microbial control agents that displace members of natural self-regulating microbial communities.

Agroforestal (SPSi and other SPS) or conventional ranching systems whose objective is grazing cattle for production of milk, beef or both, have trees, grass, animals and soil as their principal biophysical components. These principal components are affected directly by human intervention *i.e.*, the management decisions that are taken for this system. The goal of human intervention in this system is to obtain a desired response that is consistent with the production objectives, type of producer, educational level, levels of unionization, and influence on policy decision-making, type of economy, access roads and communications, among others.

Phase 3. Discussion of central process with academic colleagues

Using the theoretical model proposed in Phase 2 as material, the central process that had been established as: 'Ticks in cattle ranching systems' and the nine components of the system were discussed. The group of experts proposed that the central process should be 'infestation by ticks on cattle of the Abanico de Ibagué' considering that the initial proposal had not established any spatial limits for the process and that it referred to cattle ticks in general terms rather than as a specific process of interest. The process to which limits the tick in the cattle ranching agroecosystem was therefore proposed to be 'infestation'. On the other hand analysis of the system components is based on a systemic, transdisciplinary agroecological approach, highlighting the relationships established between these elements by means of the processes.

Phase 4. Reconstruction of the theoretical model of the system

Using the initial model as a starting point, reconstruction of the theoretical model of the system is oriented from the methodology proposed *6*. The research question, central process, components of the system, process levels and analysis were discussed. The central process is redefined as: 'Infestation by ticks in cattle of the Abanico de Ibagué' (Figure 4). Three levels of analysis were established within this system: the first with 11 processes that directly affect the central process; the second with 10 processes that directly affect the first level processes and indirectly affect the central process; and a third level with five processes, directly affecting the second level processes and indirectly affecting those of the first level and the central process.

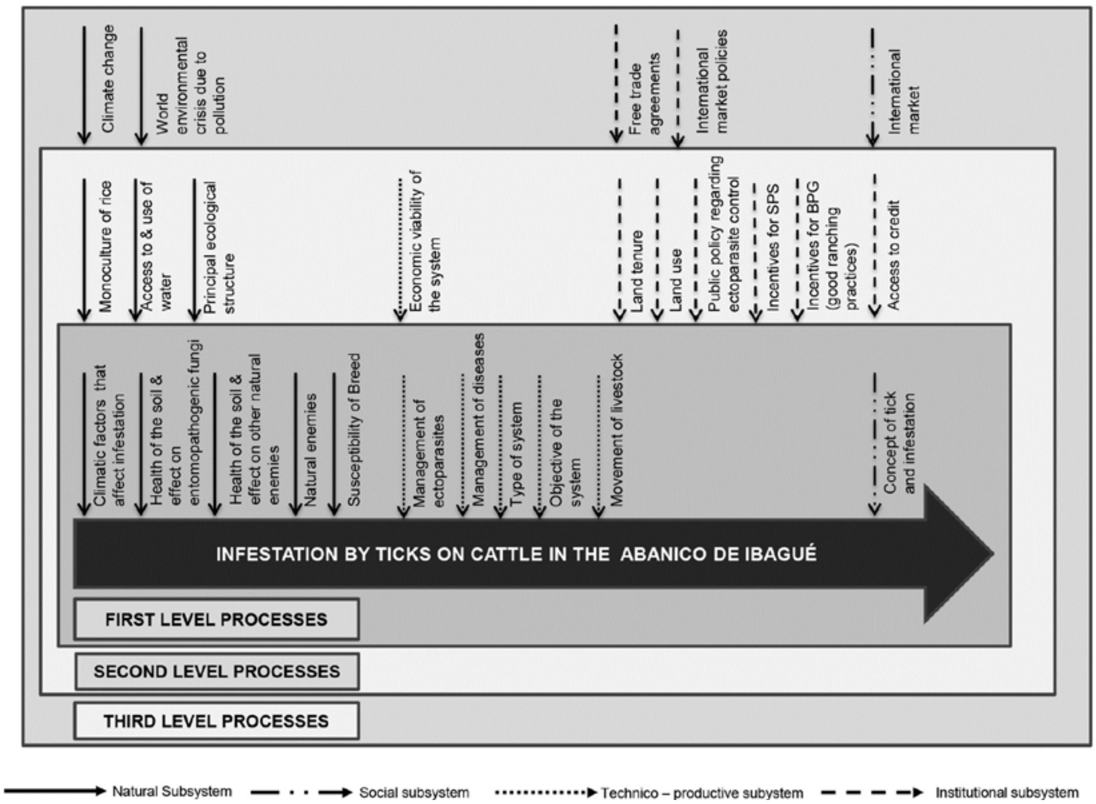

Figure 4. Reconstruction of the theoretical model of the system: central process, levels of processes and analysis and definition of subsystems.

Lastly, four subsystems were identified according to their ontological natures:

- Social: this includes economic, cultural and political aspects
- Natural: this includes ecological, biophysical, climatic and geographical aspects, as well as hierarchically lower systems such as the animals, soil and plant components.
- Technico-productive: this includes all aspects related to the type of production and producer, management and production objective [19]. It deals with specific aspects of the field of agriculture[16] such as materials and technology [20].
- Institutional: This includes aspects related to the mechanisms of social order and cooperation that seek to regulate the activities of the individual or group. This concept is used to organise all forms of structured and repetitive interaction between individuals or groups such as families, neighborhoods, businesses, churches, governmental and non-governmental organisations, among others [30].

Phase 5. Validation of the model with different stakeholders of the investigative process

The group of key stakeholders confirmed 'Infestation by ticks on cattle of the Abanico de Ibagué, Tolima' as the central process of the system, considering it to be an important veterinary health problem for the cattle ranching agroecosystem that they manage (Figure 5).

The natural, social, technico-productive and institutional subsystems are maintained. Three first level processes are included, *i.e.*, animal nutrition, animal immunity and life cycle of the tick. The process susceptibility of breeds of the subsystem natural passes to the technico-productive technico-productive subsystem as selection of breeds susceptibility and resistance, the others remaining the same. The only social susbsystem process to be maintained is concept of the tick and process of infestation. At this level of analysis processes related to the institutional subsystem are not considered.

With respect to the second level process, rice monoculture and principal ecological structure are conserved from the natural subsystem. The process denominated access to and use of water changes to quality and quantity of

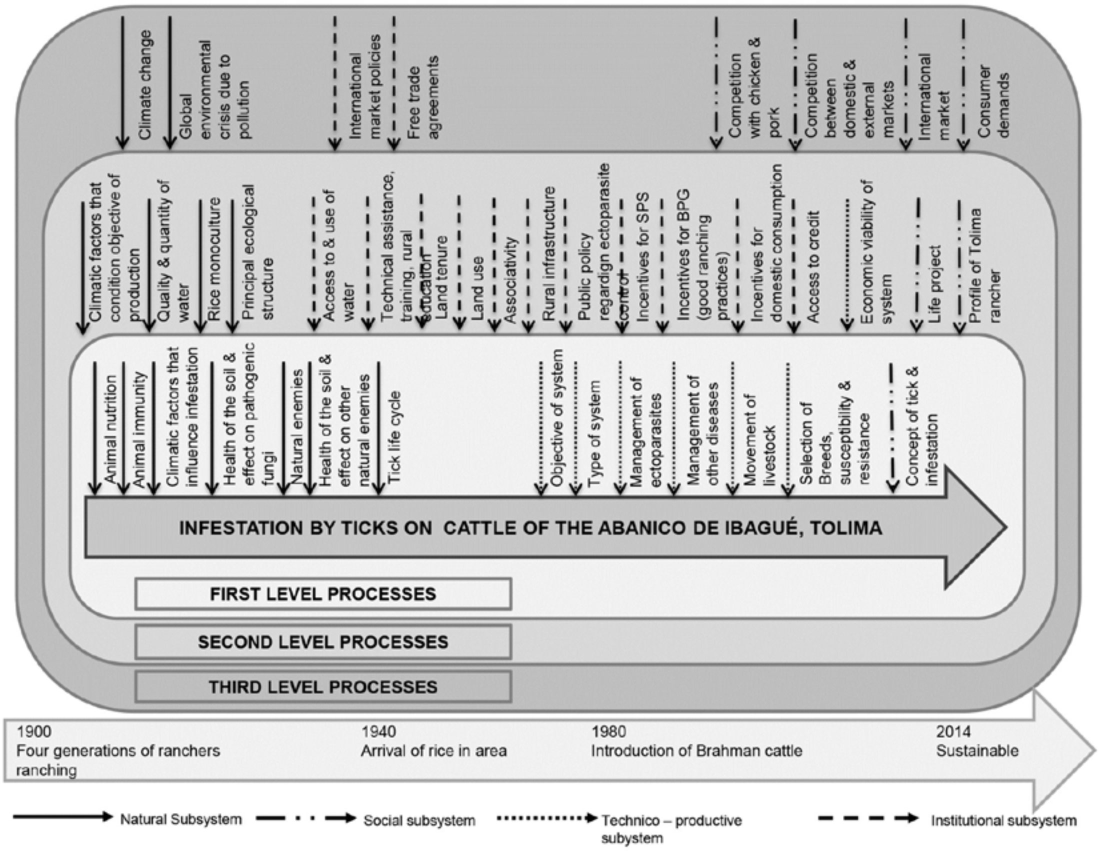

Figure 5. Theoretical model of the system of tick infestation on cattle of the Abanico de Ibagué, Tolima.

water; a new process denominated climatic factors that condition the objective of production is added. The only process retained from the technico-productive subsystem is economic viability of the system. In the social subsystem two new processes are defined, denominated 'profile of cattle ranching in Tolima' and 'life project'; although these were not taken into account in the previous model they are of capital importance to producers. The institutional subsystem includes the processes access to and use of water; technical assistance; rural training and education; associativity; rural infrastructure and incentives for domestic consumption, the other processes being maintained.

On the third level of analysis the processes of the natural and institutional subsystems were validated by the focus group. Furthermore three new processes are defined within the international market social subsystem *i.e.*, competition with chicken and pork; competition of the domestic market with the external one and consumer demands.

Finally the timeline was defined. According to the stakeholders, cattle ranching was established in this region in the early 20th century so that there have been four generations of ranchers. The arrival of rice around 1940 represented an important milestone for agricultural development in the Abanico de Ibague, as did the introduction of Brahman cattle to improve the genetic quality of herds in the 1980s. This opened the door to the introduction of other specialised breeds in later years. The Sustainable Colombian Ranching program currently promoted by Fedegan, which introduces agroforestal systems as environmentally sustainable alternatives, has generated important transformations in the way producers manage their cattle production systems in the region.

Discussion

Livestock production systems such as SPS and conventional ranching systems are complex, multidimensional and related to their environments. These agroecosystems are structurally and functionally complex, due to the interactions that are established between the ecological and sociocultural processes. Their interactions may cause new qualities to emerge that can only be explained from the relationships that are established between the components15. Starting from this new agroecological perspective it is important to approach the system as a whole, the components only providing a partial understanding. A systemic approach is therefore needed that makes visible the relationships established in these systems and allows their dynamics to be explained.

Several considerations need to be made before attempting to model theoretically a silvopastoral system of livestock production and predict the emergent attributes that explain tick infestation on cattle: The first of these makes reference to the fact that the nature-society systems of livestock production type are not closed and isolated from their environments. Furthermore they may also correspond to subsystems of a hierarchically greater system, as in the case of a vereda, municipality, region and even country [19]. The second consideration is that the SPS can be a subsystem of the ranch or agricultural state system and thus cannot be isolated for analysis of any phenomenon present in them (for example proliferation of ticks), or from the environment in which they occur. Livestock systems of production are open systems that exchange flows of energy, matter and information with the environment to which they belong, meaning that if these flows stop, the system enters into disequilibrium. Analysis of a production system should thus be done in its own context. Third, complex systems are adaptive, which allows them to react in the face of various internal or external circumstances and therefore the phenomena of the system should be observed and analysed from its dimensions or temporal and spatial scales. Finally, the components of a system and their attributes cannot be made into a hierarchy by assigning more value to some elements than others, given that they all have the same importance to the system. They are essential and any changes in their attributes may affect the entire system, either positively or negatively.

On the other hand, it is pertinent to consider that a livestock production system is also immersed in so-called nature – society systems, reciprocity existing between man and nature as well as society and nature[23]. Thus the development of society depends on nature, the nature – society couplet is indivisible and any phenomenon of a livestock production system to be studied must be approached from that premise.

Two large units can be considered to facilitate understanding of the theoretical model proposed to examine agroecological phenomena as well as its methodological approach, each with dimensions that will be explained later. One of these units is based on the concept of nature and the other on that of society, the silvopastoral ranching production system lying in the confluence of the two. Thus, the components of the ranching system with its silvopastoral production sub-system and essential attributes lie between the biophysical or ecological dimensions specific to the natural unit and the socio-cultural, socio-economic and socio-political dimensions particular to that of society.

This approach of complex systems becomes an opportunity to redesign conventional farming systems to silvopastoral systems, where you can open new markets, generate more productive interactions with other systems and revitalize aspects cultural and institutional related to this kind of systems. Complex systems approach to the design of livestock systems are a commitment to diversification of agricultural lines from a new mentality of producers, government agencies and markets, promoting a new philosophy of responsible consumption that is related to the new policies for environmental care without sacrificing productivity.

Finally, as a logical conclusion to an investigative process based on the complex systems approach, suggest that two additional phases should be developed[2,11]. Methodological tools and instruments would be defined in Phase 6, based on the theoretical model. Here the observables and field data to be collected on the technico-productive, economic, cultural and political aspects could be established, using qualitative methods such as ethnography. Measurements could also be made of biophysical aspects such as: percentage parasitaemia by *Babesia, Anaplasma* and *Trypanosoma* spp.; parasite load in the animal and number of ticks per area of pasture sampled; percentage colonisation of roots by mycorrhizae, percentage of system biodiversity and its degree of complexity; and weight of dry material in fodder. Agroclimatic data from the records of producers complemented by that from secondary sources should also be incorporated. The process could then be completed with Phase 7, corresponding to a systematic explanation carried out by analysing the observables at each level of complexity, based on qualitative and quantitiative results. These would establish the relationships, emergencies and reorganisations that could be used a posteriori to make decisions at different levels of the system, whether from ranch to institutional. Synthesis of this information and research findings provides the material for future conversion proposals or schemes to monitor the existing system.

Acknowledgements

The authors wish to express their most sincere thanks to the population of San Francisco de Asís, guardians of the forest and its magic, source of deep learning. They also want to recognise the collaboration of Tolima livestock producers in building the theoretical model of the system studied.

Funding

The authors thank the Comité para el Desarrollo de la Investigación (CODI), University of de Antioquia for financial assistance in carrying out the half-time research project of Convocatoria 2010, from which this article is derived. They also thank the Sustainability Research Group of the University of de Antioquia and acknowledge the support given by Departamento Administrativo de Ciencia, Tecnología e Innovación (Colciencias) through call no. 510 (National Doctoral Studies) in 2010.

References

1. Altieri MA, Nicholls CI. 2000. Agroecología Teoría y práctica para una agricultura sustentable. 1a edición. Serie Textos Básicos para la Formación Ambiental. México: Programa de las Naciones Unidas para el Medio Ambiente Red de Formación Ambiental para América Latina y el Caribe.

2. Álvarez-Salas LM, Polanco-Echeverry DN, Ríos-Osorio L. 2014. Reflexiones acerca de los aspectos epistemológicos de la agroecología. Cuadernos de Desarrollo Rural; 2 (74): 55-74.

3. Bahamonde, H. 2005. Efecto de variables ambientales sobre la Productividad Primaria Neta Aérea y la concentración de proteína bruta de gramíneas en Sistemas Silvopastoriles de ñire (Nothofagus antarctica): creación de un modelo de simulación. Tesis de maestria, Escuela para Graduados Ing. Agr. Alberto Soriano Facultad de Agronomía – Universidad de Buenos Aires.162 p.

4. Caporal FR, Costabeber JA, Paulus G. 2006. Agroecologia Matriz disciplinar ou novo paradigma para o desenvolvimento rural sustentável. Brasília (DF). [acceso: 12 de febrero de 2014]. URL: http://agroeco.org/socla/wp-content/uploads/2013/11/Agroecologia-Novo-Paradigma-02052006-ltima-Verso1.pdf

5. Caporal FR, Costabeber JA, Paulus G. 2009. Agroecologia: uma ciência do campo da complexidade. Brasília. [acceso: 14 de abril de 2014]. URL: http://www.cpatsa.embrapa.br:8080/publiceletronica/downloads/OPB2447.pdf.

6. Departamento Administrativo Nacional de Estadísticas – DANE. 2013. Reporte de prensa *Encuesta Nacional Agropecuaria* – ENA 2013. Bogotá. [acceso: 12 de abril de 2015] URL: http://www.dane.gov.co/files/investigaciones/agropecuario/enda/ ena/2013/ cp_ena_2013.pdf.

7. Funes-Monzote FR, Monzote M, Lantinga EA, Ter Braak CJ, Sánchez JE, Van Keulen H. 2009. Agro-ecological indicators (AEIs) for dairy and mixed farming systems classification: identifying alternatives for the Cuban livestock sector. Journal of Sustainable Agriculture; 33 (4): 435-460.

8. Funes□Monzote FR. 2009. Agricultura con futuro. La alternativa agroecológica para Cuba. Matanzas: Estación Experimental 'Indio Hatuey', Universidad de Matanzas.

9. Gallardo JS, Morales J. 1999. *Boophilus microplus* (Acari: Ixodidae): Preoviposición, oviposición, incubación de los huevos y geotropismo.; Bioagro, 11 (3): 77-87.

10. 10. Gallopin G. (2001). *Science and technology, sustainability and sustainable development*. ECLAC. LC/R.2081. [acceso: 1 de febrero de 2015] URL: http://repositorio.cepal.org/bitstream/handle/11362/31809/S02157.pdf?sequence=1

11. García R. 2006. Sistemas Complejos. Conceptos, método y fundamentación epistemológica de la investigación interdisciplinaria. Barcelona: Gedisa.

12. Gliessman SR. 2002. Agroecologia: procesos ecológicos en agricultura sostenible. Costa Rica: CATIE.

13. Gómez U. 2010. Propuesta de un modelo de simulación de ganadería intensiva bovina. En: Memorias del 8º Congreso Latinoamericano y 8º Encuentro Colombiano de Dinámica de Sistemas.

14. Guglielmone AA, Beati L, Barros-Battesti DM, Labruna MB, Nava S, *et al*. 2006. Ticks (Ixodidae) on humans in South America. Experimental & Applied Acarology; 40: 83–100.

15. Guzmán-Casado G, González M, Sevilla E. 2000. Introducción a la Agroecología como desarrollo rural sostenible. 1ra ed. Madrid: Ediciones Mundi-Prensa.

16. Hecht, S. 1999. Cap 1: La evolución del pensamiento agroecológico. En: Altieri, M.A. (Editor). Agroecología: Bases científicas para una agricultura sustentable. 1ra ed. Montevideo: Nordan–Comunidad; pp. 15-28.

17. Hilimire K, Gliessman SR, Muramoto J. 2013. Soil fertility and crop growth under poultry/crop integration. Renewable Agriculture and Food Systems; 28 (2): 173-182.

18. Holling CS. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and systematics; 4:1-23.

19. León TE. 2012. Agroecología: la ciencia de los agroecosistemas – la perspectiva ambiental. 1ra ed. Bogotá: Instituto de Estudios Ambientales –IDEA-, Universidad Nacional de Colombia.

20. Machado H, Suset A, Martín GJ, Funes-Monzote FR. 2009. Del enfoque reduccionista al enfoque de sistema en la agricultura cubana: un necesario cambio de visión. Pastos y Forrajes; 32 (3): 1-8.

21. Mahecha L, Gallego L, Peláez F. 2002. Situación actual de la ganadería de carne en Colombia y alternativas para impulsar su competitividad y sostenibilidad. Revista Colombiana de Ciencias Pecuarias; 15 (2): 213-225

22. Mahecha L. 2003. Importancia de los sistemas silvopastoriles y principales limitantes para su implementación en la ganadería colombiana. Revista Colombiana de Ciencias Pecuarias; 16 (1): 11-18.

23. Malpartida AR, Lavanderos L. 1995. Aproximación a la Unidad Sociedad-Naturaleza, el Ecotomo. Revista Chilena de Historia Natural; 68: 419-427.

24. Masera O, Astier M, Lopez-Ridaura S. 1999. Sustentabilidad y Manejo de Recursos Naturales el Marco de Evaluación MESMIS. 2ra ed México: Grupo Interdisciplinario de tecnología rural apropiada. (GIRA A.C.).

25. Méndez VE, Gliessman SR. 2002. Un enfoque interdisciplinario para la investigación en agroecología y desarrollo rural en el trópico latinoamericano. Manejo integrado de plagas y agroecología; 64: 5-16. Ministerio de Salud, Republica de Colombia. 1993. Resolución 8430 de 1993. Normas científicas, técnicas y administrativas para la investigación en salud. [acceso: 30 de abril de 2015] URL: http://www.unisabana.edu.co/fileadmin/Documentos/Investigacion/comite_de_etica/Res__8430_1993_-_Salud.pdf

26. Morin E. 2003. Introducción al pensamiento complejo. 7Ma ed. Barcelona: Gedisa.

27. Murgueitio E, Ibrahim M. 2008. Capítulo I: Ganadería y Medio Ambiente en América Latina. En: Murgueitio E, Cuartas C, y Naranjo J. (eds.). 2008. Cali: Ganadería del futuro: Investigación para el desarrollo; p. 21-39.

28. Navas A. 2003. Influencia de la cobertura arbórea de sistemas silvopastoriles en la distribución de garrapatas en fincas ganaderas en el bosque seco tropical. Magiste dissertation, Costa Rica: CATIE

29. Ostrom E. 2005. Understanding Institutional Diversity. 3ra ed. United Kingdom: Princeton University Press.

30. Quiroz H. 1994. Parasitología y enfermedades parasitarias de los animales domésticos. Eds. N, Utera. 5 ed. México D.F. MX. p. 768-802.

31. Ramírez S, Cocho G, Torres-Alcaraz C, Torres-Nafarrete J, Duval G, *et al*. 1999 Perspectiva en las teorías de sistemas. 1ra ed. Mexico: Siglo XXI Editores.

32. Ríos H, Vargas D, Funes-Monzote F. 2011. Innovación agroecológica: adaptación y mitigación del cambio climático. 1ra ed. Cuba: Instituto Nacional de Ciencias Agrícolas (INCA).

33. Salas-Zapata WA, Ríos Osorio LA, Álvarez Del Castillo J. 2012. Bases conceptuales para una clasificación de los sistemas socioecológicos de la investigación en sostenibilidad. Revista Lasallista de Investigación; 8 (2): 136-142.

34. Sánchez M, Rosales M, Murgueitio E, Osorio H, Speedy A. 2003. *Agroforestería para la producción animal en Latinoamérica (conclusiones y evaluación de la conferencia electrónica)*. Conferencia electrónica de la fao sobre agroforestería para la producción animal en Latinoamérica. [acceso 10 de enero de 2015] URL: http://www.fao.org/ag/aga/agap/FRG/AGROFOR1/rosale25.txt .

35. Soto-Pinto L, Perfecto I, Caballero-Nieto J. 2002 Shade over coffee: its effects on berry borer, leaf rust and spontaneous herbs in Chiapas, Mexico. Agroforestry Systems; 55 (1): 37-45.

36. Szott L, Ibrahim M, Beer J. 2000. The hamburger connection hangover: cattle, pasture, land degradation and alternative land use in Central America. Costa Rica: CATIE.

37. Van der Hammen T, Andrade G. 2003. Estructura ecológica principal de Colombia – primera aproximación. 1ra ed. Bogota: Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM).

38. Vásquez L, Matienzo Y. 2010. Metodología para la caracterización rápida de la diversidad biológica en las fincas, como base para el manejo agroecológico de plagas. Instituto de Investigaciones de Sanidad Vegetal (INISAV) Ministerio de la Agricultura. La Habana, Cuba. [acceso 23 de febrero de 2015] URL: http://doctoradoagroecologia2010.pbworks.com/f/INISAV+Metodolog%C3%ADa+para+la+clasificaci%C3%B3n+r%C3%A1pida+de+la+biodiversidad+.pdf

39. Walker BH, Holling CS, Carpenter SR, Kinzig A. 2004. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society; 9(2):5-10.

40. Zapata-Buenfil G, Bautista-Zúñiga F, Astier M. 2012 .Caracterización forrajera de un sistema silvopastoril de vegetación secundaria con base en la aptitud de suelo. Revista Mexicana de Ciencias Pecuarias; 47 (3): 257-a.