DISSERTATION

SILVOPASTORAL SYSTEM FOR SUSTAINABLE CATTLE PRODUCTION IN THE TROPICS OF MEXICO

Submitted by

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ABSTRACT

SILVOPASTORAL SYSTEM FOR SUSTAINABLE CATTLE PRODUCTION IN THE TROPICS OF MEXICO

Traditional production system has exhausted natural resources and depleted soil nutrients reducing farm productivity and forcing farmers to expand farm lands, which, increases deforestation and pollution. Global warming and an increasing global population pose additional strain to the already fragile global food security, making it urgent for innovative production systems to be developed. Such systems, adapted to local circumstances and designed to reduce deforestation and increase food production, must emerge to provide an expanding global food demand while enabling preservation of natural resources.

In Mexico, a five-year research project, derived from a national initiative has proposed a silvopastoral model for the Tepalcatepec valley, in the State of Michoacan, as an alternative to conventional livestock ranching in the tropics. The primary objective for this research project was to characterize the advantages and disadvantages of an alternative livestock farming model, the silvopastoral system. One hundred and fifteen farmers in the Tepalcatepec valley were surveyed to characterize their farms, their family demographics, main cattle breed, crops farmed, cattle diet, measures of animal performance (productivity) commercialization (marketing practices) and animal health management practices. An analysis of the progress of the various national SPS initiatives was also performed in order to identify gaps in research, collaboration, stakeholder education, and application of SPS farming in Mexico.

A systems analysis was conducted on the research project using the information compiled from the team of scientists surveyed. Components related to carbon capture, biodiversity, soil quality, nutrient recycling, and larger-scale cycles such as water cycle need to be incorporated into future research. An accurate measure of the true economic and ecological impact of SPS farming is an essential goal. Improved communication among scientists, government agencies, and stakeholders is also essential for successful research into SPS farming.

The animal health component of the five-year Mexican national SPS project is the focus of this dissertation. Traditional livestock health practices on participating small farms were characterized, and common health problems of cattle were identified. A community based livestock syndromic surveillance system was developed, implemented, and observed for two years on five selected farms. Observations from farmers and veterinarians were triangulated to validate data on animal health collected by laypeople. For each farm under study, monthly cumulative incidence per animal category (calf, grower or adult), the most frequent disease syndrome, and the syndrome that carried the greatest economic impact were calculated. Most Rho correlation coefficients for farmer's and veterinarian's observations were high.

Farmers that implemented the silvopastoral model were considered typical of those who practiced this farming method elsewhere within the region. Because participating farms shared production system, husbandry, livestock health status, disease preventive measures, products, and commercialization channels, they were considered an epidemiological compartment for quantitative risk analysis. Six different scenarios were created and analyzed using the software @Risk™ to measure the risk of introduction of bovine tuberculosis into this epidemiological compartment. The Mexican national program for control and eradication of bovine tuberculosis norm, regional prevalence on bovine tuberculosis, and current cultural practices in Tepalcatepec valley were considered for this analysis. The introduction of replacement heifers or sires into the farms, and the probability of the introduction of at least one infected animal was estimated. The least probable scenario for the introduction of tuberculosis into this compartment was the introduction of at least one infected animal, despite the prevalence of source herd, after applying tuberculin caudal fold test and cervical comparative test in parallel.

Although some farmers are aware that the silvopastoral system is profitable, environmental friendly, and socially acceptable, initial investment appears to be the first barrier for adoption. Alternatives for funding SPS development are needed such as preferable interest rates, credit, and loans; notably, an accurate assessment of the costs for establishment of SPS should be more thoroughly studied. The initial three years of SPS implementation have the highest amount on investment; for those years, special attention should be placed on recording the contributions of timber and/or fruit to financial returns, since these products may be the key for offsetting the cost of SPS implementation.

Further research is needed to more accurately measure the economic, ecological, animal health, and human health impact of the silvopastoral model of farming in the tropics. An ample variety of species combinations, suitable for silvopastoral production, should be studied and different arrays proposed to encourage scaling up the model. Research funding is scarce; however, public awareness of the need for a change in production practices and the allure of environmental friendly-produced animal products can produce a market-driven change in these small-scale food production operations. This could engender greater research support from industry and government sources, as well as non-governmental organizations dedicated to promoting sustainable agricultural practices in a changing global environment.

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INTRODUCTION AND LITERATURE REVIEW

Introduction

Human kind evolved by adapting to the climates they lived in and by using and converting natural surroundings to obtain resources to supply their needs for food, water and shelter. Climate, however, is variable, and deviations from the norm too far or too long, can be disruptive and lead to difficult times (Leary et al., 2008; Sidahmed, 2008).

During the recent years, a substantial body of evidence has been accumulated by scientists that shows that the earth has warmed since the middle of the 19th century, leading to climate change (CC). CC can be the result of natural and man-made causes; however, human influence on CC is striking. For example, recent anthropogenic emission of greenhouse gases (GHG) such as carbon dioxide (CO_2) nitrous oxide (N_2O) and methane (CH_4) are the highest in history. Furthermore, changes in use of land for agriculture or other industries (e.g. lumber production, fossil fuel production) may be a driver for CC. CC is expected to bring warmer temperatures, changes to rainfall patterns, and increased frequency -and perhaps severity- of extreme weather (Wheeler and Von Braun, 2013; IPCC, 2014).

Climate change has a role in the redistribution of hosts, vectors and pathogens, and can therefore change the global distribution of disease agents. Under CC, a pathogen may find access to new territories and host landscapes; it may become more pathogenic in CC-compromised settings where the hosts have become more abundant and/or immune-compromised; a pathogen may even perform a host species jump, possibly in response to enhance host species mixing or an increased frequency of contacts among hosts that CC may drive. Vector-borne diseases are also expected to be affected by the expansion of vector populations into more temperate zones. Changes in rainfall pattern could also lead to expanding vector populations in uncharacteristically wetter regions, potentially resulting in large-scale outbreaks of vector-borne diseases (Lubroth, 2012).

Temperature and humidity variations could have a significant effect on helminth infections, thus leading to a greater risk of disease in the future. Changes in crop and livestock practices could also produce effects on the distribution and impact of diseases in many systems. For example, irrigation practices could increase surface water deposits in certain locales, thereby enhancing the survival of certain insect vectors and the persistence of water-borne infectious agents (Thornton et al., 2008). Although there is attention to the emergence and re-emergence of infectious diseases as a response to CC, there is not much evidence to date to implicate CC as the driver (cause) of these changes in disease occurrence (Heffernan, 2015; Randolph, 2013; McMichael and Lindgren, 2011; Heffernan and Salman, 2012).

Global contemporary challenges, Climate Change and Food Security

The global population continues to grow, which has resulted in an increase in demand for high-quality animal protein as meat and milk. The increase in animal protein demand has led livestock producers to increase the size of their herds; the greater land and resource use by larger herds has produced environmental deterioration, increased deforestation to convert forests into range lands, and incursion of livestock into wildlife habitats, which potentially threatens livestock health. This attempt to meet the need for more protein by increasing livestock production will have positive impacts by increasing the food supply for the population. The negative impacts will center mainly on the environment and also by the potential enhancement of disease transmission from livestock to people, either directly or indirectly through products such as milk, meat, hide or manure (Salman and Steneroden, 2015). Reducing hunger is of utmost importance for our society since hunger manifests as multiple health and societal problems. These include macro- and micronutrient deficiencies, poor quality commodities, governmental instability, and lack of purchasing power by the impoverished. Moreover, food scarcity and poverty causes complex interactions among nutrition, sanitation, and infectious diseases that together contribute to poor health in the hungered population (Brown et al., 2015; Gerber et al., 2013; Wheeler and Von Braun, 2013; Chukwuone and Okeke, 2012; Salman et al., 2008).

Originally, the term "food security" was used to describe whether a country had access to enough food to meet dietary energy requirement of its population. National food security was used by some to imply the country's self-sufficiency in food production and distribution (Brown et al., 2015; Andersen, 2009); however, the United Nations' Food and Agriculture Organization (FAO) defines food security as "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Currently, across the globe, more than a billion people have no food security. Approximately 60% of rural communities in the tropics and subtropics are persistently affected by a decline in household food production, with households in sub-Saharan Africa and parts of Latin America, the Caribbean, and Central Asia performing the most poorly (Stockman, 2003).

CC, scarcity of natural resources, overpopulation, and the spread of emerging or re-emerging infectious diseases are some of the greatest challenges humanity is facing at present; these challenges require global, multi-, inter- and transdisciplinary approaches to create sustainable solutions.

Novel agroecological approaches should offer some promise for improving yields and food security in developing countries where CC is affecting food production (Brown et al., 2015;

Rosegrant and Cline, 2003). A vital current research goal is the development and implementation of sustainable livestock production through the adoption of technologies that could maintain or increase soil quality, preserve natural resources, and reduce adverse environmental impact (Dousset, 1995).

In the past, researchers in this arena had pursued alternatives to mitigate the negative impact livestock production has had on natural resources while simultaneously optimizing livestock productivity. Nowadays, researchers face this challenge under the CC effects, which has redirected mitigation measures to enable food systems to be resilient to CC. However, as of yet, they have offered no lasting solutions to chronic poverty or a clear path to sustainability (Martin-Breen and Anderies, 2011).

One of the proposals to reduce the negative impact extensive ruminant production has on the environment is increasing the number of fodder production species included in the paddock by combining grasses, shrubs and trees for forage production. This is called a Silvopastoral system (SPS). The introduction of trees and shrubs into tropical grasslands provides a better diet to the grazing animals and could mitigate the scarcity of forages during the dry season (Pezo and Ibrahim, 1996). SPS also has a role recovering the structure of soil, improving the nutrient recycling and preventing the rangelands from deterioration. SPS creates a better microclimate for grazing and browsing livestock that could also be a more attractive habitat for wildlife.

The links between animals, humans, and the ecosystem are also relevant to emerging infectious diseases of animal origin. The “One World One Health” concept proposes an international, interdisciplinary, cross-sectorial approach to surveillance, monitoring, prevention, control and mitigation of emerging diseases, as well as to environmental conservation (FAO, 2008). In this sense, a better environment for livestock production, along with better nutrition and welfare, could translate into healthier animals and therefore a lower risk of diseases.

CC and Livestock production

The International Fund for Agricultural Development (IFAD, 2009) acknowledges that CC is one of the major factors affecting rural poverty; this is a challenge that needs to be addressed promptly. Scientific evidence is clear that CC is real, that humans are the primary contributors to current global warming, that it will become worse, and that the poorest and most vulnerable people will be the most adversely affected (IFAD, 2009; IPCC, 2014). CC is a global phenomenon; however, its negative impacts are more severely felt by rural poor communities in less developed countries (LDC) where people more directly rely on natural resources for their livelihoods than in developed countries (IFAD, 2009; Thornton et al., 2008)

The Intergovernmental Panel on Climate Change (IPCC) predicts that by 2100 the increase in global average surface temperature to be between 0.3 ° C and 4.8° C, being the lowest for the best scenario, under stringent mitigation measures and the highest value for scenario without additional efforts to constrain emissions (IPCC, 2014). With a 4° C increase in temperature, the risk of fire in many parts of the world increases, as well as the risk for terrestrial and fresh water species extinction; widespread coral reef mortality and potential extensive loss of biodiversity with concomitant loss of ecosystem resources (IPCC, 2014a). Mitigation practices to reduce the level of emission of gases contributing to global warming are necessary to decrease the rate at which the earth is warming (IFAD, 2009, FAO, 2012).

Meat, milk and wool production will also be affected by CC, mainly by the impact of CC on natural grasslands and rangeland productivity. Furthermore, in many regions warmer weather will bring heat stress to animals which will likely reduce feed intake, reduce growing rates, and increase disease susceptibility.

According to some authors, LDC in tropical latitudes, where a large proportion of population still lives in the rural areas, may have better chances to adapt to CC challenges than population living on the urban zones (Rowlinson, 2008; Preston and Leng, 2008). However, CC may increase mean temperature and decrease mean rain fall which will result in lack of water and increased frequency of drought in certain countries, leading to worsening food insecurity and conflict over scarce resources (IFAD, 2009; Rowlinson, 2008).

The livestock sector occupies about 30 percent of the land surface of our planet through grazing and feed-crop production. It is considered the leading driver for deforestation, land degradation, and pollution (FAO and LEAD, 2006). Cattle ranching currently occupies more than 550 million hectares (ha). Even though cattle ranching is the principal purpose for land use in Latin America, the average stocking and productivity rates are relatively low, supporting 0.59 animals per ha, and producing 19.9 kg of beef or 89.7 liters of milk per ha per year, respectively (FAO, 2006). Despite its inefficiency and its multiple negative effects on the environment, this activity is deeply rooted in the Portuguese and Spanish ancestry culture and practices may reflect reaction to agricultural failures that are borne from the biophysical constraints inherent to the climate (Broom et al., 2013; Murgueitio and Ibrahim, 2008; Murgueitio et al., 2011). In addition, there is an increased demand for all livestock products and cattle ranching has become instrumental as a means to consolidate land control (Murgueitio and Ibrahim, 2008).

In LDC, the majority of resource poor households in rural areas own at least one type of livestock. Livestock is a key asset for poor people, fulfilling multiple economic, social and risk management functions such as: A) A source of cash income, by selling animals or their products;

B) A liquid asset - by selling animals, the family can deal with contingencies such as medical treatments; C) Inputs to crop production, such as draught labor and manure to fertilize crops; D) Use of land owned by others may benefit communal lands by grazing cattle in those lands in exchange of manure; E) Diversification for risk mitigation, allowing to thrive on drought years when crops are not harvested; and F) Livestock products can be an important source of protein (Conroy, 2005).

CC will increase vulnerability of livestock systems and reinforce existing factors that are affecting livestock production systems. For rural communities, losing livestock assets could trigger a collapse into chronic poverty and have a lasting effect on livelihoods (FAO, 2013; Pagiola et al., 2016).

Livestock production. Impact on the environment

The link between livestock production and deforestation is strongest in Latin America, where cattle ranching activities have expanded largely at the expense of forests. A simplified form of cattle ranching based on grass monocultures has been practiced for centuries in Latin America. This type of system has promoted environmental degradation because monocultures are contrary to the natural dynamics of tropical forest ecosystems (Wassenaar *et al.*, 2007).

There are three main sources of GHG emissions in the livestock production system: enteric fermentation, manure (waste products) and emissions emanating from production of feed and forage (FAO, 2007; Dourmad et al., 2008).

The livestock sector is undergoing a complex process of technical and geographical change. Extensive grazing still occupies and degrades vast areas of land; however, there is an increasing trend towards intensification and industrialization. In addition, livestock production is changing geographically, first from rural areas to urban and peri-urban zones, to get closer to consumers, and closer to the sources of feedstuffs. Finally, the global livestock sector is also in direct competition with the human sector for scarce land, water, and other natural resources.

These changes are pushing towards improved efficiency, thus reducing the land area required for livestock production and increasing and concentrating the pollution created, but at the same time, marginalizing smallholders and pastoralists (FAO and LEAD, 2006; Kim et al., 2016).

Land degradation

The livestock sector is by far the single largest anthropogenic user of land. The total area occupied by grazing is equivalent to 26 percent of the ice-free terrestrial surface of the planet. In addition, the total area dedicated to feed crop production amounts to 33 percent of the total arable land on the planet. In all, livestock production accounts for 70 percent of all agricultural land and 30 percent of the land surface of the planet. Expansion of livestock production is a key factor in deforestation. About 20 percent of the world's pastures and rangelands, with 73 percent of rangelands in dry areas, have been degraded to some extent, mostly through overgrazing, compaction, and erosion created by livestock action. The dry lands in particular are affected by these trends, as livestock are often the only source of livelihoods for the people living in these areas (FAO and LEAD, 2006; Akinnagbe and Irohibe, 2014; Kim et al., 2016).

Changes in livestock practices to avoid land degradation could include: (i) diversification, intensification and/or integration of pasture management, livestock and crop production; (ii) changing land use and irrigation; (iii) altering the seasonality of operations; (iv) conservation of nature and ecosystems; (v) modifying stock routings and distances; (vi) introducing mixed livestock farming systems, such as stall-fed systems with pasture grazing.

Intensification can reduce GHG emissions from deforestation and pasture degradation. Restoring historical losses of soil carbon (C) through conservation tillage, cover crops, agroforestry and other measures could sequester up to 1.3 tons of C per hectare per year, with additional amounts available through restoration of abandoned pastures (FAO and LEAD, 2006; Akinnabe and Ironhide, 2014; Cuartas et al., 2014; Kim et al., 2016).

Overgrazing can be reduced by grazing fees, reducing stock density and by removing obstacles to mobility on common property pastures. Land degradation can be limited and reversed through soil conservation methods, silvopastoralism, better management of grazing systems, limits to uncontrolled burning by pastoralists, and controlled exclusion from sensitive areas (Murgueitio et al., 2011; FAO and LEAD, 2006).

Atmosphere and climate

The livestock sector accounts for 9 percent of anthropogenic CO_2 emissions. The largest share of this derives from land-use changes – especially deforestation – which is driven by expansion of pastures and arable land for feed crops. Livestock are responsible for much larger shares of some gases with far higher potential to warm the atmosphere; the sector emits 37 percent of anthropogenic methane (CH_4) (with 23 times greater global warming potential (GWP) than CO_2) most of that from enteric fermentation by ruminants. It emits 65 percent of anthropogenic nitrous oxide (N_2O) (with 296 times the GWP than CO_2), the great majority from manure. Livestock are also responsible for almost two-thirds (64 percent) of anthropogenic ammonia (NH_3) emissions, which contribute significantly to acid rain and acidification of ecosystems. This high level of emissions opens up large opportunities for CC mitigation through livestock actions (FAO, 2009; FAO and LEAD, 2006; Akinnabe and Ironhide, 2014; Kim et al., 2016)

Water

The world is moving towards increasing problems of freshwater shortage, scarcity and depletion, with 64 percent of the world's population expected to live in water-stressed basins by

2025 (FAO and LEAD, 2006). The livestock sector is a key player in increasing water use, accounting for over 8% of global human water use, mostly for the irrigation of feed crops. It is a significant source of water pollution, contributing to eutrophication, "dead" zones in coastal areas, degradation of coral reefs, human health problems, emergence of antibiotic resistance and many others. The major sources of pollution are from animal wastes, antibiotics and hormones, chemicals from tanneries, fertilizers and pesticides used for feed crops, and sediments from eroded pastures. Livestock also affect the replenishment of freshwater by compacting soil, reducing infiltration, degrading the banks of watercourses, drying up floodplains and lowering water tables. Livestock's contribution to deforestation also increases runoff and reduces dry season flows (FAO and LEAD, 2006, IFAD, 2009).

Water use by livestock systems can be reduced through improving the efficiency of irrigation systems. Pollution can be tackled through better management of animal waste in industrial production units, better diets to improve nutrient absorption, improved manure management (including biogas capture) and better use of processed manure on croplands. Industrial livestock production should be decentralized to accessible croplands where wastes can be recycled without overloading soils and freshwater. Policy measures that would help in reducing water use and pollution include full cost pricing of water (to cover supply costs) and regulatory frameworks for limiting water use and waste, are necessary (FAO and LEAD, 2006).

Biodiversity

Impact of livestock systems on biodiversity is mainly driven by deforestation and the leading drivers of land degradation, pollution and CC. Fifteen out of 24 important ecosystem services are assessed to be in decline and livestock systems now account for about 20% of the total terrestrial animal biomass, and the 30% of the earth's land surface that they now use was once a habitat for wildlife. In addition, resource conflicts with pastoralists threaten species of wild predators. 66% of global hotspots for biodiversity loss and most of the threatened species suffering from habitat loss are reported to be affected by livestock (FAO and LEAD, 2006, Murgueitio et al., 2011; Solorio et al., 2015; Kim et al., 2016).

Many of livestock's threats to biodiversity arise from their impact on the main resource sectors such as climate, air and water pollution, land degradation and deforestation, but interactions with wildlife and parks and raising wildlife species in livestock enterprises should be addressed. Reduction of the wildlife area used by livestock can be achieved by intensification. Protection of wild areas, buffer zones, conservation zones and diversifying the grazing areas can increase the biodiversity. Efforts should extend more widely to integrate livestock production and producers into landscape management (Calle et al., 2012; FAO and LEAD, 2006).

Livestock and its social role

Livestock may not be economically an important contributor to the gross domestic product (GDP) and impact negatively the environment; however, the livestock sector is socially and politically very significant. It employs 1.3 billion people and creates livelihoods for one billion of the world´s poor. Livestock production is deeply rooted in all cultures in the world and ancient knowledge about livestock production is a vital part of pastoralists' heritage.

Critical knowledge gaps exist on how the impact from gradual or extreme CC events will be distributed among households. Poor farmers and pastoralists are usually considered as most threatened by CC disruptions in the production process. For urban poor consumers, CC is also threatening their economies if food prices increase in order to reflect the impact of CC on production or if the true cost of food is adjusted to reflect environmental concerns (Karfakis et al., 2012).

The Kyoto Protocol's clean development mechanism (CDM) can be used to finance the spread of biogas and Silvopastoral initiatives involving afforestation and reforestation. Methodologies should be developed so that the CDM can finance other livestock-related options such as soil C sequestration through rehabilitation of degraded pastures (FAO and LEAD, 2006).

Livestock production systems in Mexico

Livestock production in Mexico is an inherited activity brought by the Spaniards on their second voyage to the new world in 1493, when horses, dogs, pigs, cattle, chicken, sheep and goats were brought to America. Presently, livestock production is a deeply rooted economic activity with more than 732, 500 registered farms with almost 16.5 million cows for an estimated total of 30.8 million head of cattle (PGN, 2016).

Latin American livestock producers base their production systems on incomplete adaptations of systems developed for temperate climates. In Mexico, extensive grazing systems for cattle in tropical regions use more than 90 million hectares (INEGI, 2009). Low productivity, land degradation, over grazing and pollution are a serious menace for the preservation of natural resources. Grazing areas are frequently opened by the systematic clearing of tropical jungles with slash and burn practices followed by the introduction of exotic grass species, not well adapted the tropical humid and semi humid ecosystems. (Wassenaar et al., 2007; Sánchez, 1999; Dousset, 1995).

Once the original abundant vegetation, which is known to be rich in number of species and in photosynthetic biomass, has been removed, soils exposed to weather actions are not able to maintain organic matter and nutrients which are lixiviated, contributing to decrease in soil fertility (Solorio et al., 2016). The failure of these conventional livestock systems to be sustainable (both financially and environmentally) promoted migration to urban areas seeking for better life conditions (Wassenaar et al., 2007; Sánchez, 1999; Dousset, 1995).

Silvopastoral Systems (SPS) as an Agroforestry model

Agroforestry is one of the options to reduce GHG emission from agriculture. While there is no clear, and universally accepted definition of agroforestry, it can be defined as any practice to purposefully grow trees together with crops, and/or animals with the intent of increasing crop production, preventing soil deterioration, conserving biodiversity and enhancing soil fertility and water quality (Nair, 1993; Solorio et al., 2013; Murgueitio et al., 2015; Kim et al., 2016). Agroforestry is a relatively low-input integration of trees into crop and pasture systems; its implementation in LDC in the tropics, where people are moved to marginal lands by poverty and inequitable land distribution, could represent an important tool for improving their livelihoods. Marginal lands, considered with little or no potential for profitable production, are critical to wildlife and the preservation of watersheds, but are being rapidly deforested to grow crops, which leads not only to loss of the natural cover resource, but to the loss of the soil resource through erosion, damage to watersheds, and to a widening spiral of poverty for the poor people of the world.

In most Latin American countries, the prevailing policy encouraged deforestation for timber extraction and conversion of forest areas to pastures and crops. Such encouragement came from subsidized credit, guaranteed prices, and other incentives that motivated land owners to expand grasslands at the expense of forests. The extent of these policies has been substantially reduced in recent years but large scale ranches continue to practice large-scale deforestation in many areas (Pagiola et al., 2004; 2016).

Livestock producers have traditionally adapted to various environmental and climatic changes by building on their knowledge on the environment in which they live (Sidahmed, 2008). In this sense, livestock production can be improved by promoting biodiversity in forage production and mixing different multipurpose trees, which will, in turn, improve soil cover, reduce lixiviation of nutrients, promote nutrient cycling, support a richer abundance of food webs, thereby providing a more stable ecosystem for livestock production.

Diversity-based approaches to agricultural adaptation have been developed for thousands of years in regions with difficult climates. For example, intercropping and mixed cropping were ways farmers minimized risk and ensured at least some productivity in unfavorable years (Yumamoto et al., 2007; Nguyen, 2013, Kim et al., 2016).

SPS

Integrating livestock production into fruit, timber or any other forestry practice is a form of SPS. SPS implies the presence of animals grazing directly among trees. SPS combines trees with pasture and offer an alternative to prevalent cattle production systems in Latin America. SPS ranching supports a deep rooting, perennial vegetation which is persistently growing and has a dense but uneven canopy (Sanchez, 1999; Murgueitio et al., 2011; Solorio et al., 2015). Many different combinations of trees, shrubs and grasses comprise the SPS. SPS combines the high-density cultivation of fodder shrubs for the direct grazing of livestock with improved tropical grasses and trees. The top vegetation layer may consist of tall trees or palms, in accordance with the biophysical and climatic conditions of each agroecosystem. Tree products – such as timber and fruit – may be directed to local markets, agribusiness or the protection of biodiversity (Solorio *et al.*, 2016). This alternative seeks to maximize the efficiency of biological processes such as photosynthesis, nitrogen (N_2) fixation and nutrient recycling in order to boost biomass production and enhance soil organic matter.

The inputs of naturally intensive systems are biological processes rather than fossil fuel and synthetic compound processes, and they apply modern scientific knowledge to combine and manage species with different traits (Ayala et al., 2013a). SPS are a good example of natural intensification, where the productive benefits of the system such as meat or milk are derived from the same processes that sustain the ecosystem (Ayala et al., 2013b).

SPS can also be integrated with protected areas or connectivity corridors to become a tool for landscape restoration. The transition from input-intensive cattle grazing on degraded pastures to environmentally friendly silvopastures could enhance the resilience of soil to degradation and nutrient loss, sequester large amounts of C, reduce GHG emissions and contribute to the protection of water resources by improving soil properties and reducing pollution. Jobs could be created, and high-quality food and other products could be produced, in a sustainable way (Amendola et al., 2015; Calle et al., 2012).

SPS is suitable for beef, milk, dual-purpose or specialized cattle farming as well as buffalo, sheep and goats. (Murgueitio et al., 2011; Murgueitio et al., 2012; Calle et al., 2012; Ku Vera et al., 2014). Some key features of SPS are high biomass production of a high quality fodder; rotational grazing using high stocking rates with brief grazing periods followed by long periods of plant recovery; and high per-ha productivity. SPS allow farmers to concentrate production in the most suitable areas of their farms and release fragile lands for soil recovery and biodiversity protection (Calle et al., 2012; Solorio et al., 2016). SPS require rigorous management, administrative control and continuous adjustments based on careful monitoring. Management protocols are simple but mandatory, such as fire or pesticide proscription (Calle et al., 2012; Ayala et al., 2013b; Solorio et al., 2016).

SPS are designed to tolerate direct browsing by cattle, thus electric fencing must be handled properly to guarantee the heavy but instantaneous grazing of shrubs and grasses in each paddock. These short rotations minimize the negative impact of compaction on the soil and facilitate the recovery of shrubs and grasses. Once the cattle have moved forward to a fresh fodder paddock, dung beetles and earthworms quickly bury or degrade the dung, interrupting the life cycles of various parasites (Calle et al., 2012). SPS differ from commercial timber tree plantations in their lower planting densities, the spatial arrangement of trees in rows alternating with strips of pasture or shrubs, the west–east (instead of north– south) orientation of tree rows, and the timing and intensity of tree thinning and pruning, both chosen to minimize pasture shading. SPS can enhance biodiversity in agricultural landscapes; for example, diversity of ant species was equivalent to that recorded in remaining forest and bird species in Michoacan SPS, similar to those in forested areas (Pagiola et al., 2016; Pagiola et al., 2004; Calle et al., 2012; Broom et al., 2013; Solorio et al., 2016; Solorio et al., 2015 Flores and Solorio, 2013).

Classification of SPS:

SPS can be grouped in:

a) Systems in which high densities of trees and shrubs are planted in pastures, providing shade and diet supplements while protecting the soil from packing and erosion.

b) Cut and carry systems, which replace grazing in open pasturelands with stables in which livestock is fed with the foliage of different trees and shrubs specifically planted in areas formerly used for other agricultural practices.

c) Use of fast-growing trees and shrubs for fencing and wind screens. This system, widely used in some countries of tropical America, provides an inexpensive alternative for fencing and supplements livestock diets.

d) Livestock grazing in forest plantations. In this system, grazing is used to control the invasion by native and exotic grasses, thus reducing the management costs of the plantations.

e) Intensive Silvopastoral Systems (iSPS) this particular array includes a genetically improved species of tropical grass, such as *Panicum maximum,* a high fodder production shrub, such as *Leucaena leucocephala* and different kinds of local multipurpose trees.

On-site benefits

From the farmers' perspective, the benefits of SPS derive from (a) additional production from the tree component; (b) maintaining and/or improving pasture productivity; (c) diversification of production; and (d) contribution to the overall farming system, by providing fodder or income at a time when other sources do not. The shade provided by trees may also enhance livestock productivity, especially milk production by improving animal welfare (Amendola et al., 2015; Broom et al., 2013; Calle et al., 2012).

Other benefits

SPS are also likely to positively affect water services. Infiltration generally increases with the presence of trees, reducing superficial runoff and soil erosion. Improved livestock management can help reduce compaction, further reducing surface runoff.

The presence of trees also leads to increased evapotranspiration, tending to decrease water yield, which is the amount of water that runs off a watershed eroding and carrying soil and organic matter towards fresh water bodies (Pagiola et al., 2004; Murgueitio et al., 2011; Solorio et al., 2016). Additionally, tree component has a protective role in the ecosystem, preventing landslides.

The variety of tree' species is important; trees of different root depths are required for effective soil anchorage, particularly during torrential rains that accompany tropical storms (Pagiola et al., 2004; Murgueitio et al., 2011).

Trees and SPS

SPS can combine the short-term profit from milk and/or meat production with a long-term investment in timber. Tree species, silvicultural management and agroecological factors determine timber production in SPS. Timber trees are planted in double or triple lines separated by 15–30 m wide grazing strips. With light interception (amount of sunlight blocked by plant leaves) by timber trees canopy varying between 10 and 40 percent, SPS enables grass growth and grazing until the final harvest of the trees. Controlled grazing is allowed four to eight months after the grasses and fodder shrubs have been planted; however, entrance of the cattle to the timber lines is restricted for up to 18 months by electric fencing. The total volume of wood is estimated to be 30 percent lower than in conventional plantations, but this reduction is offset by the increased price of timber at final harvest (Calle et al., 2012).

SPS aims tree species selection towards N_2 fixing species, fruit trees that can supplement the diet of cattle, and timber sources for farm use, local markets, and industry. Crown architecture is another important aspect of tree selection in SPS. Species with straight trunks and small crowns and that are self-pruning are preferred. Concurrently, large N_2-fixing trees with edible seeds such as *Albizia saman* and *Enterolobium cyclocarpum* are usually kept within SPS at a low density, even though they have open crowns but allow enough sunlight to reach the ground. Such trees are used instead of trees with dense canopies that block sunlight; sunlight blockage is to be avoided because it will impair grasses and shrubs growth. Mango trees are an exception because the benefits provided by their large crops of nutritious fruit and the increased nutrient recycling compensates for the reduced fodder production beneath their crowns. Species with small and rapidly decomposing leaflets are preferred to those with large, thick leaves that form persistent litter. *Tectona grandis* is an exception because the cattle eat some fallen leaves, while the combination of trampling and urine accelerates the decomposition of remaining leaves. Native, multipurpose species should be favored over exotic species (Calle et al., 2012; Ayala et al., 2013a).

Barriers to adoption

Despite their many benefits, SPS have only been adopted to a limited extent (Pagiola et al., 2004; 2016). An important constraint to the adoption of silvopastoral practices is their high cost of establishment for individual land users; besides labor and seeds, there are opportunity costs resulting from the time lag before the systems become productive. Moreover, in farms with small herds, it is costly to increase the number of livestock in the herd to take advantage of the anticipated increase in fodder production. Estimates show rates of investment return on SPS establishment of between 4 and 14 percent, depending on the country and type of farm (Pagiola et al., 2004; 2016) These estimates only consider the on-site benefits of silvopastoral practices and although cost-benefit analyses should include the many other long-term benefits (such as biodiversity conservation and C sequestration), these larger societal and ecological benefits are not highly relevant to the farmers' immediate needs and short-term financial planning.

Awareness should be promoted in farmers about the on-site benefits offered by SPS, such as reduced dependency on chemical fertilizers and pesticides, savings in water for irrigation, soil protection and enhanced fertility, and the potential for additional incomes from harvesting fruit, fuelwood, and timber. Limited knowledge of these on-site benefits further reduces the perceived benefits to land users. Even if silvopastoral practices were financially viable, the high initial investment costs required pose problems for credit-constrained land users (Pagiola et al., 2004;

2016). The long-term nature of investments in most silvopastoral practices means that tenure of land security is an important factor in their adoption. Payments for environmental services (PES) programs have attracted considerable attention as a strategy to protect natural resources and improve their long-term management (Pagiola et al., 2016), however these schemes are not widely available.

SPS Initiative in Mexico

For the Mexican tropics, Fundacion Produce Michoacan A.C. and Consejo Nacional de Ciencia y Tecnologia (CONACYT), have funded a research project named "Development of a sustainable production system for the dual purpose cattle production in the Tepalcatepec valley" conducted by the University of Yucatan in the Michoacan and Yucatan States. This project follows a Mexican national strategic initiative to generate and diffuse the SPS prototype as a model for sustainable livestock production (Flores Estrada, 2013; Flores and Solorio, 2011; Murgueitio et al., 2011; Solorio et al., 2016).

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CHAPTER 2

SILVOPASTORAL MODEL RESEARCH AND THE ANIMAL HEALTH COMPONENT IN THE TRADITIONAL PRODUCTION SYSTEM, TEPALCATEPEC VALLEY, MICHOACAN, MEXICO

Introduction

Traditional production system has exhausted natural resources and depleted soil nutrients reducing farms' productivity and forcing farmers to open new lands, increasing deforestation and pollution. Innovative production systems, adapted to local circumstances are necessary to decrease the speed of deforestation, while increasing production if we expect to meet increasing demand in animal protein (Flores, 2013; FAO, 2011).

A national initiative in Mexico to research and promote silvopastoral system (SPS), described by Flores and Solorio (2011 and 2013) started in 2010; as part of this initiative a SPS project was conducted by a team of nine scientists to characterize farms and farmers involved and to develop a model suitable for the conditions in the Tepalcatepec Valley location in Michoacan State, Mexico.

Michoacan State has 62,762 cattle herds accounting for more than two million head and producing annually 52, 329 tons of meat and 331 million liters of milk (CEFPP Mich., 2017). Tepalcatepec valley is located among the "Sierra Madre del sur" and the high lands of central Mexico, an area called "Tierra Caliente" or warm land (See figure #1). Tropical weather with an average precipitation of 400mm annually, the Tepalcatepec valley is an area with large number of cattle herds, mainly focused on dual purpose production (CEFPP Mich., 2017).

The Tepalcatepec valley hosts a group of farmers with very long history and deeply rooted cultural practices such as the preparation of an artisan semi aged cheese commonly known as "Cotija" cheese. This kind of cheese was originated in the Tepalcatepec valley, produced and stored for months until, by the end of the year, it was transported to the city of Cotija de la Paz, Michoacan, where inhabitants and merchants bought it to be sold in the market of Mexico City (Solis Mendez et al., 2013).

Figure 1 Map of "Tepalcatepec valley" area in Michoacan, Mexico.

This research project was funded by Conacyt to develop a sustainable livestock production system that could revert environmental deterioration and be readily adopted by Tepalcatepec valley farmers. To fulfill this objective, two surveys were performed; the first survey was aimed at farmers in the Tepalcatepec valley (Farmer's Survey) to characterize the family demographics of the farm owners, characteristics of the farm, main cattle breed, crops farmed, cattle diet and measures of performance, commercialization and animal health management, which is the component that will be discussed in detail in this chapter. The second survey (Researcher's Survey) gathered general information from the nine scientists involved in the initial SPS project, particularly about each scientist's aims, interactions, expected results, and the interest from students in the SPS project.

Methods

Farmer's Survey

A structured survey (see annex 1) was designed and applied to ascertain the socio-economic and production factors of the farms, the owners, and workers from four communities of the Tepalcatepec valley. The main characteristics and processes of the traditional cattle production system and particularly for the animal health component. One hundred fifteen farmers were interviewed to determine family demographics, characteristics of the farm, main breeds of cattle kept and crops raised, cattle diet and measures of performance, commercialization / marketing strategies and animal health management.

Farms visited during this survey were located in Apatzingan (19^0 05' 23" N; 102^0 20' 55" W), Buenavista Tomatlán (19^0 12' 72" N; 102^0 35' 07" W), Cenobio Moreno (19^0 06' 01" N; 102^0 30' 17" W), and Tepalcatepec (19^0 11' 29" N; 102^0 51' 10" W).

Components of the survey

Multiple researchers were assigned to the different sections of the farmer's survey and are presented in table 1.

Table 1 Survey sections, researcher responsible and institution

Section	Researcher	Institution
General Information	Carlos Sanchez Brito	Fundacion Produce Michoacan
Family information	Armin Ayala Burgos	University of Yucatan

Farm Structure	Carlos Aguilar Perez	University of Yucatan
Socio economic aspects	Luis Ramirez Aviles	University of Yucatan
Livestock and crops production	Javier Solorio Sanchez	University of Yucatan
Feeding management	Juan Ku Vera	University of Yucatan
Commercialization and trade	Octavio Castelan	University of Mexico State
Animal health management	Jose Erales Villamil	University of Yucatan

Briefly, the following information was captured by the Farmer's Survey:

General Information

This section gathered information regarding demographics of the farm owners such as main activities, education level; and also general infrastructure of the farm, for example electricity, water supply, roads.

Family information and education level.

This section included information of the family members of the farm's owner, their education level, their main occupation and time dedicated to the farm.

Farm Structure

Information on the size of the farm, paddocks, trend on number of paddocks (increasing or decreasing over time), type of property (owned, rented or communal), destiny of different areas (cut and carry fodder, grazing paddocks, maize, sorghum, fruits, others). Untilled areas (garden, nursery, forest, jungle, pens, facilities), was gathered in this section.

Socio economic aspects and production organization

The time dedicated to the farm, other occupations of the farm owner, main income for the family, number of employees on the farm, access to loans or credits, associated to local, regional or national unions, participation on government subsidies, level of mechanization and animal workers, were captured in this section.

Livestock and crop production

Information collected included crop varieties, irrigation system, irrigated area, fertilizers and products used, pesticides used on the farm, slash and burn practices, fodder storage, paddock rotations, type of fence used, livestock population, breeds, and aim of the farm (beef, milk, or dual purpose), were gathered.

Productive and Reproductive aspects

Information collected included on mating practices used on the farm, reproductive indicators (such as days open, calving interval, number of matings per pregnancy), average milk yield, lactation length, milking procedure (cleaning, drying off, sealing), use of calves for milking, mastitis prevalence, amount of milk destined to calves and colostrum management.

Feeding management.

Information on feeds available, feeds used for adult, young or calves, amount per day, period of supplementation, other supplemented animals, grazing pattern, offer of supplemental minerals, were gathered in this section.

Commercialization and trade of products, feeds and supplies

In this section, information was collected on the sale of animals, milk and milk products, price obtained, destiny, type of buyer, type of products sold and others.

Animal health management

Information was garnered about testing for bovine tuberculosis (BTb) or bovine brucellosis (BBr), vaccination against rabies, anthrax, hemorrhagic septicemia, malignant edema, and, against *Boophilus microplus* ticks; the use of vitamin supplementation, anthelminthic treatments, and the use of chemicals for ectoparasite control; record keeping on animal health events and calving assistance. The survey also captured animal diseases for the different animal stages; calves defined as animals from the day of birth to the last day of weaning; growing animals, defined as one day after weaning to the day of mating in females or the day to be sold in males; and adults which included mated females and sired bulls; for this section, farmers were expected to answer if they have ever observed their animals to suffer specific disorders. These questions asked required a yes or no answer and the proportion of the affirmative answers are reported. Open questions were asked on the annual proportion of animal that got sick and for those questions descriptive statistics such as maximum, minimum, average, median and mode were calculated using Excel® (Microsoft corporation, 2016, Redmond, WA, USA).

Researcher's Survey

Nine scientists were interviewed and asked to describe their themes and topics researched and how each theme and topic interacted either in the research process or if the results from one topic was necessary for the other. Additionally, a set of questions was e-mailed to the scientists to collect the following information:

1. Name of each scientist
2. Institution of each scientist
3. Research Aim of each scientist
4. Methodologies used by each scientist
5. Results obtained and results expected by each scientist
6. Interactions with other scientists within or outside the research project
7. Number of students that were involved in each research project

Scientists were approached by the director of the project, to notify them they will receive the questionnaire and that the information gathered will only be used for the present purpose and to have an insight about to research efforts.

Date was collected and presented below.

Results

Farmers surveyed

One hundred and fifteen surveys were completed and used for this analysis. Ninety-five percent of responders were male, head of family and their main occupation was farm production. Answers for the Animal Health section are summarized in the following paragraphs

Health management section

Diseases under national campaign

87% of farmers reported to have tested their herds to detect animals infected with Bovine Tuberculosis (BTb) or Bovine brucellosis (BBr). 30% report that they have an official certificate of free of disease (BTb and BBr) herd status.

Vaccines

70% surveyed farmers declared to use vaccines on their herd. The vaccines used were against Rabies (*rabies virus*, 22%), Anthrax (*Bacillus anthracis,* 18%), Pneumonic pasteurellosis (*Pasteurella multocida*, 10%), Malignant edema (*Clostridium septicum*, 4%) Ticks (*Boophilus microplus*, 4%).

Vitamins

26% from surveyed farmers declared they use vitamins once a year to supplement their animals

Anthelminthic treatment

71% of farmers declared they use at least once a year an anthelminthic treatment for their animals, particularly for their calves.

Record keeping

17% of farmers declared to record health events observed in their animals.

Calving support

70% of farmers declared to pay attention to calving and provide care to the cow while calving; 17% of the farmers disinfect calf navel and 94% makes sure the calf gets enough colostrum.

Calf diseases

54% of farmers reported their calves have suffered diarrhea, 24% reported their calves have suffered pneumonia, and 12% reported their calves have suffered navel disease. On average, farmers reported that 6% of their calves get sick at least once (*Max 100%, Min 0%, Median 1%, Mode 0%*).

Growing animal diseases

9% of farmers reported to observe skin lesions, 6% reported to have observed lameness and 5% have observed pneumonia. The average proportion of growing animals that get sick were reported to be 1% (*Max 14%, Min 0%, Median 0%, Mode 0%*)

Adult animal diseases

Adult animals were considered from mating in females and sires for males. 42% of farmers declared to have ever observed abortions in their cows; 28% declared to have observed dystocia in their cows; 14% declared to have observed metritis and/or pyometra; 9% of farmers declared to have had downer cows; 34% declared to have had cows with mastitis; 100% of farmers declared they have observed lameness in their cows; 10% of farmers have observed skin lesions in their cows; 36% have observed fetal membrane retentions. The average proportion of adult animals that get sick annually famers declared to be 2% (*Max 25%, Min 0%, Median 1%, Mode 0%*).

A summary of this information is presented in table 2

Table 2 Percentage of animals that get sick annually and most frequent disorder, according to farmer's opinion

Diseases on animals	Percentage of animals that get sick per year	Max	Min	Mode	Most frequent disorders observed by farmers
Calves	6%	100%	0%	0%	Diarrhea (54%), Pneumonia (24%), Navel (12%)
Growing animals	1%	14%	0%	0%	Skin lesions (9%) Lameness (6%) Pneumonia (5%)
Adults	2%	25%	0%	0%	Lameness (100%) Abortions (42%) Fetal Membranes retentions (36%) Mastitis (34%) Dystocia (28%) Metritis and pyometra (14%) Skin lesions (10%) Downer cow (9%)

Ectoparasite control

Farmers reported to control tick infestations by applying different brands and chemical insecticides. On average, the number of treatments applied per year was 2 (*Max 13, Min 0%, Median 1%, Mode 0%*).

Researcher's surveyed

Information from the researcher's survey is described in table 3. Nine scientists from five Universities were involved in the SPS research project. Carlos Aguilar had the most students interested from a total of 23 students that were involved in the project. Both under graduate and graduate degrees were obtained from this project.

Table 3 Researcher, Institution and research aim of the team on SPS in Mexico

Scientist	**Institution**	**Research Aim**	**Methodologies**	**Results**	**Link w/others**	**Students**
Gabriela Corral	University of Chihuahua	Meat quality	Conformation, Carcass composition, organoleptic evaluation of cuts, Marbling	Characterization of meat on different breeds under iSPS	Provide meat quality evaluations of diff breed to help determine the best fit breed	Miguel Terrazas Sergio Pinion
Octavio Castelan	University of Mexico State	Cheese Characteristics	Milk and cheese sampling at different farms, describing the process of Cotija type cheese	Descriptive chart of Tepeque Cheese Bio Chemical analysis of cheese	Participates in the Milk-cheese chain	Raquel Loperena Alejandra Donahi
Guillermo Salas	University of Michoacan	Milk yield and hygiene	Evaluation of milk yield of different nutritional stages Evaluate the quality and sanitary condition of milk and milking Microbiologic milk analysis	Milk quality and hygiene and measures to improve it	Nutrition effect on Milk yield	David Ramirez Roberto Ramirez Nestor Morraz

Juan Ku	University of Yucatan	Forage quality and GHG emission mitigation	Studies under controlled conditions (gas chambers and laboratory) using animal models to measure the relationship between forage quality and GHG emissions	Nutrient contents Forage Digestibility CH_4 emissions	Validates diets with different arrays in Shrub-Grass proportions	Jorge Canul Angel Pinieiro Freddy Lazos
Carlos Aguilar	University of Yucatan	Milk yield and composition Reproductive performance	Comparative study (iSPS vs traditional) measuring milk yield and repro performance by US ovary activity and pregnancy rates. Monthly milk sampling for composition	Milk yield Repro performance Milk composition	Related with agronomy (forage availability, composition) and economic studies	Maria Botini Eusebio Mayo Ashem Mahmud Henry Lizarraga
Armin Ayala	University of Yucatan	Identification best fit breed for iSPS in the tropics	Field trials with different breed groups, measuring meat production and milk yield. Ethology observational studies	DWG Milk yield Animal behavior	Dependency on quantity and quality of fodder	Magda Utrilla Erick Eb Victor Arjona

Javier Solorio	University of Yucatan	Estimate Fodder production, Carbon sequestration, Nitrogen fixation. Management of iSPS	Direct sampling on field through year N_2 fixation determination (analysis in Brazil, EMBRAPA) C store determination by equation to estimate below ground store of trees	Fodder availability (Kg DM/ha/y^{-1}) C stored Kg N_2 fixated/ha/y^{-1}	Stocking rate Sustainability Fodder availability	Lucero Sarabia Hector Bacab Jose Erales
Luis Ramirez	University of Yucatan	Stock rates Grazing strategies Soil quality	Stocking rates comparison on different Grass: Shrub proportions, different water regimen and different soil types	Best stock rate for irrigated and no irrigated areas	Fodder availability, grazing area composition and stock rates	Ahmed Mahmud Adrian Dzul
Jose Erales	University of Yucatan/ Colorado State University	Animal Health	Community-based syndromic record keeping	Cumulative incidence of syndromes	Independent	

Most researchers were involved in measuring the availability of fodder, the stocking rate it allowed and the final product obtained from the animals, such as daily gain, milk yield, quality of milk and cheese obtained, as well as meat quality. 3 researchers were measuring performance of cattle (reproductive, health and behavior), and only 2 were measuring agroecological processes such as soil' fertility and structure.

Discussion

Animal health section

Diseases under national campaign

A national campaign to control and eradicate zoonotic diseases such as BTb and BBr is observed across most of Mexico. As a result, there was no surprise that the proportion of herds tested among farmers surveyed was high (87%); however, only 30% of farmers stated to have a "free of disease" herd certificate. This situation is important to note, since raw milk sale is frequent among surveyed farmers. In order to eradicate BTb and BBr, which are zoonotic communicable diseases, all animals must be tested. Eventual testing of the 13% of herds not tested is important to reach a "negative" or "free of disease" herd status in the Tepalcatepec valley. Efforts to eradicate these 2 diseases should be promoted among Tepalcatepec valley farmers.

Vaccines

Vaccination was declared to be performed by 70% of farmers; however, when farmers were asked about the types of vaccines or against what agents these vaccines were directed, a low proportion (4 to 22%) could mentioned at least one agent or disease. Lack of complete understanding prevailed among farmers who declared to vaccinate against ticks. While vaccines against *B. microplus* are available in Mexico, vaccination against ticks is not a common practice. It is likely that the farmers were referring to an insecticide used to control ticks and not vaccination against them. Further producer education on vaccination is clearly necessary in this region.

Vitamins

Only 25% of farmers reported to supplement their animals with vitamins. In tropical regions where the variability and availability of fodder is markedly different between rainy and dry seasons, a supplemental application of vitamins such as A, D, and E are typically considered necessary for ruminants, especially during the dry season.

Anthelminthic treatment

Internal parasites can cause significant production loses and result in economic loses for farmers. 70% of farmers surveyed declared to apply anthelminthic treatment to their animals at least once a year. In tropical climates with grazing cattle, this practice may to be insufficient to control helminth infestations, particularly in growing animals. Adult cattle, when raised under low stress management, a high plane of nutrition limited concurrent disease, have shown the ability to control their internal parasite infestation by preventing establishment of the parasites, by eliminating the parasites once they have established or by affecting growth of fecundity of parasites by specific antibody and cell mediated immune responses. Special attention and action should be provided with young animals as they do not have the benefits of adult cattle to control parasite infestations.

Ectoparasite control

Ectoparasite control is an important practice to preserve health in cattle farms, particularly in the tropics where ticks' populations can show explosive growth when humidity is adequate. Likewise, tick transmitted diseases in the tropics such as Anaplasmosis and piroplasmosis are life threatening if not treated adequately. Monitoring of tick infestation and control measures applied is necessary to characterize ticks' population growth and adjust control measures to reduce the risk of infestation and tick borne diseases presentation.

Record keeping

One important notation of this survey was that only 17% of farmers declared to keep records, yet most of them were able to state diseases and proportion of animals that they have observed sick. In Mexico, farmers tend to pass on information orally. They also tend to use their memory to keep track of business matters as opposed to transcribing the information for further use. The problem with this cultural practice is that communication and recall can be inconsistent.

This low proportion of farmers keeping record on the animal health related events led us propose the design and implementation of an animal health record keeping system. Documentation of disease presentation and frequency would also help both veterinarians and farmers, to identify the important areas for education and training to support farmers and optimize animal health.

Calving support

Most of farmers identified calving period as critical for farm profit and dedicated enough time and effort to monitor calving cows and make sure the calf gets enough colostrum. Building on this practice, disinfection of calf's navel could be easily generalized by most farmers and may reduce the amount of calves that develop umbilical infections.

Disease

In terms of common diseases reported by farmers to exist in calves, growing or adult animals, farmers declared to have observed similar health problems as those reported in the veterinary literature, which are respiratory, digestive, and lameness. The proportion of animals that were reported presenting those problems were similar to what is found in other areas globally (Radostits et al., 2007). In this sense, there is no reason to assume that the frequency of disease presentation or proportion of animals which get sick is different from any other area however, precise information is needed to promote better practices to prevent disease introduction, limit endemic disease, and to determine the baseline prevalence of common diseases.

Actions taken

The animal health management results and discussion were used to implement a community based livestock syndromic surveillance system to record and do surveillance on animal health events. This will be discussed in further details in chapter 4 of this dissertation.

Research on SPS model for the Tepalcatepec Valley

To contextualize and discuss the results from Researcher's survey, the SPS model proposed for farmers in the Tepalcatepec valley needs to be described and explained. SPS model is described as a livestock production system that integrates animal production with fodder production by the association of grasses, shrubs and multipurpose trees, with the aim of increasing productivity, feeds quality and preserve or improve biodiversity. (Solorio et al., 2011; Murgueitio et al., 2015; Solorio et al., 2016)

This model was proposed as an option to recover and improve agroecosystems by the use of *Leucaena leucocephala,* a nitrogen (N_2) fixating legume, associated with other fodder species, particularly grasses, to increase biomass production and increase productivity in a sustainable, environmental friendly way (Solorio, et al., 2011; Solorio et al., 2015).

Combination of grasses, shrubs and trees allows the system to improve physical, chemical and biological traits of the soil, by means of the different levels of above ground vegetal strata that is reproduced below ground as well. Different level of roots allows the plants to access nutrients from deeper levels of the soil and be able to bring these nutrients back to the first layer of soil or horizon "A" (by leaves and other organic matter decay) to be absorbed and used by species with shallow roots such as grasses. Further details are presented in Ayala et al., (2013) and Solorio et al., (2016).

Legumes, such as shrubs and trees, are able to fix atmospheric N_2 for their own use and for grasses use. N_2, is a limiting nutrient in most soils, particularly in the tropics thus, the interaction of legumes with other species, such as grasses, allows to increase production of better quality fodder which could positively influence reduction on CH_3 emissions (Ku Vera et al., 2014).

The presence of shrubs and trees in a paddock that was a grass - only area previously, improves the microclimate for grazing animals due to the shade provided by trees. Trees also benefit birds and small animals that can find shelter in this kind of array; further benefit is given to the grasses, where the increased humidity is beneficial for their growth. Shrubs and trees increases the amount of C that the area can store (Solorio et al., 2011; Solorio et al., 2015).

The model should be adapted to each farmer in terms of agro ecological characteristics, and farmer' socio economic conditions to make an efficient use of the natural resources and financial capacities each farm and farmer possess. The Tepalcatepec valley is considered a plot of land where soil and climatic conditions is relatively homogenous and thus, model proposed could be implemented in any community within the valley.

Paddocks

Grasses: Should include at least two species of grasses. The first specie, a tall grass, preferable a high production – high quality grass such as *Panicum maximum,* cultivar Tanzania or Mombasa should be included in the paddocks. The second specie should be a stoloniferous grass, such as *Cynodom nlemfuensis* which will grow between the Tanzania plants and completely cover the soil.

Shrubs: Grazing areas should include legumes, basically *Leucaena leucocephala* in high density (35,000 to 60,000 plants per hectare) in rows of 1.6m wide. Distance between plants will vary, depending on the density desired.

Trees: Two different levels are considered in the tree component. A lower stratum that will include different fruit trees such as Lemon (*Citrus aurantifolia)*, Mango (*Mangifera indica*), Tamarind (*Tamarindus indica)*, avocado (*Persea americana*), forage trees such as Ramon (*Brosimum alicastrum*) and a higher stratum including Coco nuts (*Cocos nucifera*), timber species such as Teak (*Tectona grandis)*, or Cedro (*Cedrela odorata*) and Ceiba (*Ceiba pentandra*), Guanacaste (*Enterolobium cyclocarpum*) or Saman, (*Samanea saman*) as described by Murgueitio et al.,(2011) and Solorio et al.,(2016).

Management

A very important trait for the success of the model is the management. This includes, use and rest time for the paddocks, and the use of electrical fences to have high, instant (short duration), stock rates (1 – 2 days). Stock rate should be adjusted to one or two days of use maximum, allowing the animals to consume most of fodder available but without forcing the animals to seek for other areas for grazing-browsing. Rest time for the paddocks will range from 35 to 50 days depending on the soil characteristics and the rain/irrigation regimen and season (Solorio et al., 2016).

Technologic menus for adoption

Manuals for a step by step adoption of SPS model in their farms was put together by FMP and offered to the farmers interested (Flores et al., 2013). A schematic description of this menu is presented in figure 2

Discussion on the themes and aims under study by the research team

According to Researcher's survey and the previous description of the model, there are many different aspects involved in the system that are not measured or monitored and which could be determinant for the SPS model to be adopted and diffused to other farmers.

The research project under study grouped nine scientists from five universities which indicates that developing such models for sustainable cattle production is important and interesting for scientists and students, since 23 of them pursued a degree while collaborating with this research.

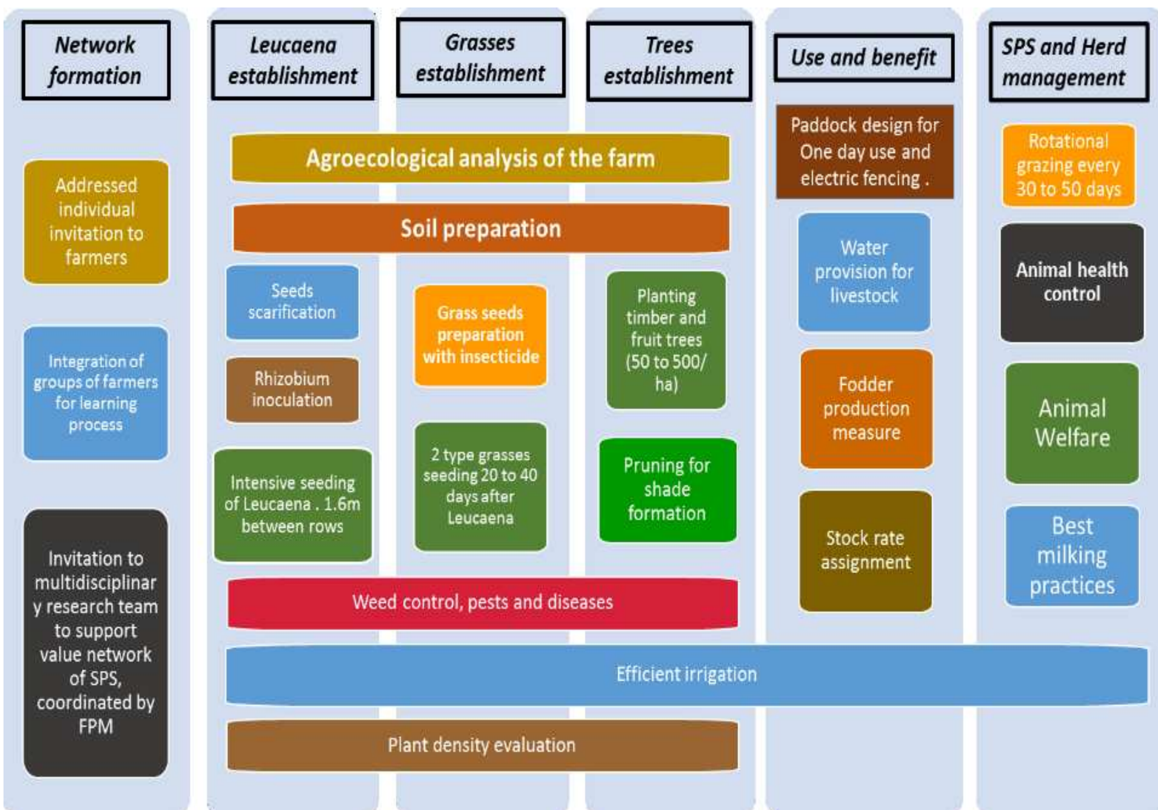

Figure 2 Manuals for SPS adoption (Adapted from Flores et al., 2013)

From table 3, we can note that the increase in biomass production, quality of fodder and productivity of the paddocks are one of the main concerns of SPS research since this theme has three researchers working on it. The productivity of the animals, whether measured as meat or milk production is the second most attended aspect of the research project, grouping also 3 researchers.

Animal health, reproductive performance, quality of milk, cheese and meat are studied by one researcher each, as well as GHG emissions, N_2 fixation and C store. Although including these themes is important, longer term benefits such as recovery of agroecosystems, activation of nutrient recycling or increase in biodiversity are not currently under study and should not be left aside and be included in a regular monitoring strategy.

Some authors have expressed (Pagiola et al., 2004 and 2016) that the initial investment could be considered a barrier for adoption and this aspect is not currently under study. A detailed record on investment and expenses during the establishment and operation should but be monitored by a specialist and not left this activity merely to the farmer.

Any source of income such as fruits, timber, firewood, or any other should be recorded for the economical evaluation of the model. Annual balance is obtained from the subtraction of total expenses to the total income (Rushton, 2009). One of the SPS declared benefits is the economic benefit for the farmer. The economic evaluation should not only consider increases in production and income, but it should also include increases in labor costs and other expenses for the establishment and operation of the SPS.

Sustainability is also declared as one of the characteristics of the SPS; however, there is no declared study to evaluate in any of the main dimensions of sustainability such as Environmental, Biological, Economic and Social. Studying these aspects can help direct or re-direct efforts to propose better approaches.

Recycling of nutrients and biodiversity composition regarding birds, insects, and small animals should be monitored to notice if these reported benefits can be verified. Improved Soil traits, such as physical, chemical and biological declared to be observable in the SPS are not currently under study, except for the C sequestration and N_2 fixation of Leucaena and compaction after grazing.

One of the possible sources for funding the farmer to adopt SPS is considered the Payment for Environmental Services (PES) however, the team surveyed did not mention any comprehensive study related to support the hypothesis that SPS offers environmental services and should receive PES (Pagiola et al., 2004; Pagiola et al., 2016; Tennigkeit and Wilkies, 2008).

At present, the limited interaction among scientists, if continued, will impair collaboration and therefore will limit the development of refined research questions for future investigation.

Conclusions

Animal health component survey applied to Tepalcatepec valley farmers gave us sufficient information about where to direct education efforts for farmers to improve their preventive practices and also to design, on a community basis, a record keeping system to do surveillance on animal health events.

As Kim et al., (2016) mentioned, mindful proposals to stop further increases in GHGs, by reducing changes in land use or land management that can contribute to reducing the burden on the global atmosphere will pose an important role. Agroforestry systems, such as SPS, has proved is one of those options; for a variety of benefits including increasing crop production, preventing soil erosion, conserving biodiversity and enhancing soil fertility and water quality.

SPS has been adopted by farmers on a limited scale.; one of the possible reasons is the lack of credit access or the high price of debt (interest rates) which play a role in allowing farmers to have financial resources to invest in their farms. Further detailed research on the return over investment should be done.

Main pillars for sustainability, such as environmental, social, biological and economic dimensions play an important role for an activity to be adopted and persist over time. For the economical and biological perspectives, SPS model still needs in depth research studies and observations *in situ* over a long period of time. However, in terms of social perspective, farmers have expressed their willingness to adopt the SPS model, even though it represents an increase in farm activities and thus, more time dedicated to the farm to correctly manage the SPS system.

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CHAPTER 3

SYSTEMS THEORY APPLIED TO SILVOPASTORAL LIVESTOCK PRODUCTION RESEARCH

Introduction

As civilization evolved, larger scale problems began to arise in society. Reductionist approach attempts to determine how everything in universe work by dissecting, learning the properties of the parts and from them, deduce the behavior of the whole. Over specialization and compartmentalization proved its inability to handle complex phenomena; for these phenomena, systems theory was developed. The general systems theory attempts to re unity science and counter act the drift apart between different disciplines, its primary aim is to solve problems in real life with an interdisciplinary approach. Tools from systems theory and analysis were designed to enhance synthesis and take over the function of a system by modelling and simulating. (Skyttner, 2005; Lazlo, 1996; von Bertalanffy, 1968).

Farming systems are probably the oldest of man-made systems, they are a process of transforming the original natural ecosystem, along with all the great diversity, to a restricted assemblage of crops, animals, pests and weeds (Conway, 1987). Over the years, farming also brought deforestation and loses in biodiversity; furthermore, livestock production is now considered one of the main drivers for global warming and climate change; for these reasons, mindful proposals such as Silvopastoral production system (SPS), as a model to reduce deforestation, stop further increases in GHG emissions, decrease the rate for land use changes or land management practices, that can contribute to reducing the burden on the global atmosphere, need to be assessed. The objective of this study is to apply the general systems theory to the SPS research efforts to identify themes and aspects and their interrelation not currently under research, to promote their inclusion in future studies.

Foundations of Systems Theory

According to reductionist approach of Descartes, a problem could be divided into small problems and by solving the small problems, the primary problem would be solved as well. Cartesian' method neglects interactions between the multiple elements that take part in the problem to be solved thus, making impossible to solve complex problems with this approach (Staerk, 1998). The first record about the systems theory is the Aristotelian dictum of the whole being greater than the sum of its parts. The purpose of systems theory is to serve as a platform to bring together different disciplines through inductive discovery of universally applicable models, principles and laws that help explain 'system' phenomena, for transcending the boundaries of the classical sciences (Laszlo 1996; Bertalanffy 1968; Boulding, 1956; Skyttner, 2005; Katina, 2016). Systems thinking is a pragmatic alternative that focuses on relationships and patterns rather than on parts and events (Staerk, 1998); systems thinking sets in motion a different level of thinking, based in understanding systems behavior/performance not being explained from traditional reductionist thinking.

As per Katina (2016) "the current state of systems theory can be summarized as a set of concepts, laws, principles, and theorems from different disciplines to describe different system structures and their behaviors". A set of 45 concepts and principles representative (but not complete or definitive) of systems theory are presented by Katina (2016) some are presented in Table 4.

Table 4 Contemporary concepts of systems theory. Adapted from Katina, 2016.

Concepts of Systems theory	Description
Law of complementarity	Any two different perspectives or models about a system will reveal truths about that system are neither entirely independent nor entirely compatible
Law of hierarchy	Complex natural phenomena are organized in hierarchies with each level made up of several integral systems or sub-systems
Law of requisite parsimony	Human short term memory is unable to deal or recall more than 7 (+/-2) activities
Law of requisite saliency	All the factors considered in a systems design are seldom of equal importance. Saliency of each factor will be discovered later
Law of requisite variety	Control achieved by a regulatory subsystem is limited by the variety of the regulator and the channel capacity between the regulator and the system.
Principle of balance of tensions	To release tension in a complex system a meta systems structure must be used to create a right balance between 1.- Autonomy of subsystems and the integration of the systems as a whole, 2.- purposely design and self -organization, and 3.- focus on maintaining organization stability and pursuing change. There is not right or wrong balance of tensions, rather a shifting balance based on the system's needs.
Principle of buffering	Stability of systems is enhanced by maintaining a surplus. Storage capacity, petroleum reserves or wheat reserves helps to buffer the system against and unexpected increase in demand.
Principle of circular causality	An effect becomes a causality factor for future effects

Principle of darkness	Each component of the system is ignorant of the behavior of the systems as a whole. It responds only to information that is available to it locally. If each element knew what is happening in the system as a whole, then all complexity would have to be present in that element.
Principle of homeostasis	The property of an open system to regulate its internal environment to maintain a stable condition by means of multiple dynamic equilibrium adjustments controlled by regulation feedback mechanisms
Principle of equifinality	If a steady state is reached in an open system, then it is independent of the initial conditions and determined only by the systems parameters
Principle of eudemony	Well-being in complex systems involves more than financial profitability. It involves a sense of happiness which might involve the right balance in terms of material, technical, physical, social nutritional cognitive spiritual and environmental aspects
Principle of low probability	The fundamental mission of the systems should not be jeopardized to accommodate or maximize events of low probability in individual subsystems or entities.
Principle of feedback	All purposeful behavior is considered to have a negative feedback. If a goal is to be attained, then some signals from the goal are necessary at some time to direct behavior.
Principle of omnivory	Stability in a complex system is achieved by having a greater number of different resources and pathways for their flow to the main system components.
Principle of holism	A system has holistic properties possessed by none of its parts. Each of the system part has properties not possessed by the system as a whole. It is the parts in a definite

	structural arrangement and with mutual activities that constitute the whole
Principle of homeorhesis	Dynamical systems will return to a trajectory or path, even if disturbed in development.
Principle of least effort	To attain a particular goal, all complex systems will naturally choose the path of least resistance.
Principle of Pareto	Ina large complex system, 80% of the outputs will be produced by 20% of the system means.
Principle of resilience	Complex systems exhibit the ability to withstand, recover from and reorganize in response to disturbances.
Principle of sub-optimization	Independent improvement of a particular sub-system may actually worsen the overall performance of the whole.
Theory of system boundary	Every system has a set of boundaries that delimitates what is included and what excluded from the system. Boundary description is necessary to differentiate it from its environment.
Theory of systems environment	Every system operates in an environment which is outside the control of the system and yet, it can influence systems process and behavior. Systems can only adapt to changes in the environment
Theory of socio technical systems	Design and performance of complex systems can only be improved and work satisfactorily if the social and the technical are brought together and treated as interdependent aspects of a work system.
Theorem of purposive behaviorism	Complex systems purpose must be deduced from the actual production (behavior, performance, outcomes) and not from what is intended to produce. Systems purpose is related to results and not to desires or intentions.

Systems pathologies

Pathologies of a system are known as circumstances that act to limit systems performance or reducing viability and the likelihood of meeting performance expectations (Katina, 2016). Most of pathologies are expression of a lack of use of Systems Theory principles or a direct violation of any law, principle and theorem, which brings deep implications for systems performance (Katina, 2016). Systems analysis can identify misperformances of a system as a whole, a subsystem or a process within a subsystem and from there, identify if a system's principle or law has been violated or if the limiting factor is the poor behavior from a different predecessor component. Gap analysis is a tool frequently used to asses a single component of a system. Gap analysis can only enunciate a breach between the current state and the expected state of a process or a component behavior, whereas System Analysis allows to identify the source of the misperformances, the various effects within the system and the interactions induced, to formulate a solution and allow the system to flow.

Farming systems

Farming, as mentioned before, is the process of transforming the original natural ecosystem into a restricted assemblage of biological components with the objective of produce food. As Sachs (2005) mentioned, a rising population of smallholder farmers at the forest margin, leads to deforestation as forests are cut to make room for new farms; at the same time, existing farmland is abandoned because of land degradation, soil erosion, and soil nutrient depletion; there are other, probably stronger drivers for deforestation such as urbanization. A model for a simple farm system is presented in figure 3

Hierarchy in Farming Systems

In the process of transforming the natural ecosystems, the basic ecological processes such as competition, herbivory and predation, are still present however, they are controlled by the human component and his intentions or objectives. The goals of any farming system are the human needs; in this sense, farming systems will always have a strong socio-economic dimension. Agroecosystems, as per Conway (1987), are ecological systems modified by human beings to produce food, fiber or other agricultural products.

Agroecosystems are structurally and dynamically complex agro-socio-economic-ecological systems that humans created with the purpose to satisfy his needs.

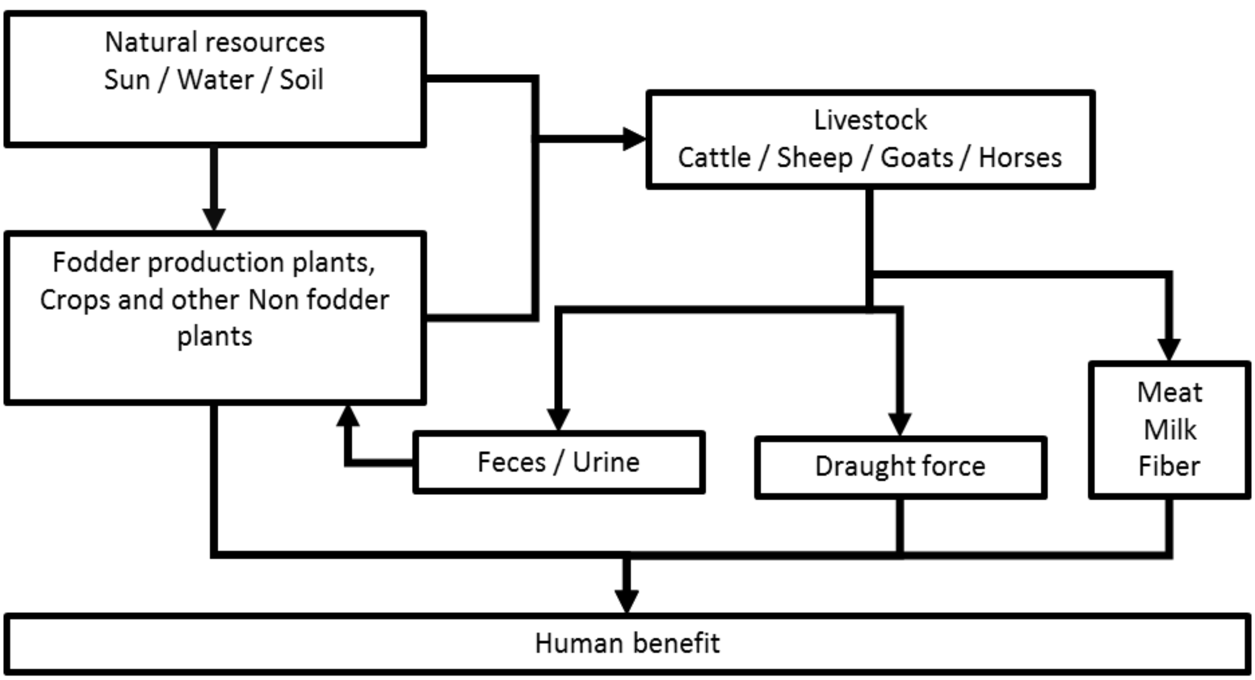

Figure 3 Diagram of a farm system, adapted from Street, 1990 in Jones and Street Eds. 1990.

Agroecosystem's ecological and socio-economic dimensions create the need for a hierarchy of such sub-systems; the farming system is one of the strategies for the family or household to make a living, at the bottom of the hierarchy, the agroecosystem comprises the individual plant or animal, which humans will harvest to gain benefits; the next level is the field and the paddock, then the village, the area, the region, the country, and the world where the agroecosystem operates. This agroecosystem is also linked to national and international markets through the global trade of agroecosystems outcomes. Systems theory holds that the behavior of higher systems in such a hierarchy, cannot be determined from a simply study of lower or upper systems but, each level in the hierarchy should be analyzed for its function and contributions to the entire system, since each different level will have a different goal and a group of sub-systems working on these goals (Conway, 1985).

SPS research in the Tepalcatepec valley

As mentioned before, the SPS model for farmers in the Tepalcatepec valley, proposed by the team of researchers in Mexico, was supported by a research project coordinated by the University of Yucatan and three other academic institutions. This research project had different aims, each of them focused on answering a question in one of the sub-systems or components of the SPS. The components researched are presented in 5

Table 5 Components and outcomes studied on the project

Component	**Outcome measured**	**Process**	**Final effect on system**
Environmental services	GHG emissions	CH_4 emissions depending on diet	Adjust Grass: Shrub ratio
Fodder	Digestibility / Nutrient content	In vitro and In vivo analysis of diet	Adjust Grass: Shrub ratio
Fodder	Fodder availability	Measure of performance depending on rest days, soil and water regimen	Adjust management for best combination of rest days and

			water regimen on different soils
Fodder	Fodder availability	Determine different stock rates depending on fodder availability under different Grass: Shrub ratio and water regime	Adjust stock rate to fodder availability
Livestock	Meat quality	Adjust livestock breed	Adjust livestock breed
Livestock	Milk yield	Nutrition effect on milk yield depending on breed	Adjust livestock breed
Livestock	Milking process	Hygiene during milking process	Improve milk quality
Livestock	Reproductive performance	Repro parameters comparison	Adjust Grass: Shrub ratio
Livestock	Daily weight gain	Adjust livestock breed	Adjust livestock breed
Livestock	Behavior	Consumption rates depending on shade availability	Adjust livestock breed
Livestock	Health	Healthier animals will perform better	Better performance of livestock
Milk	Artisan cheese	Adjust process to maintain public health and improve product	Characterize cheese produced
Milk	Composition of milk	Characteristics of milk measured in laboratory	Characterize milk produced
Soil	N fixation	Nitrogen fixation by legumes	Improvement on soil characteristics
Soil	C fixation	Below ground fixation of C	Improve soil characteristics, Environmental services

Soil	Soil characteristics over time	Physical characteristics of soil as a response to grazing (soil compaction)	Adjust stock rate and plant species to soil characteristics

System analysis

The goal of an interdisciplinary analysis is to achieve an interaction between the disciplines that produce insights which significantly transcend those of the individual disciplines. The system, defined as the assemblage of elements contained within a boundary such that the elements within the boundary have a strong functional relationship with each other but limited or no relationship with elements in other assemblages (Conway, 1985). The system analysis works in four assumptions:

1. It is not necessary to know everything about an agroecosystem to produce a realistic and useful analysis.

   SPS system is under research and development, practices from other countries have been adopted and adapted to the current tropical circumstances in Mexico. In this terms, basic knowledge on the characteristics of the ecosystems allows us to propose animal breeds and plant species in an attempt to make the system optimal. Not all the components, outputs, inputs, interactions and wastes are under study; the main animal outputs such as milk and meat are the main interest of the research project.

   Current model proposes one species of legume due to their high protein content, ability to support browsing, N_2 fixing ability and proved adaptation to Mexican tropics, however, this reduces diversity of the paddock and reduces the resilience of the SPS if a pest should enter the system. Perhaps additional legume species for direct browsing should be incorporated and tested for productivity and the ability to restore natural agroecological cycles. In addition, this particular legume (*Leucaena leucocephala*, var. Cunningham) possess a non-protein amino acid with toxic effects named mimosine. Mimosine and its metabolites could cause alopecia, anorexia, excessive salivation, esophageal lesions, reduced weight gain, enlarged thyroid and low circulating thyroid hormones representing a problem for cattle not adapted to the consumption of Leucaena. The rumen bacteria *Synergistes jonesii* is capable to metabolize and detoxify mimosine and its metabolites, allowing the animals to consume Leucaena without toxic effects (Hammond, 1995; Jones and Hegarty, 1984; Kudo et al., 1984; Gosh, 2007; Halliday et al., 2013).

Another important concern is when consuming large amounts of fast growing legumes as they may induce bloat in cattle. This may be the case for paddocks including Leucaena, since the flow and cycle of grazing-browsing animals may sometimes be shorter than 30 days. To prevent bloating, legume consumption should not be greater than 50% of total feed (Majak et al., 2003; Lehmkuhler and Burris, 2011)

2. *Understanding the behavior and important properties of an agroecosystem requires knowledge of only a few key functional relationships.*

One of the major processes in the SPS for the livestock production is the herbivory, thus, enough and timely fodder production is vital for maintaining livestock production flowing. In the tropics of Mexico, the rainy season is not always enough in duration and amount therefore, fodder must be stored to account for the uncertainty of rain. Farmers can maintain livestock production during the dry season by scaling the irrigated areas proportional to the size of their herds, increase the size or number of paddocks accordingly, to consider areas for grazing and browsing. Alternatively, stocking rate could be reduced during states of reduced forage availability.

Tree component have special requirements depending on the purpose of the tree. For example, timber trees will not succeed if herbivory is present, whereas fruit trees can withstand grazing and browsing of livestock if allowed to become adequately established and grow to a resilient state of maturity.

There is insufficient knowledge about C storage, N_2 fixation, and nutrient recycling from vegetal component, mainly because the rate for each will depend on the characteristics of each vegetal species. These have not been included in the present research project.

3. *Producing significant improvements in the performance of an agroecosystem requires changes in only a few management decisions.*

For SPS, determining the paddock's capacity for fodder production and thus the ability to maintain a number of animal per unit of area are key to improve the performance and sustain the production over time without running out of resources. These characteristics are particular for each farm and depends on many factors such as soil fertility, soil physical characteristics, hydric balance, sun radiation, and vegetal species, among others. Also important is the rest time needed for a given paddock to fully recover and produce enough fodder; this aspect will also change from farm to farm, depending on the characteristics of the soil, vegetal species and weather.

4. *Identification and understanding of these key relationships and decisions requires that a limited number of appropriate key questions defined and answer.*

In these terms, for the SPS research project the three key questions are:

8. Define the objectives of the system: For SPS, the objectives are: Provide food, employment and income to farmers, while preserving or improving natural resources and biodiversity for future generations.
9. Define the system: SPS is a complex system of interacting components such as soil, plants, animals, and human beings, in a determined environment, with the purpose of transforming diverse natural elements such as sun radiation, water, nutrients from the soil and other inputs, into products of direct and indirect benefit for humans such as fruits, meat, milk, seeds. Other beneficial outputs are the increased belowground *C* store associated with the inclusion of trees and legumes, N_2 fixation, increasing the bioavailability for non N_2 fixing species such as grasses.
10. Pattern analysis: By analyzing SPS in space, time and flow, the main patterns are identified and used to identify interactions among components and performance limiting factors. Briefly, the main fluxes come from sunlight, humidity and minerals from the soil, used by the plants component to grow and increase biomass. This biomass is used by the animal component to feed and grow, converting this vegetal biomass into meat and milk, or animal origin protein. Livestock is extracted from the system after wastes such as feces and urine are incorporated into the soil. This process occurs in a continuum, eventually extracting N_2 and P from the system.

SPS research Model diagram

Diagram of the SPS research project, adapted from Spedding (1975) is presented in figure 4 to illustrate the different components, inputs and outputs of the SPS.

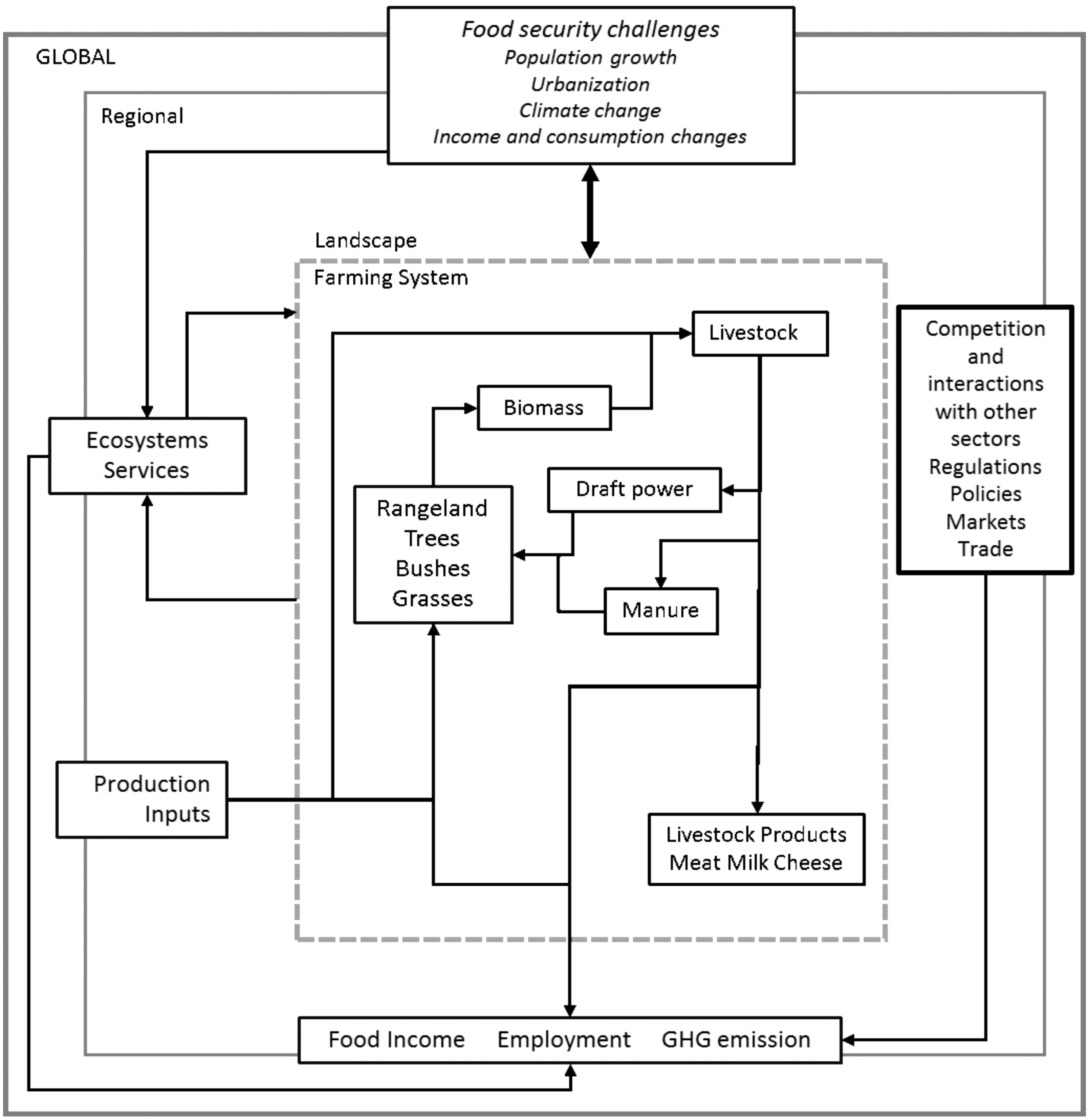

Figure 4 Diagram of a SPS, modified from Spedding (1975)

Definition of Silvopastoral System (SPS)

SPS is a complex system of interacting components such as soil, plants, animals, and human beings, in a determined environment, with the purpose of transforming diverse natural elements such as sun radiation, water, nutrients from the soil and other inputs, into products of direct and indirect benefit for humans, as described by Erales, (2017a). Specific characteristics of SPS are the inclusion of multipurpose threes, high density of legumes and improved grasses for direct grazing and browsing of livestock.

SPS attempts to recover and improve the entire agroecosystem by the use of *Leucaena leucocephala,* a nitrogen (N_2) fixating legume, associated with other fodder species, particularly grasses, to increase biomass, timber, fruit and livestock production, in a sustainable, environmental friendly way (Solorio, et al., 2015; Solorio et al., 2016). This combination of grasses, shrubs and trees provide different levels of above ground vegetal strata which is reproduced below ground as well which allows the system to improve physical, chemical and biological traits of the soil while increasing the amount of C that the area can store.

The presence of shrubs and trees in a paddock improves the microclimate for grazing animals due to the shade trees provide, it also benefits birds and small animals that can find shelter in this kind of array but also, for the grasses, where the increased humidity is beneficial for their growth (Solorio et al., 2015; Solorio et al., 2016).

Direct benefits are employment, crops, fodder as feed for animals, fruits, timber and shade. Indirect benefits come from animals, these products are meat, milk, fiber, and graft power.

There also other by products such as manure, which is useful as a fertilizer for crops and fodder production but also, greenhouse gases (GHG) which are harmful for the atmosphere and are a cause for global warming.

Purpose of SPS:

The purpose is to provide food, employment and income to farmers. SPS is also an alternative livestock production system to revert ecosystems degradation induced by traditional monoculture livestock production systems. This ecosystems degradation is a major concern in the actual global context of climate change, resource scarcity and food insecurity.

Environment or context

SPS model is designed for tropical and subtropical environments. Plants selected will grow from average sea level to 1,800 m.a.s.l.; in the tropics, high temperatures are around 30 to 40 degrees Celsius (°C) and the low temperatures are almost never below 0 °C. Radiation is intense and photoperiod oscillates between 11 and 13 hours per day during the year. Daily humidity or relative humidity varies between dry regions and humid and sub humid regions. For Rain regimen, there is not a limit to accept or reject an area as suitable for SPS, as long as the rainy season can support grasses and legumes growth but avoids temporal flooding, because Panicum grasses and Leucaena legume can't survive under flooded conditions if this conditions exceed 21 days. To avoid scarcity of biomass production, and irrigation systems is preferable to support fodder production during the dry season.

Boundaries

Boundaries of SPS are limited mainly to area of private property used by the farmer for SPS production. Could also include other areas, from a different owner, used to maintain and produce livestock within the SPS model. These boundaries include the main components (plants and animals) and their interactions and exclude the market for products, sources of other inputs (feeds, medicine, fuels, electricity source, etc.).

Vegetal component

This component includes three main groups as follows:

a) Trees; fruit, timber, or fodder trees should be included in densities that range from 50 to 500 per hectare (ha). A double layer of trees should be sought, a higher level composed of timber and palm trees and a lower level of fruit and fodder trees. N_2 fixing legumes and endemic trees should be preferred. Special emphasis should be made in selection of fruit trees, since selecting the variety to grow is probably the most important decision in relation to the final product (Arthey, 1989). This group of species of the vegetal component is one of the basic transformers of sun radiation, water and minerals into biomass, fodder and fruits and or timber. Inclusion of trees as compared to grasses monoculture, provides the opportunity to diversify production from livestock products to fruits, construction wood and timber. This diversification, increases the chances for the farmer to be better off by planning livestock production income for those months where there is no fruit production.

b) Shrubs; mainly legumes of high content and quality of protein will be included such as *Leucaena leucocephala* var. Cunningham. Density of shrubs will range from 30,000 to 50,000 plants per ha. Shrubs will be planted in rows with a 1.6m separation to allow cattle to walk through the rows to browse. The SPS model proposed for Tepalcatepec suggests the use a particular N_2 fixing, high protein content and high biomass producer legume (*Leucaena leucocephala*) however, this is a limitation for the biodiversity of the SPS. Increasing the number of species, with similar characteristics as those of the Leucaena, would increase biodiversity and thus the resilience of the system in case of the eventual emergence of pests.

c) Grasses; at least two types of grasses should be included, a tall grass, such as *Panicum spp* and a short grass such as *Cynodom spp* to grow among the tall grasses and cover completely the soil. Not definite species or varieties of grasses is indicated. Grasses to be used should be adapted to the soil and climatic condition of the area. The SPS can include even native grasses, better adapted to the environment but with the production constrains of this adaptations. Grasses with characteristics such as the ability of cope with flooding, drought and grazing; with high biomass production and high protein content are preferred

Animal component

Mainly referred to cattle, however there are SPS working with sheep and is also suitable for goat production. At this point, there is no limitation as which species should be considered or not considered in SPS production.

For cattle, breeds studied were those adapted to tropical environment such as *Bos indicus* breeds (Gyr, Brahman, Nellore, Guzerat or Indubrasil) and crosses of *B. indicus* with *Bos taurus* (Brown Swiss, Holstein, Charolaise, Angus, among others). A combination of traits is desirable since dual purpose production (meat and milk) is pursued. There was also an experience under the same project related to fattening cattle under SPS grazing-browsing conditions and compared with the commercial feedlot system; the daily weight gains for cattle were similar with the addition of 1.0 kg of rice polish offered to SPS cattle. The difference was huge when comparing costs per kg of meat produced, favoring SPS system (Solorio, B., 2013; unpublished data).

Human component

Farmers and other labor included as the human being component in the SPS. Activities were aimed to control the use of fodder by assigning area and time for use of paddocks (Labor). Farmers were also responsible for harvesting animal products and some plant products. Farmers set the goals of the SPS and were responsible for the use and management of resources to reach those goals. SPS requires an increased labor, making daily management decisions particularly in the fodder resource use; this implies that farmer should have this activity as their main economic activity.

Other resources

Besides natural resources described in the "Environment" section and labor, other inputs in the SPS studied were three different categories of inputs. a) Feeds to supplement animals. These were used mainly during milking, but also for calves, though not in a constant manner. b) Medicines and vaccines. Used strategically and sporadically, whenever sick animals needed treatment. c) Agrochemicals. These were used during the first stages of grasses and legumes establishment and were used to control weeds and assure the correct establishment and growth of desired species.

Interactions

Natural resources (Sun radiation, humidity – water, nutrients in the soil) combined, offer to the plant component the matter and energy to grow and produce. The vegetal component has its particular outcome (fruits) but also produces material to be used by the animal component in the form of fodder, to convert it to meat and milk. Animal component has also two by products, wastes (Feces and urine) and GHG emission, one accumulates in the paddock or pens and the other is dispersed to the atmosphere. Human beings participates along the process of managing the vegetal component to support animal component growth and production, assuring livestock behavior is under expected productive parameters.

Outcomes

The main outcomes from the SPS are meat and milk by means of dual purpose cattle raised and from livestock, there is also cheese from the transformation of milk. From Vegetal component, outcomes included fruits, seeds, timber or logs. Fodder is used by animal component to convert it into meat and milk, unless there is an excess in production, in which case can be sold to other farmers or stored as silo or hay.

Other outcomes should be considered such as *C* store, N_2 fixation, reestablishment of nutrient cycling, increase in biodiversity and thus resilience of the farming system, landscape restoration, shade increase in paddocks,

By products

As by products, SPS have manure and urine, methane (CH_4) and nitrous oxide (N_2O) emissions from livestock and manure. GHG emissions are supposed to be lower than those from cattle grazing in traditional monoculture grasses systems due to the improved digestibility of the diet consumed by livestock and increased biodiversity.

Properties of SPS

The basic properties or goals of an individual organism can be translated to complex systems such as Agroecosystems (Conway, 1987) being these: Productivity, Stability, Sustainability and Equitability; they are not outcomes, they are properties intrinsic to development of the system.

Productivity

Productivity measured as the output of valued product per unit of resource input. In terms of the SPS, meat or milk yield per ha. Fruits (kg or units) per ha. The basic input resources are land, labor and capital. Productivity can be measured at different levels in the hierarchy of the SPS such as region or village (Conway, 1987).

Stability

Stability considered as the ability to continue producing despite disturbances derived from natural fluctuation on nutrient cycles or variability in the environment. Fluctuations on climate, markets or social component may be expected in the SPS.

Sustainability

Sustainability is defined as the ability of the system to maintain productivity even when major disturbing forces take action. Intensive stress (small and frequent or infrequent but large) which have the potential to create an immediate large disturbance are considered major disturbing forces. Sustainability determines the durability of SPS under known or possible conditions. Sustainability includes three domains, the social, economic and the biological or environmental (Bowler et al., 2002; Clayton and Radcliff, 1996)

Equitability

This property refers to the evenly distribution of productions and gains among the human beneficiaries, as per their needs. This is directly related to farmer's family structure and the dispersal of the benefits will depend on decisions made by the family head.

Breaches identified in the research project and the current application of the SPS

After analyzing the components under research on the Tepalcatepec valley SPS project, some components need further research because they were identified to be under-considered; some are completely absent from research and need to be included to have a holistic research of the system. These breaches are presented in figure 5, as the components not circled. Details are presented in following lines.

Definition of the SPS. There is an insufficient understanding of the system in terms of its components, inputs, and outputs because a general operational definition is not widely available and is needed to evaluate performance. This operational definition will clarify what can be included in each component such as livestock, grasses, bushes, trees, environmental services, ecological processes, etc.

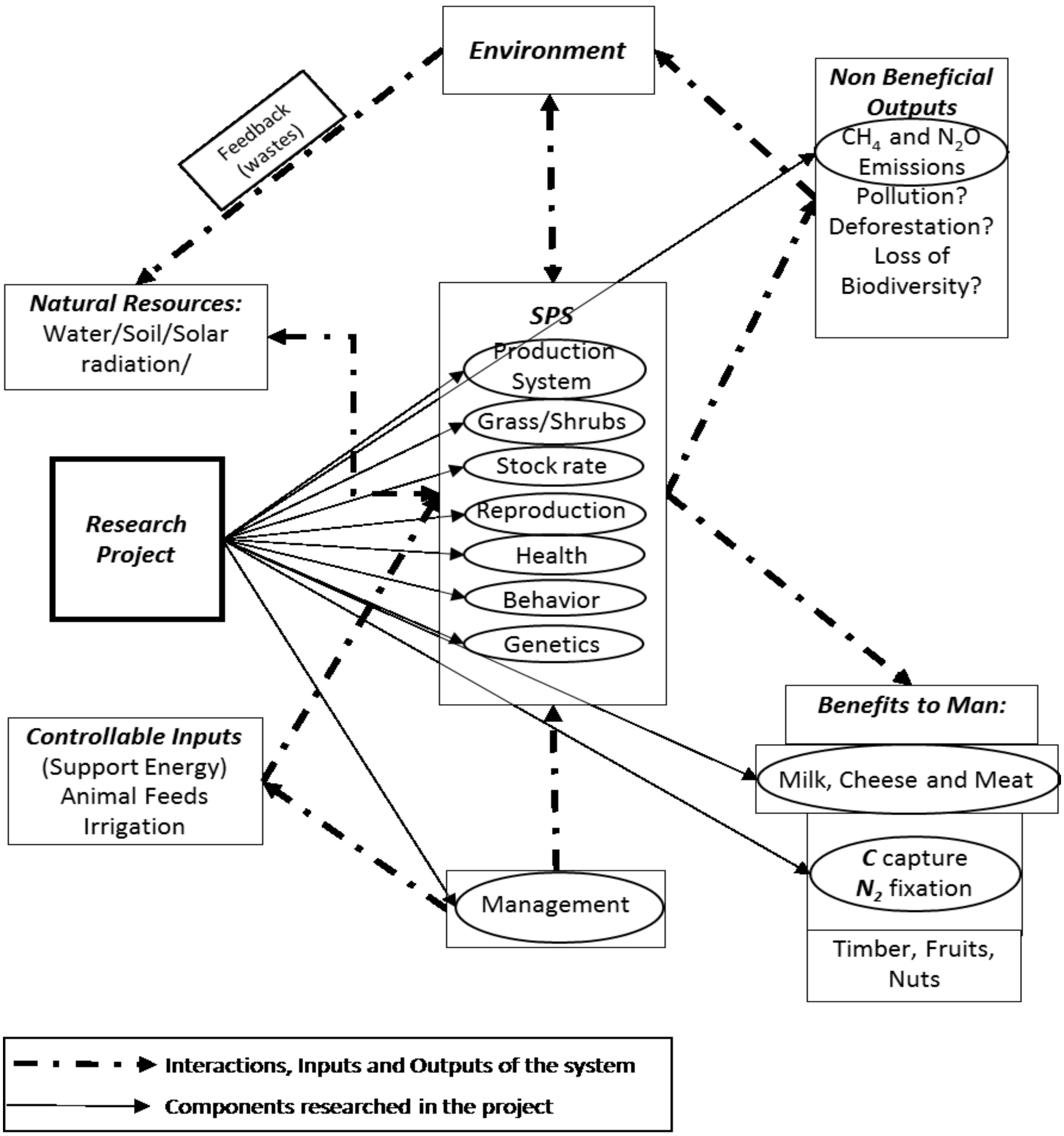

Figure 5 SPS research project. Adaptation of the basic agriculture production system by Spedding (1988).

Variation within components this will also bring diversity in outputs and those outputs should be treated equally in terms of their profitability. This variability will increase the probability of SPS to be adapted to other areas and adopted widely.

Operational definition will also help differentiate between a SPS and a diversified crop – livestock mixed farming. Definition and behavior should be different as well as the performance.

Knowledge about the ability of the SPS to adapt to different geographical locations is necessary to broaden the area of application and promote scaling up. This characteristic is directly dependent on the vegetal species included in the array, since different species will adapt to different type of soil, precipitation and temperatures. Precision in the definition of components is required, the Information component was not considered in the research project.

As Dubberly, Pangaro (2015) and Conway (1985) indicated, information and its communication are a vital component of the system if a goal is to be reached.

Information as a training in what to observe and how to interpret behavior of components can improve the system performance. In the SPS, early detection of system' pathologies in the different components such as over grazing or paddock management can help the farmer avoid losses; in these terms, no efforts are done in the research project to share this knowledge or instruct farmers, however, on how to identify and prevent sick animals, the research project developed a community based syndromic surveillance system to quantify and address animal health problems as described by Erales *et al.,* (2017b). No similar system is considered for the pathologies of plant (grass, legumes or trees) component.

For disseminating information about the SPS, Fundacion Michoacan Produce (FMP) follows a strategy that allows more experienced farmers using SPS, to share their experiences with other farmers, using their own farms as model for learning. This approach has proved to be useful, allowing farmers to talk to each other in their own terms, with the confidence of having scientific based research undergoing in their farms.

Economic performance of the SPS is considered in terms of production and productivity however, a long term prospectus that includes timber, seeds, and fruits share and incorporate their contribution into livelihoods and net return of the farm is needed to be developed. This will help in elucidating an affordable way to fund the conversion of a traditional farm into an SPS farm, other than the regular bank credit lines or loans.

In addition, there are other concerns identified and are presented as follows:

There is not sufficient promotion of SPS in a broad aspect among producers, users, and researchers. The following promotion should be considered:

a. Scientific knowledge with emphasis on reliable and credible contrasts and comparisons with other intensive and extensive systems. This requires rigorous broad interdisciplinary research with publications and presentations in wide areas of scientific disciplines
b. Ecological and environmental relevant pros and cons of the SPS needs to be researched with a more independent approach to focus on the impact of the ecological and environmental issues associated with the SPS with the aim to modify the system for the negative environmental impacts.
c. Diffuse SPS among wider and visionary producers will require a better understanding of convenience evidence and better profitability and sustainability.
d. Diffuse SPS among politicians and decision makers, will require more users of the system with the ability to show the impacts on the short, middle and long term.

Insufficient synthesis among the various research team members was observed. In order to help in the promotion of the SPS, particularly in the research and outreach arms of the current program. There is a need to move from multidisciplinary approaches of the research to interdisciplinary approaches and to open communication for the farmers to present research questions to the appropriate researcher member of the team.

A leading institution is required to work closely with the current leadership (FPM) to coordinate and synthesize the research activities. Future research should have two general aims – improving the current procedures of the SPS to fully evaluate the performance of the system and to promote SPS through the scientific community to facilitate the interaction between different disciplines and researchers.

Animal health sub system

For the animal health subsystem for the animal component, the benefits SPS claims will bring to the paddock by increasing the bio diversity of plants and improving the micro climatic conditions for livestock may also represent additional challenges such as an increase in exposure to tick populations, increase prevalence of gastro intestinal parasites in the paddocks and thus, increase the risk for exposure to those parasites. Additionally, the risk of increasing the size of biting flies' populations, such as tabanidae, among others, may represent an increase in the cattle exposure to the bites and diseases transmitted by flies. Perhaps the inclusion of other legumes than Leucaena may be beneficial by increasing the levels of tannins ingested, at least sporadically, and in some way keep under control the gastro intestinal parasite loads. For ecto parasites, similar approaches to control increased affections should be considered.

Furthermore, increased biodiversity in terms of more birds inside the system boundaries, may also represent an increase in the risk of transmission of field strains of *Salmonella* or the mechanical transmission of other pathogen bacteria or even the amplification of arboviral diseases such as West Nile virus or Influenza virus exposure by increased contacts with migratory birds.

Paddock's improved microclimate may increase wild life mammal's frequency and this may increase not-desired contacts with livestock resulting in an increased risk of *Mycobacterium* and other bacterial and viral transmissions, affecting the health status of the herd and increasing zoonotic risks.

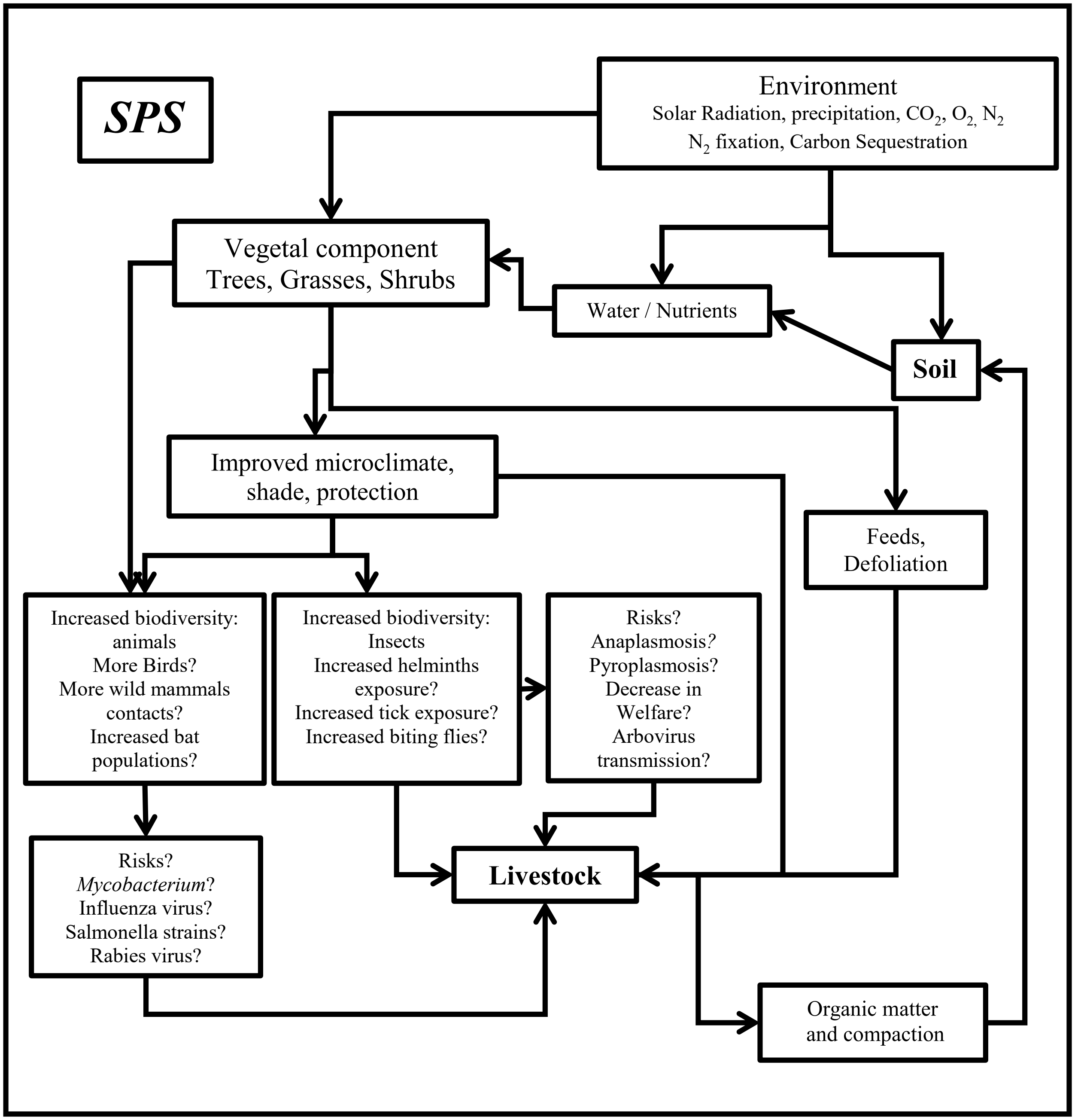

Figure 6 Animal health subsystem and the interrelation of improved microclimate, increased biodiversity and risk for pathogen exposure to livestock

Another possible detrimental effect for livestock health, posed by increasing the biodiversity in the system, as compared to livestock production on grasses monoculture, is the risk of increased bat populations, attracted by insects and fruits, chances are that hematophagous bats will also increase their populations and with that, the increase in the risk of exposure to rabies virus.

At this point, we do not have information to either accept or reject these asseverations, for this reason, it is necessary to include into the research project, measurements on the increases or decreases of wild life contacts or exposures and not merely continue monitoring the syndromic presentation of diseases in livestock. A schematic representation of the interrelations of microclimate, the increase in biodiversity and the risk for animal health this represents, is presented in figure 6.

Conclusions

Analyzing SPS model with a systems approach allowed us to identify existing components that need to be included in future research efforts, for example, economic performance and environmental services. C capture, nutrient recycling, variety of suitable species to be included, increase in soil's fertility and increases in biodiversity need to be under research, but also long term environmental impact, such as water cycle influence among others.

Further interdisciplinary researcher is needed to increase knowledge of the different components of SPS and understand their interactions, as the effect of legumes ability of N_2 fixation on grass performance.

Description of the system, definition on the components and expected functions are needed to clarify uses and misuses and avoid under performance of SPS.

Animal health is one of the subsystems of the animal component that requires further interdisciplinary research to generate missing knowledge about the possible increases in risks through more frequent contacts and interactions with wild mammals, birds and insects. Rigorous measure and comparison with traditional grasses monoculture will increase our knowledge and increase our chances for success in scaling up SPS.

Sustainability, stability and equitability as a properties of the system, need to be included in the research project as productivity is. Particularly Sustainability is declared and assumed in many papers, however no declared strategy to measured it in any of its main dimensions, Social, Economic or Biological. Although some farmers are aware that the SPS model is profitable, environmental friendly, and socially acceptable, initial investment is probably the first barrier for adoption. The amount of financial resources needed to convert traditional paddocks into SPS is not small and frequently requires the support of financial entities. For Mexican banks, there is a preferable interest rate for agricultural loans however, for some farmers, credits and loans are not easily accessed and for others, credits and loans are not correctly managed, making funding for the investment a barrier for adoption of SPS. Economic aspects from establishment of SPS to first, second and third year financial return should be thoroughly studied with special emphasis on the profitability of timber and/or fruit plantations contribution, since they maybe a key component to increase profitability of the SPS. New strategies should be explored to increase the number of farmers using SPS and provide a broader empiric knowledge to identify research needs and direct future steps over time. Scaling up is one of the biggest challenges Agroecology faces, translating results from a small farm into a bigger set of farms is frequently difficult (Dalgaard et al., 2003) however it may be possible if a clear definition of the SPS is built and the model's function is promoted with an increased variety of options per component is offered and the knowledge on gaps is acquired.

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CHAPTER 4

DEVELOPMENT OF A COMMUNITY – BASED LIVESTOCK SYNDROMIC SURVEILLANCE SYSTEM FOR ANIMAL DISEASE IN SILVOPASTORAL FARMS IN MEXICO

Introduction

Ongoing efforts to assess the health and disease status of a given population and having a plan of action to control and prevent dissemination of diseases is in the broader sense, the definition of a surveillance system for animal health. Surveillance provides early warning on any change in the health status of the animal population, but also provides information about the frequency or extend in the case a health problem is present in such population (Salman, 2003). Surveillance is also a powerful tool to detect or fail to detect diseases (to declare freedom) that could prevent domestic or international trade of animals and animal products; furthermore, Risk based surveillance is aimed to concentrate financial, labor and /or time resources, that are frequently scarce, to detect a particular health concern or hazard (Staerk, et al., 2006).

Community-based animal health surveillance programs were developed in the 1990's to provide animal health care to areas where the lack of roads, telecommunications or the insecure atmosphere for veterinary officers made it difficult for them to provide such care. These surveillance programs involve the community, farmers and animal workers to be trained to detect diseased animals and to provide primary basic care. (Mariner and Catley, 2002; Mariner, Catley and Zepeda, 2003; Catley 2006, Thrusfield, 2007; Araba et al., 2009; Catley et al., 2012).

Intra- and inter-observer variation in disease recognition, reporting, and intervention (treatment) is expected when not professional observers or veterinarians are employed. These variations can be minimized by: 1) continuing educational programs provided by veterinarians. 2) Consensus building about signs, diagnosis, and treatment options inherent to a community-based syndromic surveillance and delivery system. 3) Data triangulation which is the comparison of multiple sources of the similar data (Catley and Mariner, 2002) and data complementation which is to elaborate, illustrate or clarify findings generated by one method with another (Campbell et al., 2012).

Growing economy countries such as Mexico frequently do not have the financial resources to provide veterinary services to all livestock producers, particularly those who are small stakeholders and who are located in marginalized communities where roads and telecommunication infrastructure need improvement. Mariner et al., (2011) indicates that this produces an environment wherein centralized animal health regulatory agencies and university veterinary experts remain largely uninformed about livestock health problems in the country, and the small stakeholder and/or marginalized producers remain uninformed of optimal livestock health practices, centralized disease control programs and disconnected from sources of expert advice. To illustrate: According to the World Bank (2014), Mexico belongs to the upper middle income countries and is the second largest economy in Latin America; however rural life in Mexico is, in many cases, still developing. Regarding livestock production, we could identify a sector that is an intensive, large, commercial herd, in which the owners and managers are aware of the importance of well-designed livestock health programs and are able to afford private veterinary services. However, nearly 70% of cattle ranchers in Mexico have herds smaller than 35 cows (INEGI, 2009); these small farms are family owned/operated and with limited technology. For these near 2.5

million farms, private veterinary services are generally not affordable and/or accessible; furthermore, social disparities and other situations, such as organized crime activities, sometimes lead to internal conflicts that has destabilized the already fragile ties between animal health regulatory agencies, universities, private veterinarians, and livestock owners. This socially insecure environment further impairs the delivery of veterinary services and animal health education to small / marginalized farmers, increasing the likelihood that the animals on the farm will receive little to no veterinary care, resulting in adverse effects on animal health and welfare, farm economic status, public health, and food safety.

In Mexico a national research project to generate a sustainable model for livestock production funded by Conacyt, started in 2011 to characterize, promote and diffuse the use of Silvopastoral systems (SPS) as a model to increase production and profitability while reducing the impact of livestock production on the environment and increase resilience on farmers. The Animal health component was approached with a survey to 115 farmers/owners from the Tepalcatepec Valley in Michoacan, making evident the need for monitoring health events in their herds (Erales et al., 2017).

The lack of information regarding disease presentation or production, the insecure social environment and the herd size and small economic profit these farms obtain, led us to propose a community based livestock syndromic surveillance system to generate baseline information on animal health events and to obtain information to where education, preventive and control measures should be aimed, to reduce the impact of observed health events.

Methods

For this small, proof of concept, hypothesis testing study, a group of farmers with specific characteristics was considered the community. SPS is a production system where an array of grasses (such as *Cynodom nlemfuensis or Panicum maximum)*, shrubs (such as *Leucaena leucocephala* or *Tithonia diversifolia*) and different types of trees (such as fruit trees, palms, timber trees, other) are established to provide improved quality diet for better animal nutrition, better microclimate by providing shade and wind curtains, and environmental services such as increasing the carbon (C) sequestration, improving soil cover and structure, reducing emissions of greenhouse gases (GHG) to mitigate the negative impact of livestock production to the environment and restoring nutrient cycling. In the same way, increasing production and income for farmers, diversifying production by selling also the fruits, firewood or timber (Solorio, et al., 2015; Solorio, et al., 2016).

As part of a national project, 115 farmers from the Tepalcatepec Valley were invited to participate and respond to a structured questionnaire to describe their production system, its components and expectations regarding their participation on this research project. Very little to no information regarding records of health event presentation was retrieved however, farmers expressed their interest and desire to receive advice on animal diseases control and treatments (Erales et al., 2017).

Study sites

This SPS model was stablished in Michoacan and Yucatan states in Mexico (see figure 7) Owners and animal workers from three silvopastoral farms in Michoacan state (19^{0}12´00” to 19^{0}04´00” North and 102^{0}52´00” to 102^{0}24´00” West) and from two silvopastoral farms in Yucatan state (20^{0}52´00” to 20^{0}50´00” North and 89^{0}40´00” to 89^{0}36´00” West) were selected based on convenience to represent different herd size. Farms in Michoacan had 25, 50 and 100 cows each; one mechanical milking per day, (each farm has its own milking machine), offered from 1 to 2 kg of commercial feeds during milking, calves suckled their dams after milking, they employed from 1 to 8 animal workers and were all family own operated.

In Yucatan, farms selected had 38 and 50 cows each and were different in the level of technification, amount of feeds offered and milking process; one had hand milking whereas the other used a milking machine; both had one milking per day and both had their calves suckling after milking the cows. One was family own operated and the other belonged to an educational institution.

Figure 7 Map of North America, showing Mexico. Michoacan and Yucatan States, highlighted

Participation and Training methods

For this study, farmers and animal workers from farms were briefed about the inherent long-term benefits of animal health to farm productivity, public health, and food safety and then worked together through informal meetings on the recognition of clinical signs and syndromes using an illustrated livestock' clinical signs and syndromes guide.

According to Pretty (1994), community participation in this study is defined as Type 5 or functional participation (cooperation), in which participants forms groups and participate to reach determined objectives; although depends on external initiators and facilitators, is expected to become self-dependent.

The booklet

A data booklet (letter size) was designed during the meetings with farmers, to be easy to use, to record observations and treatments. With their suggestions, a mock of a booklet was presented to them and adjusted to their preferences (Fig 2). In the booklet, the group "VACA" Includes adult animals such as cows and sires; group "CREC": Includes animals after weaning and before being included as cow or sire; group "BEC": included newborns until weaning)

The syndromes and component clinical signs include:

- Respiratory: Cough, nasal discharge, fever, abnormal respiratory sounds.
- Digestive: Diarrhea, bloat, indigestion, unexplained inappetence
- Locomotor: Lameness, fractures, and inability to stand
- Skin/Lesions: Skin cuts, lacerations or abrasions, hematomas, wounds and eye lesions.
- Reproductive: Abortion, retention of fetal membranes, abnormal vaginal discharge
- Neurologic: Depression, incoordination, abnormal behavior
- Death: Sudden death or involuntary (non-planned) cull.
- Udder/Mastitis: Clinical mastitis manifested by abnormal quarter(s) or grossly abnormal milk

Data collection and follow-up period

Animal health data (number of animals classified with any of the syndromes) was compiled on a daily basis into the provided booklets. Data collected included the date, animal ID, clinical signs and syndrome(s), description of any treatments conducted, and related comments the farmer would wish to add. Data collection began in July of 2012 and concluded in June 2014.

URICHO

Sindrome	Dia	LUNES	MARTES	MIERCOLES
	Fecha			
Respiratorio	VACA			
	CREC			
	BEC			
Digestivo	VACA			
	CREC			
	BEC			
Locomotor	VACA			
	CREC			
	BEC			
Piel/Lesiones	VACA			
	CREC			
	BEC			
Reproductor	VACA			
	CREC			
	BEC			
Neurologico	VACA			
	CREC			
	BEC			
Muerte	VACA			
	CREC			
	BEC			
Ubre/Matitis	VACA			
	CREC			
	BEC			

Notas: ____________________

Figure 8 Page layout of a Booklet

Every week, farms were visited by a Veterinarian and by a technician on a different day, to provide support to the farmer on the use of the booklet, provide clarification on classifying a specific syndrome and to make their own records of that day, using their own identical booklet.

Data analysis and validation

Counts of syndromes recorded by farmers was summarized and used to calculate incidence risk per month, as described by Dohoo et al., (2009), dividing the number of each syndrome recorded by the average population at risk for the period. Data was analyzed to identify a) the most frequent syndrome, the one with the highest incidence; and b) the syndrome with highest economic impact, by using a simple sum of direct and indirect losses; as described by Rushton, Thornton and Otte (1999) and Rushton (2009).

To validate, data recorded by farmers were "triangulated", as described by Catley and Mariner, (2002); and Mariner, Catley and Zepeda, (2003) by comparing it to the syndromes recorded by the veterinarian and technician in each State. Additionally, farmers were allowed and encouraged to request relevant laboratory tests or post-mortem examinations, as suggested by Catley (2006), in order to obtain a more precise clinical diagnosis and complement our findings.

Correlation coefficient between farmers' observations and Veterinarian's observations were estimated using Med Calc^{TM} Ver. 10 software. The Observations from farmers corresponded to the whole year daily observations, whereas the veterinarian observations corresponded to the whole year one-day per-week observation.

Results:

Booklet use

Booklets were used in all farms in Michoacan and Yucatan States on a daily basis for two years; the frequency of syndromes was scarce. Counts of syndromes and incidence risk per month per group are presented in Table 6 for the 2012 – 2013 period, in the table, group "Cow" Included adult animals such as cows and sires; group "Grow": Included animals after weaning and before being included as cow or sire; group "Calf": included newborns until weaning)

Table 6 Sum of Syndrome counts per period and monthly Incidence for Michoacan and Yucatan States for the 2012-2013 period.

		Michoacan Farms		Yucatan Farms	
2012 – 2013		Sum of Counts per Period	Incidence per month	Sum of Counts per Period	Incidence per month
Respiratory	Cow	2	0 - 0.005	0	0
	Grow	4	0 - 0.037	0	0
	Calf	54	0.039 - 0.108	0	0
Digestive	Cow	8	0.002 - 0.016	4	0 - 0.009
	Grow	7	0 - 0.047	0	0
	Calf	36	0.022 - 0.095	18	0.023 - 0.032
Locomotor	Cow	8	0.003 - 0.009	15	0.017 - 0.013
	Grow	3	0 - 0.003	0	0
	Calf	0	0	2	0.003
Skin/Lesions	Cow	0	0	19	0.006 – 0.031
	Grow	1	0 - 0.001	0	0
	Calf	17	0.004 - 0.047	5	0.003- 0.012
Reproductive	Cow	15	0.004 - 0.025	6	0.002 - 0.010
Neurologic	Cow	2	0 - 0.003	0	0
	Grow	0	0	0	0
	Calf	3	0 - 0.017	0	0
Death	Cow	0	0	0	0
	Grow	1	0 - 0.001	0	0
	Calf	6	0 - 0.017	1	0 - 0.003
Udder/Mastitis	Cow	20	0.004 - 0.042	8	0.004 - 0.011

Counts of syndromes and incidence risk per month per group are presented in Table 7 for the 2013 - 2014 period.

Table 7 Sum of Syndrome counts per period and monthly Incidence for Michoacan and Yucatan States for the 2013-2014 period.

		Michoacan Farms		Yucatan Farms	
2013-2014		Sum of Counts per Period	Monthly Incidence	Sum of Counts per Period	Monthly Incidence
Respiratory	Cow	2	0 - 0.007	0	0
	Grow	0	0	0	0
	Calf	26	0.018 - 0.030	5	0.005 - 0.011
Digestive	Cow	1	0 - 0.001	0	0
	Grow	0	0	0	0
	Calf	68	0.033 - 0.133	33	0.045 - 0.053
Locomotor	Cow	32	0 - 0.021	20	0.017 - 0.022
	Grow	0	0	0	0
	Calf	3	0 - 0.011	1	0 - 0.002
Skin/Lesions	Cow	13	0 - 0. 021	3	0 - 0.005
	Grow	2	0 - 0.007	8	0 - 0.022
	Calf	4	0 - 0.005	5	0.005- 0.011
Reproductive	Cow	33	0.011- 0.017	20	0.018 - 0.022
Neurologic	Cow	1	0 - 0.001	0	0
	Grow	0	0	0	0
	Calf	0	0	3	0 - 0.007
Death	Cow	4	0 - 0.002	0	0
	Grow	1	0 - 0.001	0	0
	Calf	12	0.005 - 0.023	4	0.005 - 0.008
Udder/Mastitis	Cow	41	0.010 - 0.019	10	0.008 - 0.011

None of the farmers requested any laboratory test to help them diagnose a syndrome, but treated with medicines and/or management each case, without consulting the veterinarian.

Most frequent syndromes

From Table 6, the most frequent syndromes observed in 2012- 2013 period were "Respiratory" for calves, specifically calf pneumonia (54 cases observed) with up to 0.108 incidence risk per month, followed by "Digestive" for calves, specifically calf diarrhea (54 cases observed) with up to 0.095 incidence risk per month.

From table 7, the most frequent syndrome observed for the 2013 – 2014 period was "Digestive" for calves, specifically Calf diarrhea (101 cases observed) with up to 0.133 incidence risk per month, followed by "Reproductive" for cows (53 cases observed) and "Locomotor" for cows, specifically Lame cow (52 cases observed) both with up to 0.022 incidence risk per month.

Highest Impact syndromes

For both periods, the highest impact syndrome on economy and productivity was death of the animals. With only 0.017 incidence risk per month in 2012 – 2013 period (7 calves and 1 growing animal) and 0.023 incidence risk per month in 2013 – 2014 period (12 calves, 1 growing animal and 4 cows). The impact is the equivalent of the market price of the animal, being in the range of $450 to $480 USD per calf, around $ 850 USD for the growing animal and for the cow, the replacement cost is approximately $1,200 USD.

The impact of the other syndromes included the direct losses such as reduced performance and the indirect losses such as the cost of treatment (medicines, labor and disposables) and the denied access to better markets was estimated to be around $ 10 USD (Calf diarrhea) to $20 USD (Calf pneumonia) per animal treated, according to medicine costs and the reports on expenses by the farmers.

Triangulation of observations and validation

Farmers observations were compared to those observations from the Veterinarian and technician to assess the level of accuracy the farmer had identifying syndromes. Simple comparison of syndromes recorded on the day that Veterinarian and Technician visited the farm. All farmers identify correctly most of the animals affected in their herds and selected the corresponding syndrome. Differences between farmers' syndrome selection and Veterinarian selection were mainly in selecting a particular syndrome for animals that were diagnosed with anaplasmosis, a frequent blood parasite in Michoacan region. Other differences were the over reporting of sick animals during the first months of the monitoring period, when farmers reported as respiratory sick animals due to a sporadic cough or scarce nasal secretion.

Comparison with laboratory results or post mortem examinations were not possible because none of the farmers requested those studies.

Correlation of incidence

Farmer's incidence calculations were compared to Veterinarian's incidence calculations and analyzed for correlation. Spearman's correlation coefficient was estimated, using Med Calc ™ software ver. 10, for not normally distributed data. All tests resulted in a positive correlation (rho values >0.5). The results for 2012 -2013 period is summarized in Table 8

Table 8 Spearman's correlation coefficient for farmers and veterinarian observations for the 2012 – 2013 period

	Lecheria	Kampepem	Uricho	Huarinches	Chandio
DVM 1 (Yucatan)	rho=0.670 95%C.I. 0.365 to 0.845 p= 0.0013	rho= 0.643 95%C.I. 0.304 to 0.838 p=0.0032			

DVM 2 (Yucatan)	rho =0.855 95%C.I.=0.690 to 0.936 p<0.0001	rho =0.723 95%C.I.= 0.434 to 0.877 p=0.0009			
DVM 3 (Michoacan)			rho =0.508 95%C.I.= 0.122 to 0.761 p=0.0171	rho =0.718 95%C.I.= 0.434 to 0.872 p=0.0008	rho = 0.706 95%C.I.= 0.422 to 0.863 p= 0.0007

For the 2013 – 2014 period, Table 9 presents the results of the correlation analysis.

Table 9 Spearman's correlation coefficient for farmers and veterinarian's observations for the 2013 – 2014 period

	Lecheria	Kampepem	Uricho	Huarinches	Chandio
DVM 2 (Yucatan)	rho=0.748 95%C.I.=0.494 to 0.885 p=0.0003	rho=0.837 95%C.I.= 0.654 to 0.927 p=0.0001			
DVM 3 (Michoacan)			rho=0.425 95%C.I.= 0.026 to 0.707 p=0.0413	rho=0.616 95%C.I.= 0.282 to 0.816 p=0.0032	rho= 0.482 95%C.I.= 0.097 to 0.741 p= 0.0208

Discussion

Booklets were maintained to be used during the two-year duration of the present study; involvement and participation of the farmers; which is considered key to success for community development (Catley, 2006). This participation is classified as Type 5, (Pretty, 1994), vital to reach the desired goals within this research and the development of the project by providing information and actively participated in generating tools to collect new data. (Catley and Leyland, 2001).

The Incidence of syndromes recorded/observed was scarce. Special emphasis on calving and nursing, as well as first month special neonatal care could increase the probability for newborns to successfully turn into weaning age. Calf pneumonia and calf diarrhea will also be mitigated by better practices and management.

Although risk incidence was minor, health events recorded could be used, as a baseline information to avoid mislead official veterinary services to under estimate the presence and impact of a specific health problem and providing information for the implementation of cost effective preventive measures (Okell *et al.,* 2013).

In this study, triangulation of data recorded by farmers and veterinarians was used to validate the records kept by farmers and animal keepers comparing those records to the ones kept by an animal health professional. Triangulation allowed us to assess farmers and animal keeper's ability in identifying affected animals gave us an idea of how well farmers and animal keepers understood the concept of syndromes and the syndromes illustrated guide (Catley, 2006; Mariner et al., 2011; Dunkley and Mariner, 2009).

To objectively asses if the incidence observed by farmers and veterinarians were correlated, Spearman's correlation coefficient for each pair of farm-veterinarian was estimated. Every pair of raters were correlated to a significant alpha of 0.05. The correlation coefficients calculated had a median value of rho: 0.706 for the 2012 – 2013 period and a median of rho: 0.616 for the 2013 – 2014 period, which is considered a positive strong correlation.

Study limitations

The number of farmers involved in keeping the booklets is low compared to the number of farmers involved in the SPS national project. Our limitations to follow up with an increased number of farmers involved was determined by our ability to provide an accompanying veterinarian during this two-year period. Increasing the number of farmers using this system could provide a more extensive and richer baseline information from which to compare health events through coming years. If more farmers could be engaged, may be interesting to explore how to link these efforts to a national or regional epidemiologic databases to function as early warning on anomalies detected.

Lack of laboratory diagnostic tools in the region reduces our ability to precisely identify the "Respiratory" or "Digestive" agent or agents involved in the syndrome presentation, which limits the specific control and preventive measures to suggest further measures than supportive – life saving care.

Conclusion

Baseline data of animal health events among small stakeholder are possible to obtain by the use of a simple syndrome classification and involving farmers to participate in the design and development of the means to keep those observations recorded. Participation of small holders can offer an informed first level medical care for their animals and could also function as a first line of recognition and report of abnormal frequency of syndromes in their herds.

This first attempt to provide a community - based method to record and summarize livestock syndromes at small stakeholder level in Mexico, was useful, suggesting which syndrome had the highest impact and where preventive measures and/or education should be directed. This system could be linked to regional and national animal health offices to provide early warning on abnormal events.

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CHAPTER 5

QUANTITATIVE RISK ANALYSIS FOR THE INTRODUCTION OF BOVINE TUBERCULOSIS THROUGH INFECTED CATTLE IN SILVOPASTORAL SYSTEMS[1]

Summary

Bovine tuberculosis (BTb) is a chronic progressive illness of cattle and represents a serious hazard for human population because it can be transmitted through air or unpasteurized milk and milk products. Continuous efforts to control and eradicate BTb are observed worldwide. In Mexico, prevalence of BTb is reliant upon on the regional application of a national program for BTb control and eradication. This program is based on the use of tuberculin tests with culling of reactors to declare negative (free of disease) herds. To assess the risk of introduction of BTb into the Silvopastoral (SPS) cattle farms from the Tepalcatepec valley in Michoacan State in Mexico, 6 scenarios were developed based on the application of the Mexican national program and traditional commercial practices. SPS farmers in Tepalcatepec valley share a similar location, production system, and BTb herd status (free of disease); these farms were therefore considered an epidemiological unit. Using the software @Risk®, and considering the regional prevalence and

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the characteristics of the tests applied, a stochastic model was developed to simulate scenarios for the introduction of BTb. The highest-risk scenario calculated in this study was from acquiring animals from unknown health status source herds without testing the animals prior to introduction to the purchasing herd (risk = 0.00251 or 1 success in 398 trials). Testing cattle with the Caudal Fold Tuberculin (CFT) test prior to movement decreased the probability of introducing false negatives (infected cattle that tested negative) into the SPS farms. Moreover, if the CFT and the comparative cervical tuberculin test (CCT) were applied in parallel, the probability of introducing FN animals decreased to a negligible level (risk = 0.00001088 or 1 success in 91,911 trials), regardless of the health status of the source herd.

Key words: Risk Analysis, bovine tuberculosis; Silvopastoral; Dual purpose cattle, Michoacan, Mexico.

Introduction

Bovine Tuberculosis (BTb)

Bovine tuberculosis (BTb) is caused by *Mycobacterium bovis (M. bovis),* is an economically important disease of livestock. BTb causes reduction in lifespan and poor performance (Michel et al., 2010). It is transmitted from animal to animal mainly by air contaminated with *M. bovis*. Other routes of transmission include gastro intestinal tract and venereal. BTb is a zoonotic disease that can cause chronic progressive illness and mortality (Menzies and Neill, 2000; Michel et al., 2010; Salman and Steneroden, 2015). In less-developed countries, deficiencies in public health control measures for cattle and animal products make BTb an important public health concern (Etter, 2006; Miller et al., 2015). Human infection results from consumption of infected products such as meat and unpasteurized milk and milk products from wild or domestic animals. Although BTb has been largely controlled in developed countries through pasteurization and animal testing in less developed countries control measures are not always observed, resulting in human infections (Michel, et al., 2010; de la Cruz et al., 2014; Woodroffe et al., 2016).

There is global concern and effort for the eradication of BTb; the strategy is based mainly on reducing the disease in livestock herds to reduce the risk of transmission. To diagnose cattle infected with BTb regardless clinical signs, few reliable tests, such as the tuberculin skin tests and the gamma interferon test, are available for antemortem diagnosis. Tuberculin skin tests are used on a regular basis in national programs for the control and eradication of *M. bovis*. Tuberculin tests evaluate the cell-mediated immune response to mycobacteria exposure with a delayed hypersensitivity reaction that is greatest at 72 hours post injection. Tuberculin skin tests are widely used for diagnosis in cattle. They are imperfect tests, but are the best that are currently available. (Pollock et al., 2001).

Silvopastoral system (SPS)

Global food security will remain a worldwide concern for the next 50 years and beyond. Reducing hunger is a great challenge for our society since it manifests as multiple health problems. (Gerber et al., 2013; Wheeler and Von Braun, 2013, Salman et al., 2008). Agroforestry systems for livestock production is one of the strategies followed globally; one of the models used are SPS, which aims to improve the quantity and quality of forages for livestock, micro climate, animal comfort, nutrient cycling, preservation and improvement of soil characteristics and diversification of production for small farmers. (Solorio et al., 2016; Cuartas et al., 2014; Murgueitio et al., 2011 and 2015). In Mexico, recent efforts to increase resilience for small livestock producers includes a SPS model described by Erales et al., (2017), which considers the adoption of different arrays and proportions of browsed legumes such as *Leucaena leucocephala* var. Cunningham, grasses such as *Panicum maximum* var. Tanzania and multipurpose trees such as fruit trees, palm, forage or timber trees (Solorio et al., 2016). SPS farming is a tool to fulfill the "safe and nutritious" goal for food production as stated in the FAO's definition of food security (FAO, 1996). A handful of farmers in the Tepalcatepec valley in Michoacan State, Mexico have adopted the SPS; they share geographic location, some characteristics such as dual purpose production system, and BTb free status.

National program for control and eradication of BTb in Mexico

In Mexico, BTb is under a national program, designed and applied by the Federal Ministry for Agriculture and fisheries (SAGARPA), to control *M. bovis* in cattle and eventually eradicate it from cattle herds. This program is based on test and cull of positive reactors to tuberculin injections using CFT and confirmation of reactors with CCT. Reactors to CCT, are branded with a letter "T" on the right cheek, over the masseter muscle and culled. (SAGARPA, 1995, and 1998). The national program has three different phases of application: Control, Eradication and Free of disease; the application of each phase depends on the conditions of the region and the facilities available to have or not a complete geographical coverage and application of the program or on the known herd-level prevalence (SAGARPA, 2016a). In Michoacan State, the national program is operated by the State Committee for livestock promotion and protection (CEFPP Mich.) which recognizes two official prevalence zones for the eradication phase for BTb called "Zone A" with a 0.5% or less herd prevalence and "Zone B, with more than 0.5% herd prevalence (CEFPP, Mich. 2016).

Risk analysis

Risk, as defined by the OIE (2010), is the likelihood of the occurrence and the likely magnitude of the biological and economic consequences of an adverse event or effect to animal or human health. Risk comprises four main phases: 1) Hazard Identification, which in our study is the introduction of BTb into the negative tested herds of the SPS group of farmers. 2) Risk Assessment, which is the quantification of the probability of *M. bovis* entering the SPS herds, considering: a) That cattle are exposed to the agent by means of the transmission routes described previously and successfully spread within the herd. b) The consequences of cattle being infected with *M. bovis,* which include restrictions for animal movements, trade and restrictions to products trade. 3) Risk Management, which includes all the measures taken to avoid the risk or to mitigate it with conventional, relevant and affordable means. And 4) Risk Communication which includes the open discussion of the elements described above among all stakeholders (farmers, public health officials, animal health officials, consumers, etc.) and the personnel conducting the risk analysis (Zepeda, 2008; OIE, 2010a 2010b).

For this study, three SPS farmers from the Tepalcatepec valley were considered an epidemiological compartment, as described by Scott et al., (2005). For the risk analysis, 6 scenarios were applied based on the national program for the control and eradication of BTb and traditional commercial practices, such as prioritizing purchases from neighbors, friends and relatives. The aim of this study was to identify the least likely scenario for the introduction of BTb into the SPS compartment herds and to suggest the safest strategy to test animals prior to introduction into a disease free herd.

Materials and Methods

A stochastic model was developed using Excel® (Microsoft corporation, Redmond, WA, USA,) and @Risk® (Palisade Corporation, New Field, NY, USA) software to simulate six different scenarios in which the introduction of BTb might be possible through the movement of live animals into the compartment.

Basic Information and assumptions

Basic information on the characteristics of the herds, the prevalence of BTb in the region and the sensitivity and specificity of the available diagnostic tests was necessary to calculate all the inputs needed to run the risk analysis. Input parameters based on literature and national program reports were included.

Herd Prevalence

Herd prevalence in Michoacan State, as reported by the CEFPP Mich (2016) was considered to be 0.64%. As of December 2015 (SAGARPA, 2016a) there were 287 disease free herds with 19,402 head of cattle.

Herd Size

According to SAGARPA (2011) more than 75% of cattle farmers in Mexico own from 1 to 50 cows and in Michoacan State, the SPS compartment includes farms of 30 to 55 cows herd size. With this data (30, 50 55), a 38 head farm was simulated by a pert distribution as the most likely herd size.

Prevalence within herd

The national program for control and eradication of BTb bases its operations on the use of tuberculin diagnostic tests (SAGARPA, 1995 and 1998). These tests are imperfect. The uncertainty of having a false negative herd, (this is a herd where all animals test negative, but at least one infected animal is missed by the test) was considered. In this case, the within-herd prevalence was calculated according to the estimated herd size and the possibility of having one, 3 or 5 infected animals (1/38, 3/38, 5/38) and simulated a Beta distribution. The value obtained was 0.093 within-herd prevalence with a 95% confidence interval of 0.035 to 0.187.

Animals to introduce

We considered the introduction of 5 replacement animals as an estimate of the 15% annual replacement observed in these farms (Estrada, E., 2013).

Diagnostic tests

For our simulations, we considered sensitivity and specificity values for CFT and CCT reported by Farnham et al. (2012) and mentioned below.

CFT Sensitivity (Se)

A pert distribution with the values for CFT Se (0.804,0.82,0.9677) was simulated.

CFT Specificity (Sp)

A pert distribution with the values for CFT Sp (0.892,0.94,0.988) was simulated.

CCT Se

A pert distribution with the values for CCT Se (0.74,0.75,0.9355) was simulated.

CCT Sp

A pert distribution with the values for CCT Sp (0.96,0.973,0.9991) was simulated.

Sequential testing

Multiple tests are used to increase the ability of the diagnostic process. Sequential testing is used to increase either the Se (Parallel testing) or Sp (Series testing) of the tests. (Dohoo et al., 2009).

Testing in Series

Series testing is applied to those individuals that tested positive on a first diagnostic test. Retesting positive individuals with a different test may reduce the number of false positives (Dohoo et al., 2009; Gordis, 2014). For the Mexican national program, the result is to increase the Sp and thus reduce the number of false positive animals sent to slaughter.

Series CFT CCT Se

Was calculated as described by Dohoo et al., (2009) as follows:

*(CFT Se) * (CCT Se)*

Series CFT CCT SP

Calculated as described by Dohoo et al., (2009):

*1- (1 –CFT Sp) * (1- CCT Sp)*

Testing in Parallel

Retesting individuals that test negative on a first test is termed testing in parallel. This approach is used to increase Se and avoid missing infected individuals. (Dohoo et al., 2009; Gordis, 2014).

Parallel CFT CCT Se

The formula reported by Dohoo et al., (2009) was used.

*1-(1- CFT Se) * (1- CCT Se)*

Parallel CFT CCT Sp

To calculate the Sp for CFT and CCT in parallel, we used the formula reported by Dohoo et al., (2009):

*(CFT Sp) * (CCT Sp)*

Correlated test results

Sequential diagnostic tests are considered conditionally independent if the probability of getting a given result in one test does not depend on the result of the other test, given the disease status of the animal (Hui and Walters, 1985, Vacek, 1985; Dohoo et al., 2009). However, when tests measure a related biological condition such as hypersensitivity to *Mycobacterium* proteins, the results will be correlated; such is the case for tuberculin tests. Thus, results from Tuberculin tests are conditionally dependent or correlated (Hui and Walter, 1980; Vacek, 1985; Gardner, 2000; Dohoo et al., 2009; Alvarez et al., 2012). Functionally, having correlated diagnostic tests means that the gains or losses in Sp and Se from using series or parallel approaches will not be as great as predicted under uncorrelated diagnostic tests (Dohoo et al., 2009).

Herd level considerations

The risk for the introduction of an infected animal into a herd is the probability of selecting infected animals that were missed by the CFT test, due to the imperfect Se and Sp of the test. According to the Mexican national program, for a herd to be declared negative, it has to test negative to the CFT once, or if one or more positive reactors are found, the herd needs to test negative to the CCT. This testing in series scheme increases the Sp of the set of tests, but decreases the Se, which increases the probability of leaving undetected infected animals in the herd and thus the probability of having false negative animals (FN). To quantify the probability of having a FN herd, Se and Sp was calculated using the series values for CFT and CCT, according to Dohoo et al., (2009).

Herd Se

The formula used to calculate Herd Se, accounting for series application of tests, as described by Dohoo et al., (2009) is:

*HSe= 1-((1-((p*Se series) + (1-p) (1-Sp series)) ^n*

Herd Sp

To calculate Herd Sp we used the formula described by Dohoo et al., (2009)

HSp = Sp series ^n.

Herd True Negative (TN herd)

To calculate the probability declaring TN herds, we followed:

*(1- p herd) * (Herd Sp)*

Herd False Negative (FN herd)

To calculate the probability of declaring a FN herd, we follow:

*(p herd) * (1- Herd Se)*.

Herd Negative Predictive Value (NPV herd)

The NPV herd is calculated:

NPV herd = TN herd/ TN herd + FN herd

Herd 1- NPV herd (1- NPV herd)

The probability of declaring a FN herd is then:

1- NPV herd

Diagnostic Tests

Se and Sp values simulated for the CFT and CCT tests, and values calculated for the tests when applied in Series or Parallel, are presented in Table 10.

Table 10 Se and Sp values for tests used in the simulations.

Diagnostic Tests						
Animal level			Series		Parallel	
	Test 1 (CFT)	Test 2 (CCT)	Se	Sp	Se	Sp
Se	0.857	0.807	0.691		0.972	
Sp	0.926	0.982		0.999		0.909
Herd level	Formula	Cut off value of 1				
Herd Se	0.937	1-(1-((PSeSER)+((1-p) * (1-Sp SER))) ^ herd size				
Herd Sp	0.950	Sp ^herd size				
TN herd	0.94394	(Sp)(1-p)				

FN herd	0.00040	(p)(1-Se)
NPV herd	0.99958	TN/(TN+FN)
1-NPV herd	0.000587	Median Probability of an Infected herd to be declared negative (FN herd)

Scenarios

The scenarios considered represent different situations that farmers in Michoacan State may encounter on a day-to-day basis for replacing animals in their herds. The scenarios are presented in Table 11, and their full description follows in the following section.

Table 11 Description of Scenarios considered for the Risk Analysis.

Scenario	Description	Herd Status	Animal Status
1	Acquiring animals from Negative Tested Herds without testing the animals	Negative	Not Tested
2	Acquiring animals from a Not tested Herd without testing the animals	Not Tested	Not Tested
3	Acquiring animals from a Negative Tested Herd, and testing the animals CFT	Negative	Negative CFT
4	Acquiring animals from Not Tested Herds, testing the animals CFT	Not Tested	Negative CFT
5	Acquiring animals from Negative Tested Herds, testing the animals CFT and CCT	Negative	Negative CFT + CCT
6	Acquiring animals from Not Tested Herds, testing the animals CFT and CCT	Not Tested	Negative CFT + CCT

Results:

Scenario #1

Given the farmer acquires 5 replacement animals from a Negative Tested Herd (NegTH), without testing the animals, the probability of introducing at least one infected animal, given that it comes from a FNegH, is 0.0002288 or 1 in 4,370 trials.

Scenario #2

Given the farmer acquires 5 replacement animals from a Not Tested Herd (NotTH) and takes them to his farm without testing the animals, the probability of introducing at least one infected animal is 0.00251 or 1 in 398 trials.

Scenario #3

Given the farmer acquires 5 replacement animals from a NegTH and before taking them into his herd, he tests the animals with the CFT and takes the negative animals. The probability of introducing at least one infected animal is 0.0000469 or 1 in 21,281 trials.

Scenario #4

Given the farmer acquires 5 replacement animals from a NotTH but, before taking them into his herd, he tests the animals with the CFT and takes the negative animals. The probability of introducing at least one infected animal is 0.0005294 or 1 in 1,889 trials.

Scenario #5

Given the farmer acquires 5 replacement animals from a NegTH and tests the animals with the CFT and CCT taking the negative animals, the probability of introducing at least one infected animal is 0.00001088 or 1 in 91,911 trials.

Scenario #6

Given the farmer acquires 5 replacement animals from a NotTH and tests the animals with the CFT and CCT taking the negative animals, the probability of introducing at least one infected animal is 0.0001231 or 1 in 8,123 trials.

Comparative table

Probability observed under the different scenarios is presented in figure 10, where we can compare the magnitude of the probability when either we have or do not have information on the herd source and whether we test once (CFT), twice (CFT and CCT) or don't test at all.

Discussion

The results obtained through this study illustrate that although the mandatory Mexican national program for control and eradication of BTb is an important tool to reduce the number of animals and herds infected with *M. bovis*, it also has limitations that need to be considered when trying to avoid the introduction of *M. bovis* in a disease-free herd.

The limitations have three components:

1) The Herd Se is decreased when trying to declare the herd free of infected animals by increasing the herd Sp. This increase in herd specificity will maintain the lowest number of false positive reactors (FP). The reason for trying to reduce the FP rate is because culling those animals will have a negative impact on the farm's economy.

2) When the interest is to reduce the probability of having FN, applying the CFT and CCT tests in parallel is a good strategy because this results in the lowest probability of having FN results.

3) Tuberculin tests (CFT and CCT) measure the same Cell Mediated response the animal has to the infection with Mycobacterium species. For this reason, results from these tests when used in series or parallel are conditionally dependent or correlated, which means that the amount of

gains or loses we have in Se or Sp by applying sequential testing is lower that if the tests were independent or measuring different responses in the animal. This is important to consider when applying the results from this study and whenever those tests are applied to a herd or under a control and eradication program.

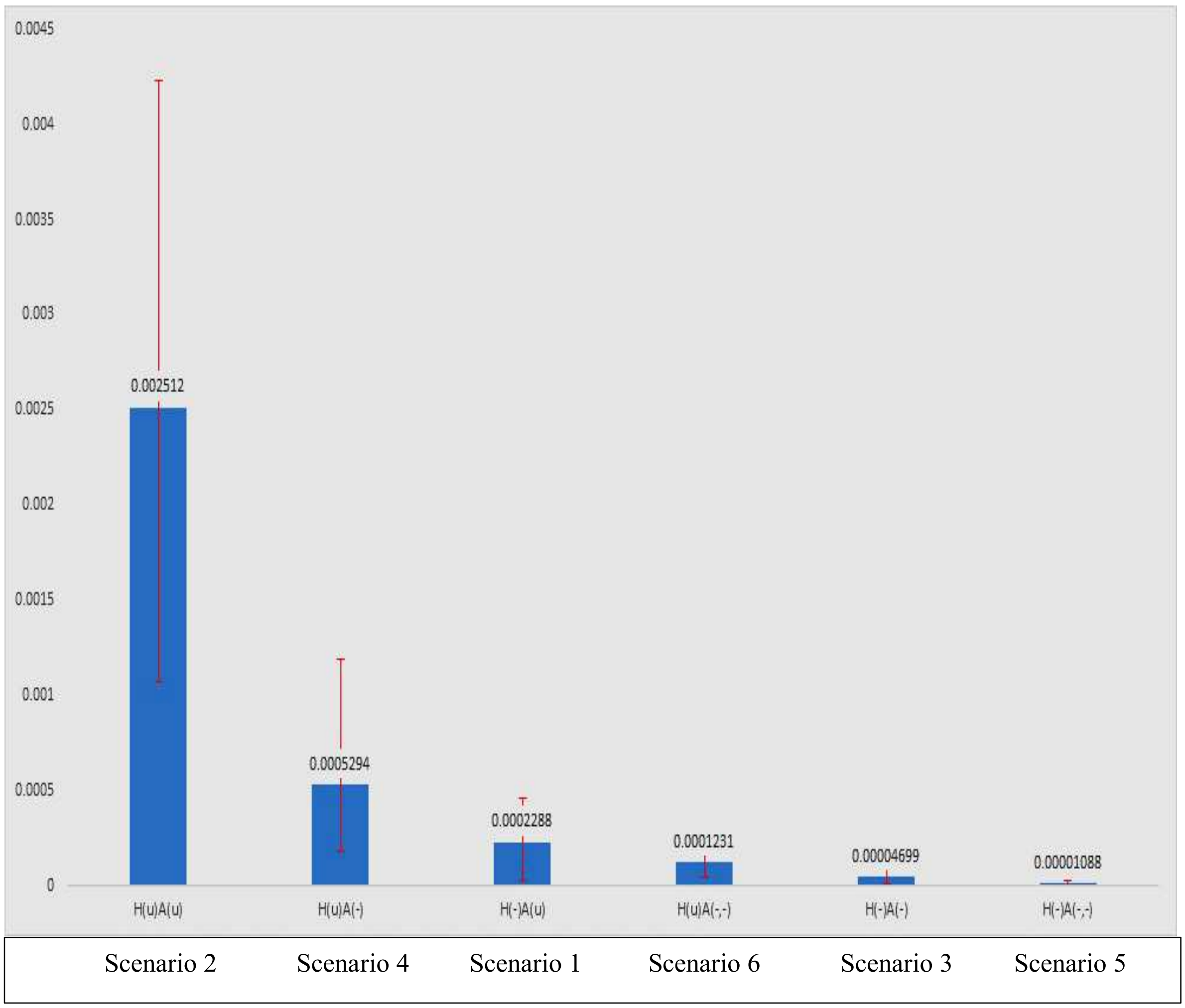

Figure 9 Probability of introducing at least one BTb infected animal into the SPS compartment based on the proposed 6 scenarios including the 5% and 95% confidence intervals

Persistence of BTb in a herd is another important factor related to CFT and CCT tuberculin testing. These imperfect diagnostic tests make diagnosis challenging and allows residual infected cattle to persist, along with the disease, in their herds (Olea Popelka, et al., 2004 and 2008; More and Good, 2015; Clegg et al., 2013). Wolfe et al., (2009) in Ireland, suggested to increase the waiting time after an outbreak, for at least six months after the herd has been cleared for trade, to decrease the probability of trading infected, yet not detected animals. Furthermore, some infected animals may not react to tuberculin injection due to immunological failures, this event is called anergy and represents a handicap on these diagnostic procedures to eliminate infected animals from a herd (Hartnack, and Torgerson, 2012). Additional strategies, such as risk-based trading, as observed in Australia (More, 2009), can be used to limit the infection risk associated with the movement of potentially infected animals.

From what was observed in the scenarios studied, the highest probability of selecting a FN animal is presented when the farmer acquires animals from a herd of an unknown BTb status and does not test the animals prior to introduce them into his herd (Scenario #2). This situation, which may seem improbable, is plausible due to the characteristics of the farms and idiosyncrasies of farmers who might prefer to buy from a friend or relative even if this transaction does not provide the safest animal health acquisition choice.

Marked reduction of the probability of the introduction of an FN animals would occur if animals were tested with CFT prior to introduction to the SPS farm herd, even without information on the health status of the seller herd. This is the situation analyzed in Scenario #4 where the herd tests negative and the probability of having a FN after CFT testing is even lower as observed on Scenario #3 results. However, if the buyer were to request a veterinary officer to apply a second test on those negative animals, the probability of having a FN animal is even lower, despite the health status of the seller’s herd, as observed in Scenarios #5 and #6.

Sound advice to the SPS farmers, would be to recommend CFT and CCT testing of all introduced animals. This would allow the SPS farmer to avoid the probability of buying FN animals from a FN herd that was tested months ago with CFT only and introducing *M. bovis* into their herds.

As part of the risk communication section, mitigation measures to reduce the risk of zoonotic transmission should be observed. Were BTb to enter a herd, the tendency for protracted subclinical infection might hinder identification to the animal on the basis of clinical signs. Thus it is important to reduce the probability of zoonotic transmission of *M. bovis* to the family and any other consumer of raw milk by pasteurizing it. Pasteurization will eliminate *M. bovis* and any other pathogen and will not interfere with milk products elaboration such as cheese or yogurt.

Conclusions:

Utilizing the 6 scenarios for small cattle farmers in Michoacan State and in particular the SPS farmers, it was possible to determine the highest risk situation for introduction of BTb into their herds and the combination of tests that would reduce the risk of introduction.

Well-designed national programs for the control and eradication of diseases such as BTb are an important tool to reduce disease prevalence in herds. The lack of perfect diagnostic tests makes these programs expensive, particularly when the prevalence is already low. The use of the CFT and CCT diagnostic tests in parallel, in addition to the regular tests recommended by the Mexican national program for the eradication of BTb, can reduce to a negligible level, the risk of introducing infected animals from untested or false negative herds into free of disease herds. Under the conditions studied here, the history of the herd of origin was of little risk for the introduction of BTb, if CFT and CCT tests were applied in parallel. Farmers should avoid introduction of untested animals into their herds, due to the probability of having false negative herds and false negative animals due to the imperfect characteristics of the diagnostic tests available.

To reduce the risk of transmitting *M. bovis* infection to the public, pasteurizing raw milk before consuming or preparing dairy products such as cheese is recommended in every herd, given the subclinical presentation of the disease, the imperfect tests and the no-zero risk of infection of the herd.

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CHAPTER 6

GENERAL DISCUSSION AND FUTURE DIRECTIONS

Summary

Global context challenges require our most intelligent and cooperative work to be tackled. Population growth, food insecurity, climate change and scarcity of resources require us to work in any possible arena to mitigate negative impact of CC, restore environmental natural cycles and ensure food production to sustain humankind. Livestock production systems need to be thoroughly analyzed and redesigned in search for a more environmental friendly livestock production model which could sustain production over generations and ensure food supply.

Agroforestry and particularly SPS, are aimed to contribute to the solution of this challenge. Farmers resilience can be improved by adopting agroforestry technologies to increasing pasture productivity, nutrient re-cycling and provide direct benefits in the form of products such as fruit, fuelwood, fodder, and timber. In addition, some agroforestry models such as SPS can offer a better diet for the animals to increase productivity of animals and lower GHG emissions, and improved microclimate to positively influence animal health and welfare. There are many aspects of SPS that need to be further clarified, particularly potential negative effects of the species that are proposed in the Tepalcatepec model, since leucaena for some, not endemic regions, could potentially be toxic to cattle.

SPS model is under ongoing research in many different tropical settings in America such as Mexico, Brazil and Costa Rica among others, all of them with encouraging results. Biomass availability component, under current research in Mexico, have provided enough information about how to manage the paddock composition to increase protein content in animal's diet. In the same way, Animal health studies under the Tepalcatepec research project and the syndromic surveillance systems developed with farmers have provided base line information on syndrome presentation and also suggested where to direct education efforts for farmers to improve their preventive practices to avoid disease. This surveillance system could be linked to a regional or national network for animal health and provide an early warning for anomalies observed. Public health concerns for zoonotic diseases, in particular Bovine tuberculosis and Brucellosis should be kept at their lowest risk to avoid infection and potential spilling of pathogens to the public. Quantitative risk analysis indicated that the least risk practices to acquire replacements from other farmers, even if the source herd is not a free of disease herd is the application in parallel of CFT and CCT tuberculin tests.

Other benefits from SPS such as GHG's emissions mitigation, increasing crop production, preventing soil erosion, conserving biodiversity and enhancing soil fertility and water quality, require further longtime research. New strategies should be explored to increase the number of farmers using SPS. A broader empirical knowledge can be obtained and we could identify future steps for research over time. Scaling up will be possible if a clear definition of the model is promoted, an ample variety of species combinations are available, and knowledge on the gaps is acquired. Although some farmers are aware that the SPS model is profitable, environmental friendly, and socially acceptable, initial investment is probably the first barrier for adoption. The amount of financial resources needed to convert traditional paddocks into SPS is not small and frequently requires the support of financial entities.

Alternatives for funding are needed. In Mexican banks, there is a preferable interest rate for agricultural related loans however, for some farmers, credits and loans are not easily accessed and for others, credits and loans are not correctly managed, and are turn into a heavy burden. Economic aspects for establishment of SPS should be thoroughly studied. The initial three years of SPS implementation have the highest amount on investment; for those years, a special attention should be put on recording the profitability of timber and/or fruit plantations contribution and financial returns, since they may be the key for farmers to cope with initial years' expenses. Research to identify alternative funding sources to help farmers cover the initial investment and first months during the time lag between the instauration of SPS and its actual use by the animals is needed, but also research for identifying and evaluating other plant species that are suitable for SPS in different tropical humid and sub humid ecosystems, species that could have a shorter time to production, are necessary.

Analyzing SPS model with a systems approach allow us to identify existing components that need to be included in future research efforts, such as economic performance, impact of tree species on profit, animal health risks for increased biodiversity and long term environmental impact. Further interdisciplinary researcher to increase knowledge of the different components of SPS and understand their interactions such as the effect of legumes ability of N_2 fixation on grass performance and overall interactions to avoid under performance is needed.

Future directions

Consumer seems to be the strongest force to drive livestock operations to a more environmental friendly operation. The reduction on animal origin food demand does not look plausible in the near future and projects to find Meat and Dairy analogs or substitutes, does not present a tangible option to reduce demand. Current livestock production models will continue to operate and increase their production while demand maintains or increases, only the consumer, by selecting meat or milk produced on an environmental friendly setting such as SPS, can drive the change on livestock production practices. In other words, public policy or farmer ethical principles have not succeeded as the case for change, but if business is the case, the change to environmental friendly practices will succeed.

In recent years many papers have been published regarding SPS however, they are focused on one or two aspects of the system. This could be a strategy to avoid putting too much information on one single paper, but also could be the result of doing research in silos, with limited coordination and interaction among researchers, which is not beneficial for the object of study. What is needed is broader team of researchers which include scientists from many disciplines to have an interdisciplinary approach to the SPS study.

The animal health subsystem should be further studied, including the possible effects of increased biodiversity that may reflect an increase in risks for bacterial and viral diseases of zoonotic potential.

Funding opportunities for research seems to be scarce, however the implications of not doing the research could decrease our ability to continue producing livestock in the tropics and further environmental deterioration will be inevitable.

Comprehensive, long term research is needed to completely support agroecological models as options to revert the negative impact traditional livestock production has on the environment. Isolated benefits per systems component are not enough for performance evaluation, overall evaluation, including measured interactions on the long term are needed.

ANNEX 1

Questionnaire applied to 115 farmers in the Tepalcatepec valley, Michoacan, Mexico.

UNIVERSIDAD AUTONOMA DE YUCATAN
UNIVERSIDAD AUTONOMA DEL ESTADO DE MEXICO
UNIVERSIDAD MICHOACANA SAN NICOLAS DE HIDALGO
FUNDACION PRODUCE MICHOACAN
FUNDACIÓN PRODUCE JALISCO

PROYECTO
"DESARROLLO DE UN MODELO DE PRODUCCION SILVOPASTORIL PARA LA GANADERIA BOVINA DEL VALLE DE TEPALCATEPEC"

Cuestionario para evaluar el sistema de producción ganadera en el Valle de Tepalcatepec

INFORMACIÓN GENERAL

Numero de cuestionario______Encuestador__________________________Fecha_________
Nombre del productor___________________________
Direccion_____________________________________Localidad________________________
Municipio______________________________________
1. Estado civil ____________Sexo _____Edad _________
2. Quien es el responsable de la unidad de producción? ______________________________
3. Tiene servicio de electricidad en la unidad? Si_________ No____________
4. Su familia tienen acceso a servicios educativos Si______ No_______
Grado máximo de escolaridad

Miembro	Numero	Edad	Total	Trabajan? Donde?
Hombre				
Mujer				
Hijos				
0-10 años				
11-18 años				
> de 18				
Abuelos				
Otros parientes				
Total				

ESTRUCTURA FAMILIAR Y NIVEL DE EDUCACIÓN

5. Cuanta gente vive en su unidad de producción? ___________
6. Cuál es la composición de su familia?

Miembro	Sin estudios	Educ. Básica	Media superior	Educ. Superior
Padre				
Madre				
Hijos				
Otros				

7. Cuál es el nivel de educación de su familia?

Sin estudios=no sabe leer y escribir., Básica=Primaria., Media-superior= secundaria, preparatoria, ó técnica., Superior: profesional o técnica.

ESTRUCTURA DE LA UNIDAD DE PRODUCCIÓN

8. ¿Cuál es el tamaño de su rancho en hectáreas? ___________

9. ¿Cuántos potreros tiene? ____________

10. ¿El tamaño de su rancho ha cambiado durante los últimos cinco años? Si No

11. ¿Si ha cambiado se ha incrementado o reducido?
Incrementado ¿por qué?____
Reducido ¿por qué?____

12. ¿Cuál es la forma de tenencia de su tierra?
P. Privada E. ejido C. comunal

13. Piensa usted comprar o vender más tierra? Si No Por que? _______________

14. ¿Qué superficie de su terreno destina a las siguientes actividades?

Superficie Labrada
Forrajes de corte______________
Praderas de pastoreo___________
Maíz________________________
Sorgo_______________________
Silvopastoril_______________________
Frutales____________________________

Superficie no labrada
Monte ________________________
Huerto ________________________
Corrales________________________
Casa ________________________
Bodega________________________
Otra________________________

ASPECTOS SOCIOECONÓMICOS Y DE ORGANIZACION DE LA PRODUCCION

15. ¿Trabaja usted de tiempo completo en la unidad de producción? Si No

No, ¿dónde más trabaja? ____

16. ¿Es la ganadería y la agricultura su principal fuente de ingreso? Si No
Si no lo es ¿cuál es entonces su principal fuente de Ingreso? ____________________

17. ¿Contrata mano de obra fija? Si No Cuántos: ________

18 ¿Contrata mano de obra eventual? Si No Cuantos: ________

19. ¿Tiene usted acceso a créditos para la producción agropecuaria? Si No

20. ¿Si tiene acceso al crédito, a cuáles? Agricultura Ganadería
Otra__________

21. ¿Pertenece usted a alguna asociación de productores? Si No

Si no, ¿por que? ____
¿A cuál? ____________________________________

22. ¿Tiene usted acceso a programas de apoyo de gobierno? Si No

¿A cuáles? ____________________________________

23 ¿Cuál de la siguiente maquinaria agrícola posee usted para la realización de su trabajo de campo?
Tractor rastra sembradora empacadora
Arado cosechadora ensiladora picadora
Otros, especifique____

24. ¿Quién se encarga del cuidado de los animales en su unidad de producción?
Hombre Esposa Hijos Peón Todos Otros____________

ASPECTOS DE PRODUCCIÓN DE CULTIVOS Y GANADO

Prácticas de manejo para cultivos

25. ¿Qué variedad o especie de forraje tiene? ___________________

26. ¿Tiene usted riego? Si ¿Qué superficie riega?____________
No

27. ¿Tipo de riego? Cintilla Gravedad (rodado) Aspersión (Cañones)

28. ¿Utiliza fertilizantes químicos?
Si ¿de Cuál? ______ Dosis _______ ¿Con qué frecuencia? __________________

No

29. ¿Aplica usted estiércol como fertilizante?

Si ☐ No ☐

30. ¿Aplica usted herbicidas e insecticidas a sus cultivos?
Si ☐ ¿Con que frecuencia?__________________

No ☐

31. ¿Realiza quemas de potreros?
Si: _______ ¿Con que frecuencia? ____________ No: _______

32. ¿Conserva forraje para la época de secas? Ensilaje Henificado

33. ¿Realiza rotación de potreros? Si No

34.- Los potreros están cercados con:
Cerco eléctrico: _________ Cerco Vivo _______ Postes madera: _________

ASPECTOS DE PRODUCCION DE GANADO

35. ¿Cuántos cabezas de ganado tiene? ____________________________

36. ¿De qué raza son?
Cebú Hosltein Cebú x Holstein

Suizo ☐ Suizo x Cebú ☐ Otra________________

37. ¿Cuál es la orientación productiva (finalidad zootécnica)?
Carne ☐ Leche ☐ Doble propósito

38. ¿Cuál es la estructura de su hato?

Tipo	**Numero**
Vacas	
Becerros	
Terneras de reposición	
Novillos p/engorda	
Toros	
Total	

ASPECTOS REPRODUCTIVOS Y PRODUCTIVOS

39. ¿Cuál es la forma de cubrición de sus animales?
Monta natural ☐ inseminación artificial ☐

40. ¿Cuál es el Intervalo entre partos? _______________

41. Número de servicios por gestación _____________

42. ¿Cuál es la producción promedio de leche/día? ______________________

43. ¿Normalmente cuántos meses ordeña a sus vacas? ___________________________

44. ¿Cómo ordeña a sus animales?
Manual ☐ mecánico ☐

45. ¿Cuántas veces ordeña al día?
1vez ☐ 2 veces ☐

46. Si ordeña una solo vez, ¿por que? No es rentable ☐ Para dejar leche ☐ al becerro

47. ¿Se apoya del becerro para ordeñar?
Si ☐ no ☐

48. ¿Aplica oxitocina? Si _____Cuánto
No_____

48a. ¿Lava la ubre para el ordeño? Si ☐ No ☐

48b. ¿Utiliza papel o paño para secarla? _____________________

48c. ¿Cómo maneja a las vacas con mastitis? ________________________________
____

48d. ¿Qué porcentaje de sus vacas presenta mastitis al año? ________________________

48e. ¿Cuánta leche deja a sus becerros?
¼ $^{2}/_{4}$ ¿Residual?

48f. ¿Cómo maneja el descalostrado? ____

ALIMENTACIÓN Y MANEJO

49. ¿De qué alimentos dispone usted en su explotación para alimentar a su ganado?

Alimento	**Propio**	**adquirido**
zacate		
maíz / sorgo en grano		
silo		
melaza		
rastrojo		
gallinaza		
salvado		
Alimento		
Cascara de cítricos		
¿Monte o vegetación natural?		
otros		

50.- ¿Suplementa con concentrado a sus animales?
Número de veces al día________________

51. ¿Cuántos kg/animal? _____________

52. ¿Cuál es el precio por kg de alimento concentrado? ___________

53. Procedencia del concentrado _________________

54.- ¿Con que frecuencia suplementa? Todo el año Seca Lluvia ☐

55.- ¿Podría indicar a qué tipo de animales suplementa?, (marcar lo que corresponda)

	Secas	lluvias
Vacas lactando		
vacas secas		
terneras de reposición		
novillos de engorda		
becerros lactando		

56.- ¿Pastorea a sus animales? Si ☐ No ☐

57. ¿Cuántas horas/día? ____________________

58. ¿Durante todo el año? ___________ ¿Qué época del año? _____________

59.- ¿Proporciona suplemento mineral a sus animales? Si ☐ No

MANEJO SANITARIO

60. ¿Se han realizado pruebas contra tuberculosis y brucelosis? __________
Cuándo fue la última vez____________________

61. ¿Cuenta con hato libre? Desde cuándo _______________.

¿No? __________. ¿Por qué? ______________.

62.-Si vacuna a sus animales ¿contra qué y con qué frecuencia?
Enfermedad ________________ Frecuencia ________________________
________________ ________________________
________________ ________________________
________________ ________________________

63.- ¿Desparasita a sus animales? ☐ Si ☐ No

64. ¿Qué productos utiliza para desparasitar? _____________

65. Frecuencia: 1 vez al año ☐ 2 veces ☐ más de 3

66. ¿Registra o apunta las enfermedades de los animales? Si ________ No________

67. ¿Ayuda a la vaca durante el parto? Si ________ No________

68. ¿Realiza desinfección de ombligo de un becerro? Sí ________ No________ ¿con que?

69. ¿Se asegura que el becerro tome calostro? Sí _____ No________ ¿Cuánto? _________

70. Han presentado sus becerros:

Onfalitis_______ Neumonía________ Diarrea_______ Otros_______

71. ¿Qué porcentaje de sus becerros se enferma? _________
¿Con qué los cura? ______________________________

72. ¿Han presentado sus animales en crecimiento?:

Neumonía__________ Cojeras________ Lesiones en piel__________

73. ¿Qué porcentaje de sus animales en crecimiento se enferma? ______
¿Con que los cura? ___________________________

74. ¿Han presentado sus vacas?:

Abortos______ Distocias______ Metritis-Piómetra ________ Vaca caída_______

Mastitis clínica y subclínica_______ Cojera________ Lesiones en piel_______

Retención de las membranas fetales_________

75. ¿Qué porcentaje de sus vacas se enferma? __________
¿Con qué las cura? _____________________________

76. ¿Cada cuando se infestan de garrapatas, moscas, tábanos, sus animales?
¿Con que las trata? _____________________ Frecuencia ____________

<u>ASPECTOS DE COMERCIALIZACION Y DE COMPRA Y VENTA DE INSUMOS</u>

77.-De la leche que producen al día sus animales
¿Cuánta de esta vende? ___________ y ¿cuánta es para autoconsumo? ______________

78.- ¿A quién vende la leche?
Botero ☐ directamente ☐ otro_____________________________

79.- ¿En cuánto se la pagan? ($/lt)
Botero__________ Directamente_______________ Otro____________________

80.- ¿Procesa su producción de leche a otros productos y en cuáles? Si ☐ No ☐
Queso ☐ Crema ☐ Yogurt ☐ Otro____________

81.- ¿Si lo procesa, cual es el precio de venta de estos?
Queso__________ Yogurt __________
Crema__________ Otro____________

82. ¿Qué tipo de queso elabora? ______ ¿Venta directa al consumidor? ________
¿Intermediario? ______

83.- ¿Piensa usted que la comercialización de sus productos es un problema en el área?
Si ☐ No ☐

84.-Si piensa que sí, como cree que ésto se pueda solucionar?_________________________
____

85. ¿Destino de la leche? Venta______ Procesamiento_______ O las dos_______

86. Precio de venta de leche (litro) _____________ Precio de venta del queso (kg) ___________

87. ¿Aplica sellador después de la ordeña?_________

88. Se realizan pruebas para determinación de mastitis
Si______ ¿Cuáles? _______ Frecuencia_______
No ___
89. ¿Vende los destetes? Si____ No____ o los engorda____________________

90. Precio de venta de los becerros

91. ¿La venta de becerros es local? Si____ No____ ¿A dónde?________________