Briefing paper 17/2

Measuring sustainability on cattle ranches

Silvopastoral systems

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Content

Summary

Traditional livestock production systems in Latin America - based on grass monoculture - tend to deplete natural resources in a process of continuous degradation. This process is currently exacerbated by the pressure of a globally increasing demand for food and hence it is imperative to identify livestock production alternatives which consider sustainability in the long term.

Silvopastoral systems (SPS) are agroforestry arrangements that allow the intensification of cattle production based on natural processes. Combining livestock production with rotational grazing using different pastures, forages, fodder shrubs and timber trees as parts of the same system, they are recognized as an integrated approach to sustainable land use. Through the adoption of SPS, this "natural alliance" makes all components mutually beneficial, achieving increases in productivity and profitability, and at the same time, improving the efficiency of natural resource use.

The *agri benchmark* Network, CIPAV, FEDEGAN, World Animal Protection and Good food Futures Ltd have joined efforts in a study to evaluate different aspects of sustainability at farm level through the implementation of SPS that includes different cattle ranching production systems. Six case studies were conducted using standard methodologies in order to allow for comparison between baseline scenarios and SPS. Results clearly confirm that by implementing SPS, improvements on animal productivity, natural resource use efficiency, profitability, animal welfare and CO2 emissions can be obtained.

Due to the multivariate nature of livestock production systems, assessing and monitoring sustainability is a complex issue. This study intends to propose an integrated analysis for assessing sustainable livestock options at farm level.

1 Introduction

Taking into account the current trend in food production and consumption, it is evident that we are facing an unprecedented challenge in terms of livestock sustainability. Urbanization, economy and population growth will generate a high demand for food during coming decades with a considerable impact on natural resources. Therefore, it is important to identify livestock production options that at the same time improve efficiency and help reducing negative effects on the environment, and fulfill the demand of good quality food that are economically efficient and respect the environment.

Silvopastoral systems have demonstrated the potential to increase cattle productivity while making an efficient use of natural resources. By growing grasses, shrubs and trees in the same area, a three-dimensional feed source is created, providing more forage with better quality. Soil quality can be improved by additional plant matter and higher root density as well as by the production of more biodegradable material, which increases water and carbon retention in the soil. These benefits can be reflected in a better cattle performance in terms of animal production and consequently in better returns.

This study aims to analyze the implementation process of silvopastoral systems at farm level, assessing their impact on productivity, economy, environment and animal welfare. In order to obtain significant results, six farms in different regions of Colombia and with different baseline situation were analyzed.

The document defines the main features of silvopastoral systems, including a brief description of research findings, describes the standard methodology applied for the assessment and presents the results comparing the situations before the introduction of SPS *also called the baseline,* and the situation once the SPS were in operation.

The assessment was conducted as a partnership project. Participants were the Colombian Cattle Ranching Association (FEDEGAN), the Centre for Research on Sustainable Agricultural Production Systems (CIPAV), the global assessment network *agri benchmark* of the Thünen Institute of Farm Economics, World Animal Protection and Good Food Futures Ltd.

As a team, each institution has contributed with resources and knowledge in its area of expertise. CIPAV has proven experience in the implementation and analysis of silvopastoral systems, forage production, environmental impacts and their interaction with animal production; FEDEGAN contributed with the expertise on production systems economics at regional and national level; World Animal Protection and Good Food Futures Ltd provided technical tools and criteria for evaluating animal welfare through quantitative parameters, and *agri benchmark* provided models and methodologies for implementing an integrated assessment, as well as its long experience in comparative analysis.

Special thanks to the farmers who have enabled this substantial progress in the search for sustainable livestock options.

2 Silvopastoral systems (revision)

Silvopastoral systems (SPS) are agroforestry arrangements that intentionally combine fodder plants, such as grasses and leguminous herbs, with shrubs and trees for animal nutrition and complementary uses (Murgueitio et al., 2011). They allow the intensification of cattle production based on natural processes and are recognized as an integrated approach to sustainable land use (Nair et al., 2009).

The main benefits of SPS compared to treeless pastures are: 1) improvement of soil properties due to greater uptake and cycling of nutrients, enhanced availability of nutrients from leaf-litter and enhanced resilience of the soil to degradation, nutrient loss, and climate change (Nair et al. 2007, Vallejo et al. 2010, Cubillos et al. 2016), 2) Improved production of higher quality forages 3) Increased efficiency of cattle production per ha (up to 4-fold) with improved animal welfare (Thornton and Herrero 2010, Broom et al. 2013), 4) higher storage of carbon in both aboveground and belowground compartments of the system and improved habitat for biodiversity (Nair et al. 2010, Sáenz et al. 2007, Montoya-Molina et al. 2016).

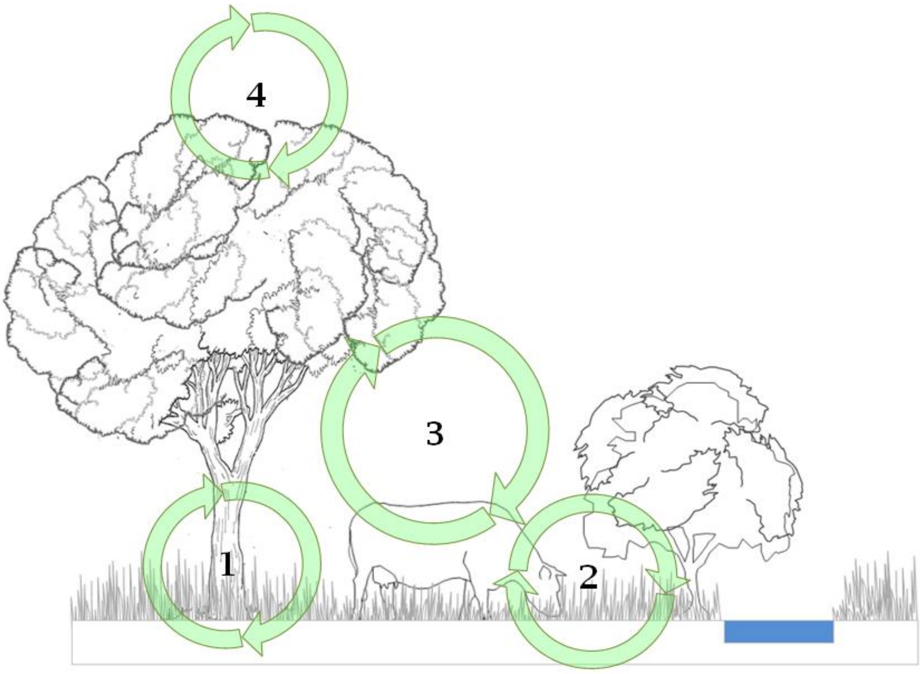

Figure 1 - Interactions in SPS. Source: Prepared by the authors

2.1 Types of Silvopastoral Systems

There are several options of SPS according to the different arrangements of the natural elements (grass, shrubs and trees), as well as specific cropping management options. They can be grouped into the following types: a) live fences, b) dispersed trees, c) pastures under forest plantations, d) protein banks, e) intensive silvopastoral systems.

Live fences consist of on-line plantings of trees and/or shrubs in order to fence off crops, pastures or boundaries between properties. Such fences do not only contribute to the existing vegetation and wild animal conservation; they offer wood, firewood, fruit and livestock fodder, too.

Dispersed trees is a type of silvopastoral system that has only few trees (individual or grouped) not exceeding 10 percent to 15 percent of the total area, with the benefits of providing timber, shade and fodder. Due to the consumption of leaves and fruits produced by the trees, there is also an improvement in livestock feeding.

Pastures under forest plantations involve the planting of pastures under forest. Livestock production provides additional incomes in addition to the forestry activity, generated before the harvest of the trees. Furthermore, costs for weed control and pasture management are reduced.

Protein banks are fodder banks where trees, shrubs and pasture legumes with high protein-containing leaf biomass are combined. Trees are planted as close as 1 m x 1 m and cut regularly to induce maximum herbage production.

Intensive silvopastoral systems are a type of SPS that combines high-density cultivation of fodder shrubs (4.000 to 40.000 plants per ha) with improved tropical grasses and trees species or palms at densities of 100–600 trees per ha. These systems involve rotational grazing with occupation periods of 12 to 24 hours and 40 to 50 days of resting periods, including ad libitum provision of water in each paddock (Calle et al., 2012).

3 Research findings

Studies have evaluated silvopastoral systems compared with traditional systems, analyzing aspects such as biomass production, nutrients and chemical composition of pastures, milk/meat production, carbon sequestrations, and economic performance.

CIPAV[2] and UN[3] report that while average forage production in Colombia makes up 7 tons DM per ha and year in traditional systems with degraded pastures, silvopastoral systems (*without the use of chemical fertilizers*) reach a production of 19.26 tons DM per ha and year, which is close to the results achieved with good management practices and an annual fertilization of 200 kg N per ha and year (Cajas et al., 2011).

It was found that the protein content of SPS-grasses was higher than the average content of tropical grasses (Table 1), which may be due to N-fixation of leucaena (Muñoz et al., 2009). Also, the meat production in Silvopastoral Systems was 7.9 to 10.7 times higher than in traditional systems.

During the FAO electronic conference '*Agroforestry for animal production in Latin America*', CIPAV has reported a total of dry matter yields of 39.3 tons per ha and year (estrella + leucaena + algarrobo) and 38.9 tons per ha and year (estrella + algarrobo), but only a yield of 23.2 tons per ha and year of monoculture grasses. This higher biomass production of silvopastoral systems is attributed to a better use of vertical space, both aerial and underground, which implies a higher uptake of nutrients and energy (Benavides, 1983).

E. Murgueitio Restrepo ('*Silvopastoral Systems in the Tropics of America*') also reports both higher quantity and quality of forage biomass in intensive silvopastoral systems, compared to monocultures of grass fertilized with nitrogen.

Table 1 – Supply and quality of forage biomass of an intensive silvopastoral system compared to monoculture of grass fertilized with nitrogen.

Variable	**Monoculture** Pasto Estrella +184 Kg. N_2 Ha^{-1} $year^{-1}$	**SSP *Leucanea*** 10.000 Ha-1 + pasto estrella 0Kg. N_2	**Variation**
Biomass (Tons DM. Ha^{-1} $year^{-1}$)	23.2	29.5	+27.15 %
Protein (Tons DM. Ha^{-1} $year^{-1}$)	2.5	4.1	+64.0 %
Metabolizable Energy (Mcal Ha^{-1} $year^{-1}$)	56,876	70,222	+23.46 %
Calcium (Kg Ha^{-1} $year^{-1}$)	83.2	142.32	+71.05 %
Phosphorus (Kg Ha^{-1} $year^{-1}$)	74.0	88.81	+20.01 %

Source: Adapted from Molina y Uribe 2002.

The fixation of nitrogen and the transformation of solar energy into vegetal biomass resulted in higher meat/milk production per hectare. Further, it increased the numbers and the variety of native bird species and reduced water consumption for irrigation. Silvopastoral systems in the southwest of Colombia have five times as many bird species as pasture monocultures in the same region. Ant richness was 62 percent higher in intensive silvopastoral

[2] Fundación Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria
[3] Universidad Nacional de Colombia – Sede Medellín

systems (Rivera et al., 2014), and dung beetle abundance and diversity were more than two times higher in relation to pasture monocultures (Giraldo et al., 2010).

In summary, silvopastoral systems have significant benefits compared with traditional systems. Nevertheless, disadvantages exist. The following overview is by Braun A., Van Dijk S. and Grulke M. *'Upscaling silvopastoral systems in South America', October 2016*.

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- Improvement of quantity and quality of food for livestock, with additional forage produced by shrubs,
- Roots of trees and shrubs avoid soil erosion,
- Trees offer shade for livestock, improving the habitat and avoiding heat stress,
- Trees have high CO_2 storage capacity,
- Roots improve the infiltration of water into the soil,
- Higher nitrogen fixation increases the amount of biomass,
- Chemical and physical soil improvement through the integration of organic matter into the soil,
- Increase of meat/milk production per hectare,
- Increase of biodiversity,
- Higher diversify of farm production, increasing family incomes.

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- Higher initial investments,
- Increased complexity when compared to monocultures,
- Competition between trees and grass,
- Cattle might cause damage to trees,
- Complexity and unfamiliarity are a disadvantage for traditional producers.

Source: Adapted from Toruño I, Mena M, Guharay F.

4 Measuring sustainability on silvopastoral systems

According to the World Council for Economic Development, sustainable development is one that "meets the needs of the present without compromising the ability of future generations to achieve theirs." Therefore, for an activity to be sustainable it must incorporate aspects such as economic efficiency (innovation, prosperity and productivity), social equity (poverty-reduction, community, health and welfare, human rights) and environmental responsibility (climate change, use of soil, biodiversity).

The multivariate nature of sustainability causes difficulties in monitoring and evaluation; current challenges involve not only measuring the different components of sustainability, but also deepening interactions and interdependencies, as well as the trade-offs of pursuing one component at the expense of another.

SPS involve a high interaction between different components of nature (see figure 1) which should be reflected in selected models and chosen variables. In this context, this study intends to evaluate the impact of SPS on the economic and productive performance, taking into account other aspects of sustainability such as CO_2 emissions and animal welfare.

4.1 Methodological approach

For evaluating the impact of SPS, we selected six farms representing different regions and different production systems in Colombia.

For each farm, two scenarios were defined: conventional grazing (before the adoption of SPS) and the SPS scenarios.

Historical data from farm records was used to define the baseline scenario. For modeling the adoption of SPS, farm records as well as applied research findings were used. Additionally, a panel formed by local and regional experts from different disciplines (advisors, farmers and researchers) contributed to the analysis and discussion.

In order to obtain meaningful results, we decided to collect data from SPS-farms for a period of ten years. This data was crosschecked with national research institutions and an external quality protocol was applied. Preliminary results were validated by advisors, researchers and farmers. Additionally, a crosschecking with regional and national studies was implemented.

To isolate the effects of the SPS from those due to economic fluctuations, prices of inputs and products (milk price, beef price, weaners' price) were kept constant during the period of analysis.

A set of variables was selected to assess different areas of sustainability, and modeled during the ten-year period. Table 2 shows key variables selected for each field of sustainability.

For modeling the scenarios, *agri benchmark* models and comparative methodologies were used (see details below).

Table 2 – Key variables considered for each field of sustainability.

<table>
<tr><th>Area</th><th colspan="2">Variable / Criteria</th><th>Unit of measurement</th></tr>
<tr><td rowspan="2">Productivity</td><td colspan="2">Forage production</td><td>Tons Dry Matter per ha</td></tr>
<tr><td colspan="2">Land productivity</td><td>Kg meat or milk per ha</td></tr>
<tr><td rowspan="2">Economy</td><td colspan="2">Whole farm costs</td><td>‘000 USD</td></tr>
<tr><td colspan="2">Whole farm returns</td><td>‘000 USD</td></tr>
<tr><td rowspan="2">Environment</td><td colspan="2">CO_2 emissions</td><td>Kg CO_2/ 100 Kg LW* ECM**</td></tr>
<tr><td colspan="2">Methane, Nitrous oxide</td><td>Kg / 100 Kg LW added (or ECM)</td></tr>
<tr><td rowspan="5">Animal Welfare</td><td></td><td>Category</td><td>Assessment measure</td></tr>
<tr><td>Good Feeding</td><td>Water availability
Sufficient quantity & quality of food
Body condition score</td><td>Water present? Yes/no and distance (m)
Forage provision
Recognized body condition scoring methodology</td></tr>
<tr><td>Good Health</td><td>Absence of injuries, disease, symptoms of pain, signs of lameness or ticks and flies</td><td>Visual assessment of clinical signs, walking ability and presence of ticks and flies</td></tr>
<tr><td>Good Housing</td><td>Thermal comfort / heat stress
Access to pasture
Comfort around resting</td><td>Presence of shade and behavioral signs of heat stress (panting etc.)
Presence of pasture
Presence of adequate space for comfortable resting</td></tr>
<tr><td>Appropriate Behavior</td><td>Absence of fear (flight distance)
Absence of aggressive behavior
Expression of important positive behaviors</td><td>Approach assessment of flight distance
Visual behavior assessment for priority positive and negative behaviors
Behavioral choice? Yes/no</td></tr>
</table>

Source: Prepared by the authors; * LW = Live Weight, ** ECM = Energy Corrected Milk

4.2 Methodological challenges

When modeling SPS adoption, we faced several methodological challenges. E.g. a gradual adoption of SPS implies that the share of SPS-areas gets bigger from year to year while areas cultivated conventionally decrease.

This causes an overlap in transition, with changing proportions of both systems, which causes some difficulties to assess forage and animal production. Additionally, a balance between forage and grass production, feeding requirements, rations and the number of animals must be reached, which is not easy, considering that values vary from year to year.

With the aim of producing an accurate analysis of these production aspects, detailed annual changes in forage production, stocking rates and animal production have been carefully taken into account.

For the animal welfare comparison, we were not able to perform 'before-after' comparisons of the farms that introduced SPS – simply because the animals were not present under baseline conditions on these particular farms anymore. Instead, where possible, we did a 'with-without' comparison using a neighboring farm (an extensive system under conventional grazing) as the baseline scenario.

Not all the farms had the same baseline situation in terms of forage and animal production. Some farms had a starting point with high productivity mainly due to intensive use of chemical fertilizers while others farms had a very low production due to an extensive use of grasslands.

The farms were at different stages of the SPS adoption this means that when the study was done some farms were already stablished while others were still developing.

4.3 Data, tools and case studies selected

4.3.1 Data sources and tools

As was mentioned previously, six farms were selected for the study. These farms shared basic characteristics; they were representative productive systems for SPS adoption valuation and for the prevailing systems of milk and beef production in each of the regions. For analyzing and modelling the data, *agri benchmark* methods and tools were made available (see Deblitz, 2015).

Data collection

The main source of data was farm level information. The information was gathered through field visits to each of the farms. In all the cases a group of expert technicians and advisers gathered to discuss and complement the data supplied by the producers. Additionally, all the **productivity** and **economic** information was validated with the national averages for its corresponding region with the data base from the Colombian Cattle Ranching Association, FEDEGAN.

Data processing and analysis

The TIPI-CAL model from the *agri benchmark* Network was used for the simulation of the 10 years periods of SPS introduction. TIPI-CAL is a production and accounting model and assessment tool. It has a 10 years dynamic-recursive structure and produces a profit and loss account, a balance sheet, a cash flow for the whole farm and all enterprises considered for each of the 10 years of simulation. It further provides very detailed information on activity levels, performance and productivity of the enterprises such as herd size, lactation yield, weight of animals, feed rations, mortality, weight gains etc.. For this project and in contrast with the standard operating procedure (Deblitz and Zimmer, 2005), real farms instead of typical farms were modeled to ensure accurate and consistent information as well as securing the link to the environmental and animal welfare related data. In some of the cases due to the requirements of the project the analysis periods were modified from 10 to 20 years.

Environmental data for each of the farms analyzed was provided by CIPAV. This institution has been studying and researching sustainable agricultural production systems for the tropical region. They have been able to gather historical information and measure the effects of SPS adoption over different components including the environment. The information from CIPAV was amended and confirmed by producing calculations on greenhouse gas emissions using the add-in of the TIPI-CAL model.

Animal welfare assessments were initially developed by animal welfare scientists at World Animal Protection in collaboration with independent external expert Prof. Donald Broom (World Animal Protection, 2014). Independent sustainability consultant Good Food Futures Ltd completed further welfare assessments using these protocols. The method used in the field gave a concise but comprehensive overview of welfare. Objective measures of welfare, both outcomes-based measures such as body condition, and environmental measures such as water provision and shade, were used. Behavioural measures were adapted and simplified from globally recognised methods developed by Welfare Quality (Botreau et al., 2009) and Assurewel (Assurewel Project, 2017), reflecting good feeding, good housing, good health and good behaviour.

4.3.2 Case studies selected

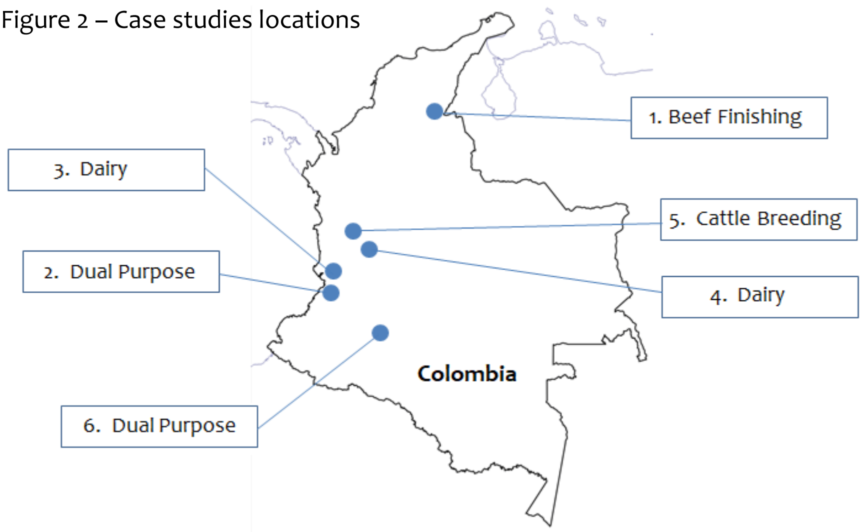
Six farms were selected as case studies to apply described methodology, representing four different regions in Colombia and four different production systems (Table 3). These farms are demonstrative experiences for each of the regions and work as practical models for the producers interested on stablishing SPS.

The geographical location of farms selected for this study can be seen in figure 2.

Table 3 – Farms selected location and area.

Case #	1	2	3	4	5	6
Colombia (Region)	Cesar	Valle del Cauca	Valle del Cauca	Quindío	Valle del Cauca	Caquetá
Production System	Beef Finishing	Dual Purpose	Dairy	Dairy	Cattle Breeding	Dual Purpose
Area (Has.)	200	30	135	74	42	100

Figure 2 – Case studies locations



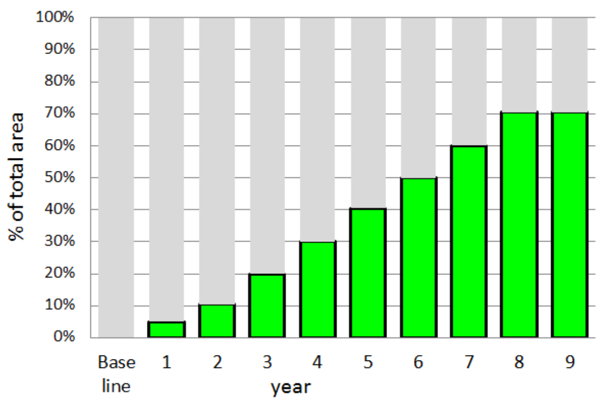
5 Colombian case studies

5.1 Case #1 - Beef Finishing / Cesar

Case Study Background

Located in Codazzi, this farm has a production system oriented to beef finishing (fattening) of Zebu animals crosses in a total area of 200 hectares with a 70 percent of the area used for the productive system. During the period described, an intensive SPS was adopted, consisting of an agroforestry system for animal production that combines fodder shrubs leucaena (Leucaena leucocephala) at high densities, interspersed with high productivity improved pastures Tanzania (Megathyrsus maximus) and timber trees (Eucalyptus tereticornis) .

Figure 3 – Percentage of area under SPS



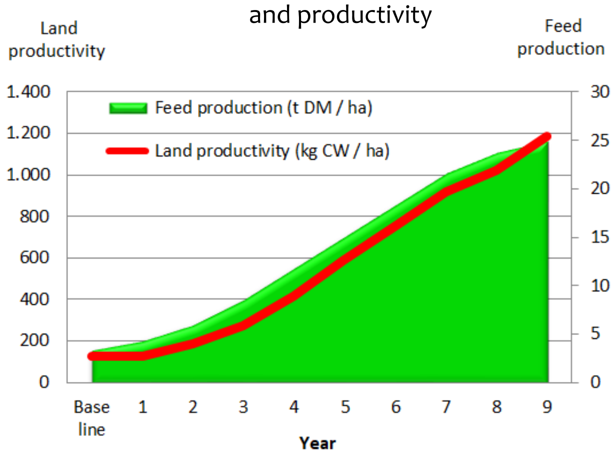
These elements are organized in a spatial arrangement that can be grazed in short periods of occupation and long periods of rest, combined with a sustainable water management.

Figure 3 shows how intensive SPS were adopted, involving 140 hectares at the end of the process.

Results

- Forage Production and Productivity

Figure 4– Forage production and productivity



One of the first visible results at SPS implementation has been on forage production (quantity and quality). Measured in tons of dry matter per hectare, forage production has increased by an average of 700 percent (7 times) over the initial situation, and by the third year it had doubled from 3 to 6 Tons.DM/ha.

The improved quality of forage is verified in higher digestibility and more energy, protein and other nutrients available. This allowed to increase fivefold the number of animals, resulting in a higher and more efficient production of meat per ha.

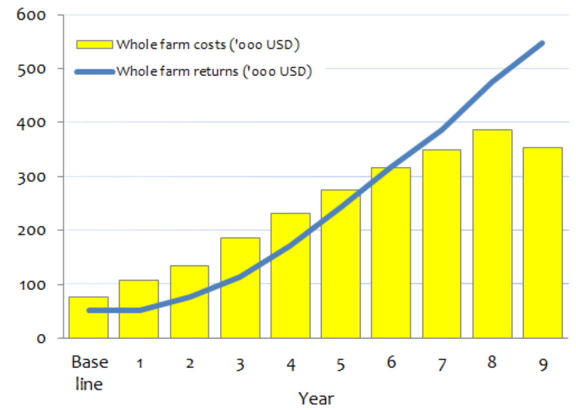
Land productivity - measured in kg of meat per hectare - shows an average increase of 450 percent (4.5 times) after stabilizing the adoption of SPS.

Economic Results

After the initial investment and a stabilization period of 5-6 years, the increase in forage production and higher productivity generate returns that ensure the economic viability of SPS.

SPS adoption implies an increment of costs, but there is an increase of incomes too. The years on negative cash flow (1-5 - figure 5) is also due to the fact that each year, the farm has to buy more animals due to the increment of forage offer and therefore, cash flow requirements increase significantly during those years.

Figure 5 – Economic results



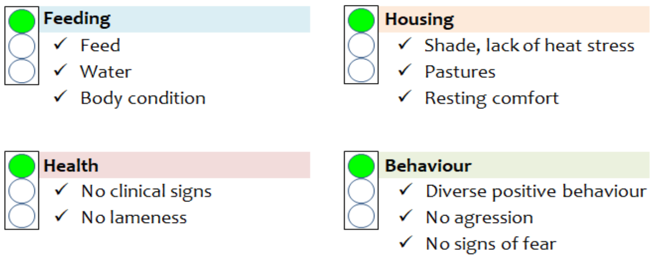
Animal Welfare

After SPS were adopted, the average body condition was 3.5 with all animals appearing healthy, alert and with normal behaviour and no aggression. Access to green fodder of high quality, fresh clean water within 250m and shade provide an ideal habitat, with no signs of heat stress. Flight distance (a measure of fearfulness of people) was reduced in the silvopastoral system, standing at an average of 2 (two) meters, possibly because of calm regular handling.

On the neighboring farm, animals were bright and alert and showed no clinical signs of disease or lameness. Cattle had access to forage but it was of poor quality and animals had a lower body condition (average 2.5). Water was freely available but not fresh. Animals could perform diverse behaviors and no aggression was seen. Some cattle showed signs of heat stress due to absence of shade.

Animals were slightly more fearful of humans, with a flight distance of 8m.

Figure 6 – Animal welfare



Environmental Impact

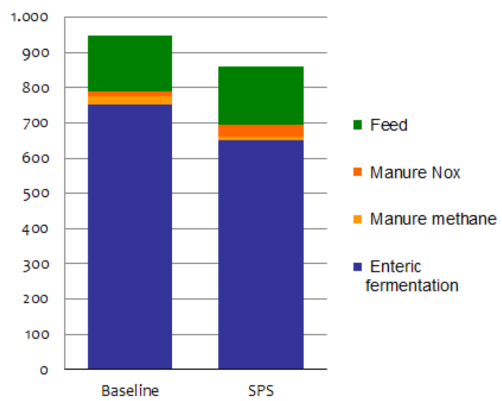
This increase in biodiversity plays an important role in the biological control of pests.

Increased biomass and vegetation cover reduce the effects of soil erosion, while changes in the water cycle - with highest retention and groundwater's use - decrease the risks of drought.

The cultivation of forage shrubs and their coexistence with pastures increased the amount of organic matter and nutrients in the soil. At the same time, the presence of nitrogen fixation legumes and the constant rotation of cattle eliminate the need for nitrogen fertilizers.

Comparing baseline measurements with SPS already implanted, CO2 emissions were reduced by 9.3 percent.

Figure 7 – Kg CO_2 / 100 kg LW added



5.2 Case #2 - Dual Purpose / Valle del Cauca

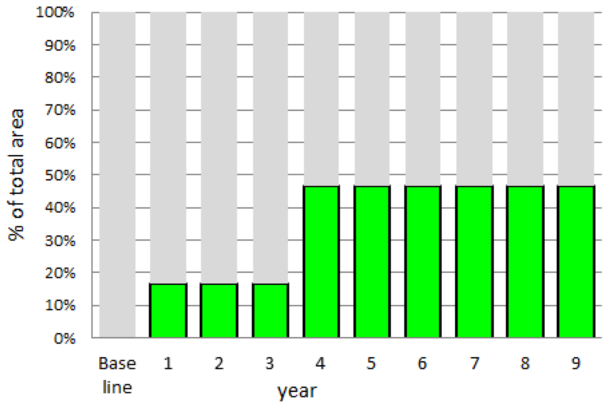
Case Study Background

Located in Jamundí, Valle del Cauca, the farm has a dual purpose productive system (weaning calves and dairy) using crossbreeds in a total area of 39 hectares from which 30 hectares are used for production.

During the period of analysis, an intensive SPS was adopted, consisting of an agroforestry system for animal production that combines fodder shrubs leucaena (L. leucocephala) in high density, interspersed with improved high productivity pastures Tanzania (Megathyrsus maximus) and star grass (Cynodon plectostachyus).

Figure 8 shows the development of the implementation of intensive silvopastoral area year by year, reaching 47 percent of the total productive area in year 9 of implementation.

Figure 8 – Percentage of area under SPS



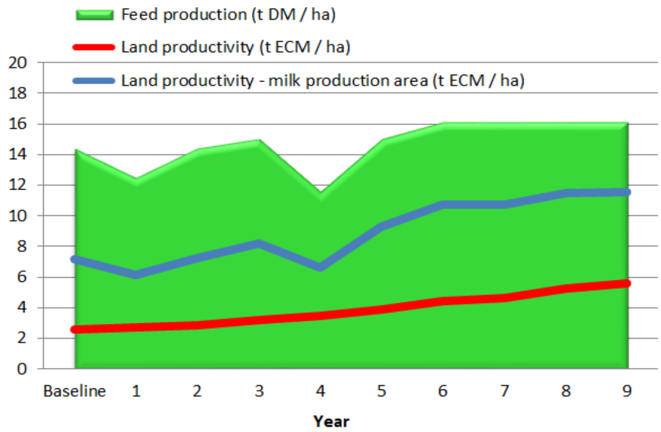
Results

Forage Production and Productivity

Due to an improved forage production, the stocking rate per Hectare has increased by 65 percent, showing the effects of a higher and more efficient production of meat and milk per ha.

As can be seen in figure 9, the land productivity, measured in kg ECM (Energy Corrected Milk) per hectare, improved considerably after stabilizing SPS, increasing from 2560 to 5576 kg/ha.

Figure 9 – Forage production



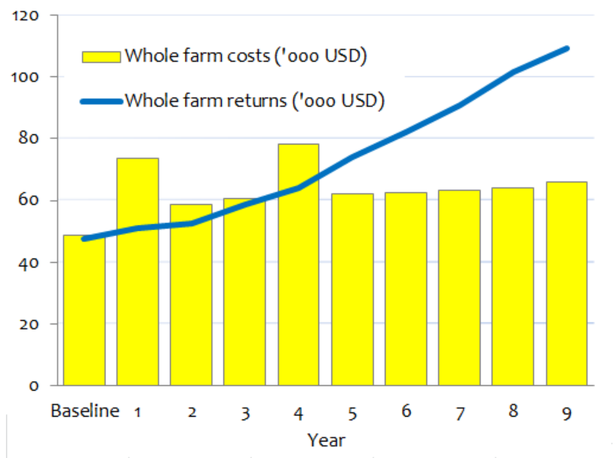
Economic Results

There was a 35 percent increase in costs during the period under review (implementation and maintenance of plant species, fences, technical advice, etc.), but at the same time, returns increased by 129 percent (see figure 10).

After the initial investments and a stabilization period of 4-5 years, the increase in forage production and the higher productivity per hectare generated returns that ensure the economic viability of SPS.

After the 5th year of implementation, revenues covered the costs and left a positive balance in the cash flow, later even achieving a considerable economic surplus.

Figure 10 – Economic results



Animal Welfare

After adopting SPS, assessments the average body condition was 3.3, showing healthy, alert animals with normal behaviors. Access to green fodder of quality throughout the day and the availability of fresh and clean water within 150m provide an ideal habitat. The flight distance was low, with an average of 2.5 meters.

Figure 11 – Animal welfare

Feeding
- ✓ Feed
- ✓ Water
- ✓ Body condition

Housing
- ✓ Shade, lack of heat stress
- ✓ Pastures
- ✓ Resting comfort

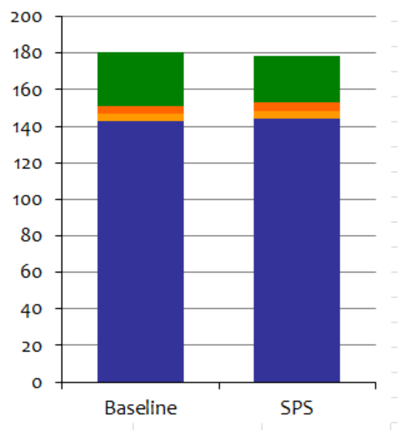
Health
- ✓ No clinical signs
- ✓ No lameness

Behaviour
- ✓ Diverse positive behaviour
- ✓ No agression
- ✓ No signs of fear

Environmental Impact

Comparing baseline measurements with SPS already implanted, CO_2 emissions remained basically on the same level.

Figure 12 – Kg CO_2 / 100 kg ECM



5.3 Case #3 - Dairy / Valle del Cauca

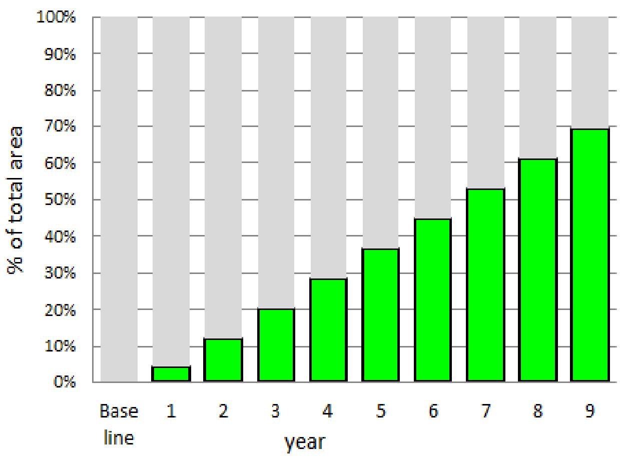
Case Study Background

Located in Cerrito, the farm has a dairy production system with animals of Lucerna breed, with a productive area of 135 hectares.

During the project, an intensive SPS was adopted- It combined fodder shrubs (L. leucocephala) interspersed with high productivity improved pastures Tanzania (Megathyrsus maximus) and Star grass (Cynodon plectostachyus) and native timber trees.

Figure 13 shows the development of the implementation of silvopastoral area, reaching around 69 percent of the premises at the end of the period, which means 94 hectares of SPS were stablished.

Figure 13 – Percentage of area under SPS



Results

Forage Production and Productivity

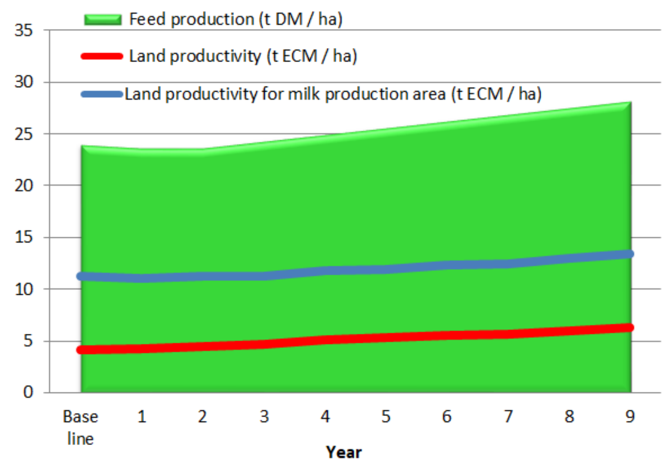
When the silvopastoral system was implemented, there was an increase in quantity and quality of the forage. Measured in tons of dry matter per hectare, forage production increased by an average of 17 percent compared to the initial situation (see figure 14).

The increase in the quality of the forage is verified in a higher digestibility and in an increase of energy, protein and other nutrients contained.

This increase in quantity and quality of forage has allowed an increase in the number of animals (+34 percent), resulting in a higher and more efficient production of milk per unit area.

As it can be seen in figure 14, land productivity, measured in liters of milk per hectare, increases by 52 percent after stabilizing the SPS.

Figure 14 – Forage production and productivity

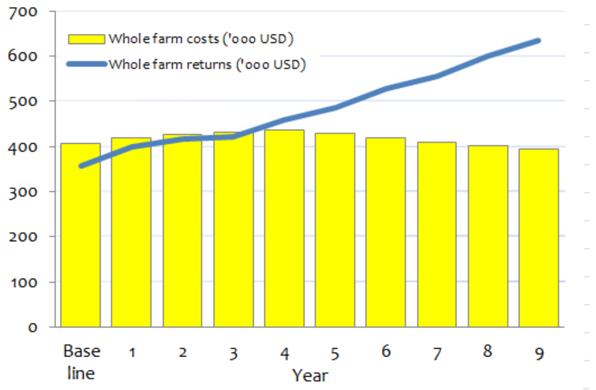


Economic Results

The respective differences in economic performance between the baseline and SPS can be solely attributed to SPS, as input and output prices were kept constant during the entire simulation period.

At this case, comparing the production system with the ones described before there is a base line situation with greater technical implementation. This condition reflects over better technical parameters but also affects production cost since there is a higher dependency on inputs such as fertilizers.

Figure 15 – Economic results



As figure 15 shows, total cost of the productive system increase during the implementation stage of SPS, but after the 4th year once the SPS stabilizes the costs starts reducing, and in return revenues increase by around 80 percent (see figure 15).

After the 5th year, the incomes cover the costs and leave a positive balance in cash flow, achieving situations of large economic surplus in the stabilization stage.

Animal Welfare

Animals were healthy, with the average body condition after adopting SPS of 3.5, with no signs of lameness. Animals had free access to water within 150m. Animals were alert, performing a wide range of natural behavior. As shown in figure 16, all criteria were achieved (good feeding, good housing, good health and appropriate behavior). No aggression was seen and flight distance was short, an average of 2.5 meters, again possibly due to calm regular handling.

Figure 16 – Animal welfare

Feeding
- ✓ Feed
- ✓ Water
- ✓ Body condition

Housing
- ✓ Shade, lack of heat stress
- ✓ Pastures
- ✓ Resting comfort

Health
- ✓ No clinical signs
- ✓ No lameness

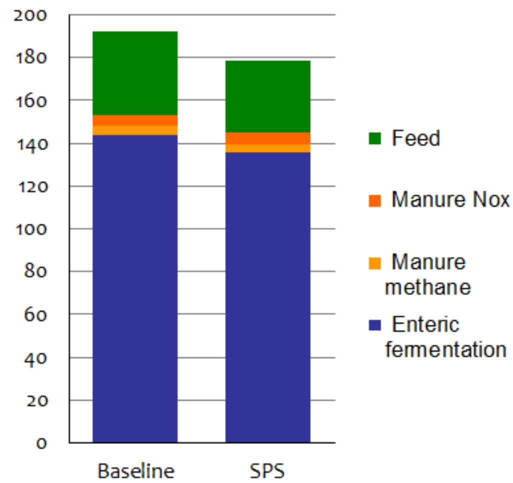
Behaviour
- ✓ Diverse positive behaviour
- ✓ No agression
- ✓ No signs of fear

Environmental Impact

Comparing the measurements of the baseline with respect to the SPS already implanted, the CO2 emission was reduced by 12 percent.

Figure 17 shows the impact of SPS considering feed, manure Nox, manure methane and enteric fermentation.

Figure 17 – Kg CO_2 / 100 kg ECM



5.4 Case #4 - Dairy / Quindio

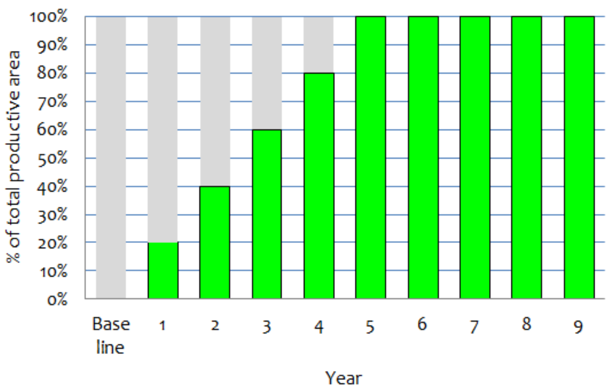
Case Study Background

Located in La Tebaida, the farm has a production system dedicated to dairy; with Holstein breed crossed animals, with a total of 76 hectares from which 50 hectares are destined for production.

During the period of analysis, an intensive SPS was adopted, consisting of fodder shrubs of leucaena (L. leucocephala) at high densities, interspersed with high productivity pastures stargrass (*Cynodom plectostachyus*).

Figure 18 shows how intensive SPS were incorporated year by year, reaching a 100 percent of the productive area at the end of the period.

Figure 18 – Percentage of area under SPS



Results

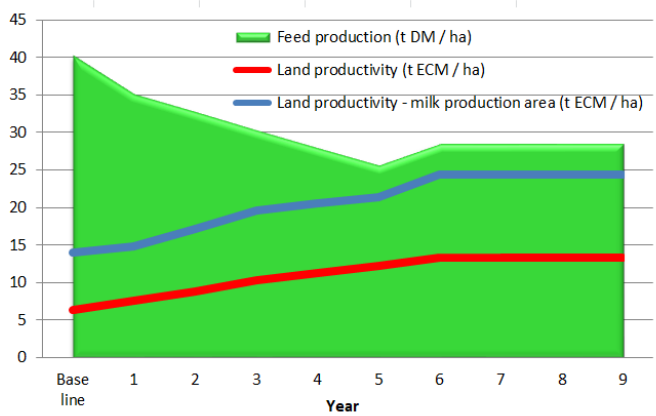
Forage Production and Productivity

Measured in tons of dry matter per hectare, the forage production reaches an average of 28 tons.

Compared with baseline situation where the production of fodder depended on chemical fertilization total feed production (tons of DM per hectare) reduces in a 30 percent, although the total production of protein an energy digestibility increased.

Stocking capacity of the system was adjusted and as can be seen in figure 19, the land productivity – measured in liters of milk per hectare – increased by 112 percent after stabilizing the SPS.

Figure 19 – Forage production



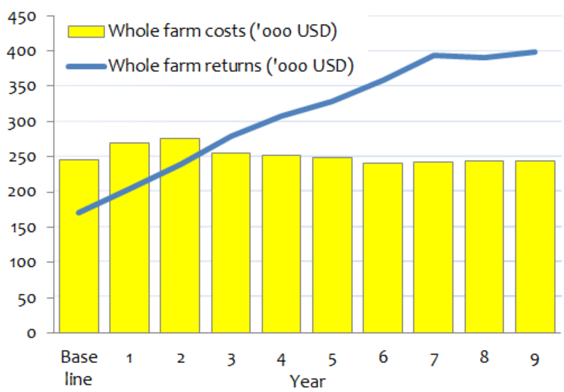
Economic Results

As figure 20 shows, incomes increase by around 135 percent compared with the baseline scenario.

After the initial investment and after a stabilization period of 3 years, the increase in forage quality and higher productivity per hectare generate returns that ensure the economic viability of the SPS.

After the 4th year, incomes cover the costs and leave a positive balance in the cash flow, achieving a large economic surplus in the stabilization stage.

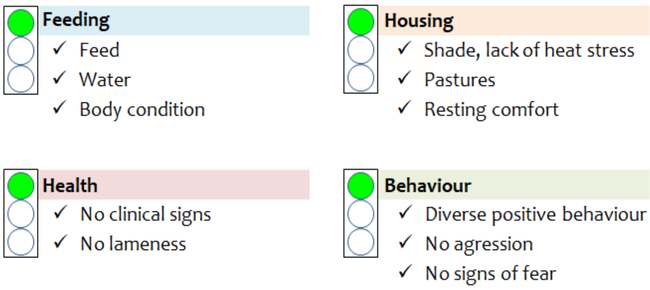
Figure 20 – Economic results



Animal Welfare

After the implementation of SPS, average body condition was 3.2, the animals being healthy, alert and showing a wide range of normal behaviors. Access to green fodder of quality throughout the day and the availability of fresh and clean water within 150m provided an ideal habitat, and due to the shade the animals had no symptoms of heat stress despite a temperature ranging between 20°C and 30°C. There were no signs of aggression, with a very short flight distance from humans at an average of 2.2 meters, suggesting animals were used to regular calm handling.

Figure 21 – Animal welfare

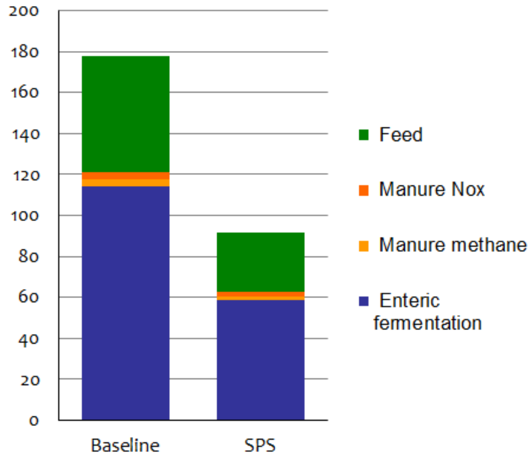


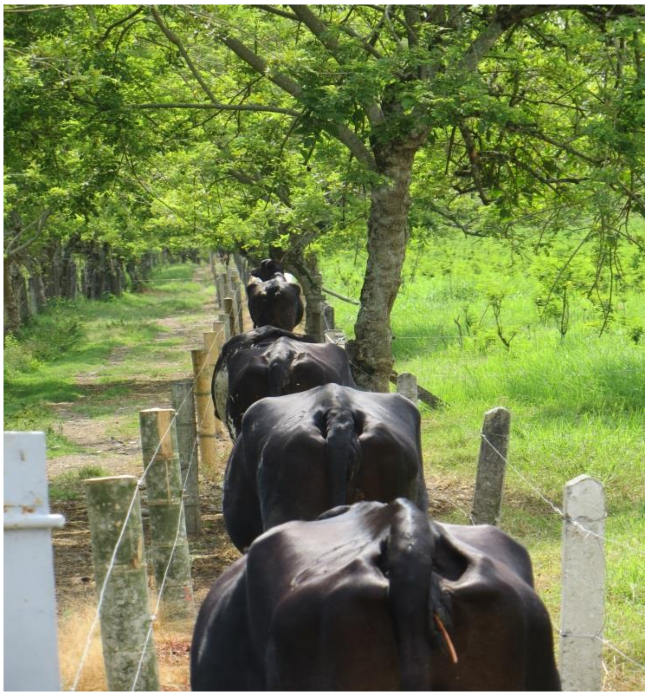
Environmental Impact

The increase in biodiversity plays an important role in the biological control of pests.

Comparing baseline measurements with the adoption of SPS, CO2 emissions were reduced by 48 percent, as shown in Figure 22.

Figure 22 – Kg CO_2 / 100 kg ECM





5.5 Case #5 - Cattle breeding / Valle del Cauca

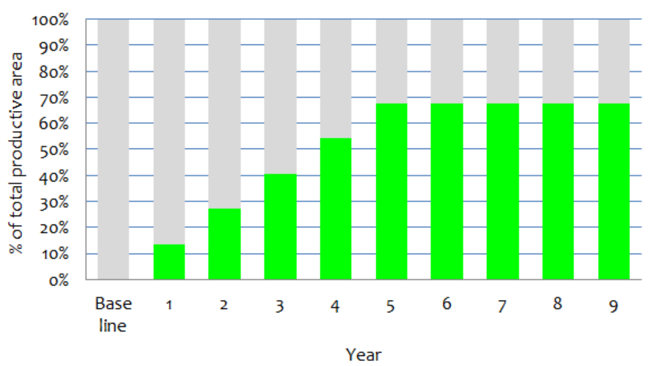
Case Study Background

Located in Alcala, the farm has a productive system dedicated to cattle breeding, with animals of the Brangus breed, in a total of 45 hectares, 37 of them with productive use.

During the project, a SPS of dispersed trees was adopted. It consists of an agroforestry system for animal production that combines leguminous trees (Inga edulis) with improved high productivity pastures (Cynodon plectostachyus).

Figure 23 shows the implementation process of silvopastoral systems reaching around 68 percent of the productive area at the end of the period.

Figure 23 – Percentage of area under SPS



Results

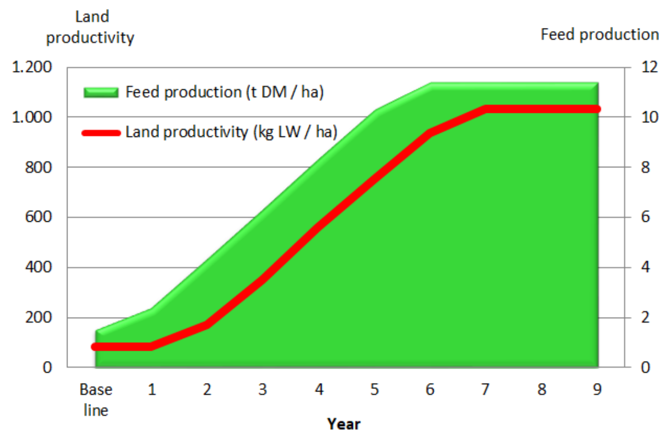
Forage Production and Productivity

There was an increase in the amount of forage from 2 tons in the baseline to 11 tons in the SPS.

This has led to an increase in the number of animals, resulting in greater and more efficient meat production per unit area.

As can be seen in figure 24, the productivity of the land, measured in kilos of meat per hectare, had a significant increase from 85 to 1034 kg LW per hectare after the stabilization of the SPS.

Figure 24 – Forage production

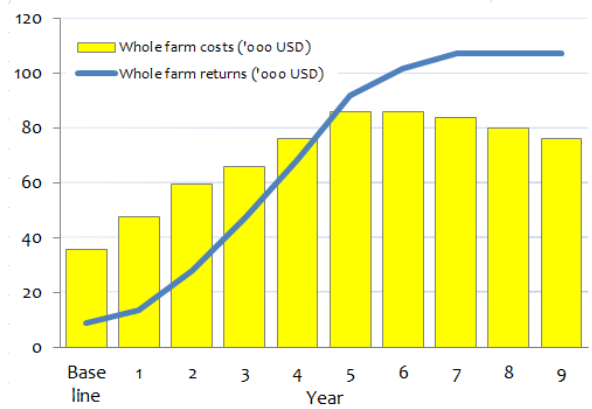


Economic Results

After the initial investment and after a period of 6 years, the increase in forage production and the higher productivity per hectare generated returns that ensured the economic viability of silvopastoral systems.

After the 6th year, incomes cover the costs and leave a positive balance in the cash flow, achieving situations of an economic surplus in the stabilization stage.

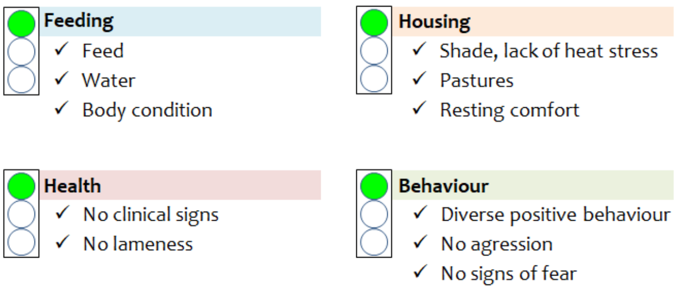
Figure 25 – Economic results



Animal Welfare

After the implementation of SPS, the average body condition was 3.4, showing healthy animals with no clinical signs or lameness. Animals showed a range of natural behavior. Access to green fodder of high quality and free availability of fresh and clean water provide an ideal habitat, and due to the shade, no symptoms of heat stress were noticeable. No signs of aggression were seen and flight distance from humans was very short at an average of 2 meters.

Figure 26 – Animal welfare



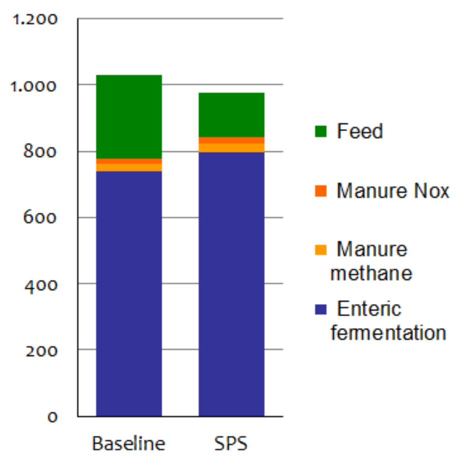
Environmental Impact

Some works carried out by CIPAV about SPS show 3 times more birds, the ant count is on average 60 percent higher than in the baseline, and the number of dung beetles doubled.

The presence of leguminous trees, their coexistence with pastures and rational rotation of cattle increased the amount of organic matter and nutrients in the soil, eliminating the need for nitrogen fertilizers.

Comparing the measurements of the baseline to the ones after the SPS are stablished, CO2 emissions were reduced by 9.5 percent.

Figure 27 – Kg CO_2 / 100 kg LW added



5.6 Case #6 - Dual purpose / Caquetá

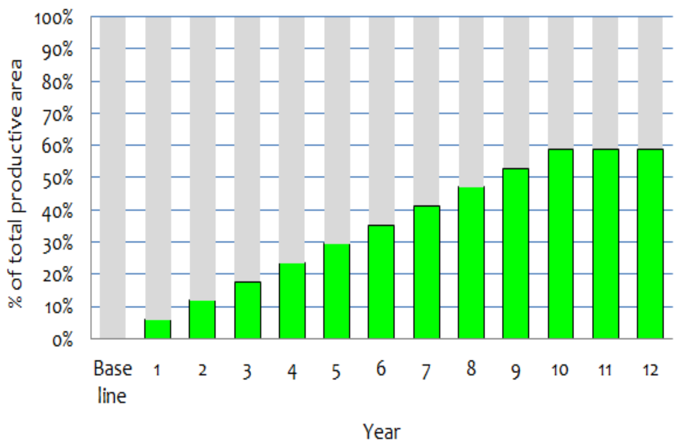
Case Study Background

Located in Morelia, the farm has a dual purpose productive system (weaning calves and dairy) using crossbreeds in a total area of 200 hectares with 170 hectares destined for production.

During the period of analysis an intensive SPS was adopted, consisting of high density planted fodder shrubs Mexican sunflower (*Tithonia diversifolia*), improved high quality pasture (*Brachiaria humudicola*) and native trees.

Figure 28 shows the adoption process of the silvopastoral area year by year, reaching around 59 percent of the total area in year 10 of implementation.

Figure 28 – Percentage of area under SPS



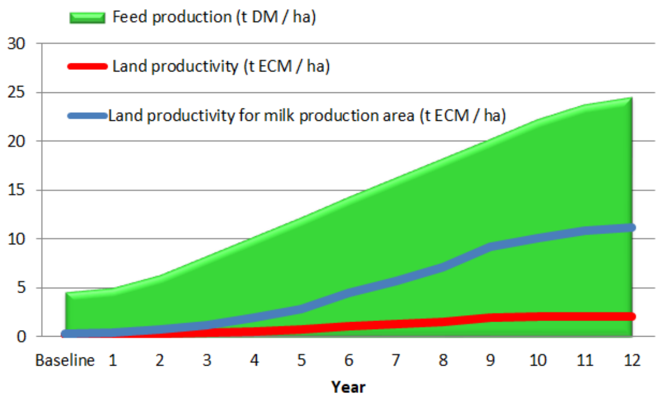
Results

Forage production and Productivity

As in the cases described previously forage production increases not only in quantity but in quality. The system passes from producing 5 tons of dry mater per hectare in the baseline to 25 tons in the SPS.

This leads to an increase in the stocking capacity of the system reflected over a greater production of milk per hectare.

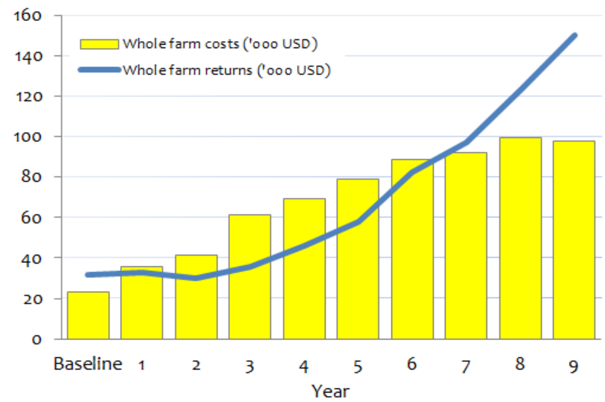
Figure 29 – Forage production and productivity



Economic Results

After the initial investment and a stabilization period of 6 years, on the 7th year with an adoption of the 70% of the total area, the increase on forage productivity and animal inventory starts generating returns that ensure the economic viability of the system and allow the adoption of the remaining area. Once the total adoption of the SPS is achieved farm receipts increase around 474 percent compared with baseline situation.

Figure 30 – Economic results



Animal Welfare

Average body condition was 3.0 (minimum 2, maximum 4), with healthy animals and no lameness. Animals showed a range of natural behavior. Animals had access to green fodder and free availability of fresh and clean water. Paddocks at time of assessment had no shade but no symptoms of heat stress were noticeable. No signs of aggression were seen and flight distance from humans was very short at an average of 2 meters.

Figure 31 – Animal welfare

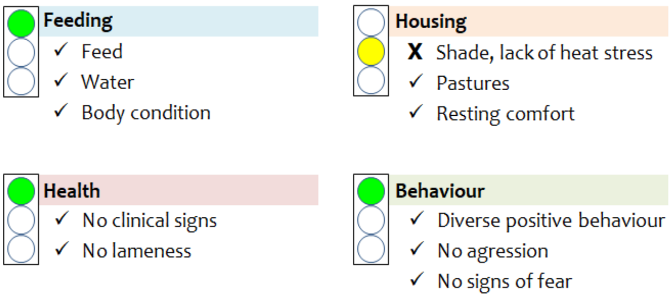
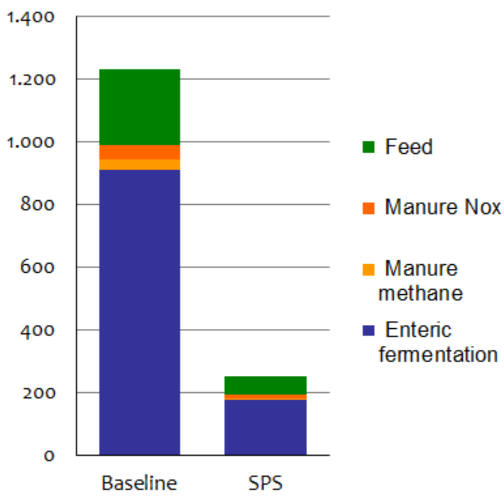


Figure 32 – Kg CO_2 / 100 kg ECM



Comparing baseline measurements with the adoption of SPS, CO2 emissions were reduced by 80 %. This dramatic decrease is mainly due to an important increase in milk yields, both, per hectare and per cow.

Environmental Impact

The increase in biodiversity plays an important role in every ecosystem but especially in this case the effect is enhanced by the strategic location of the productive system in the amazon region.

Productive systems that work as a buffer to reduce the effect of deforestation and recover tree cover are of vital importance for this region. Historically conventional livestock productions have been playing a negative role for this threatened ecosystem.

Biomass and vegetation cover reduce the effects of soil compaction and erosion. The cultivation of forage shrubs and their coexistence with pastures increase the amount of organic matter and nutrients in the soil reducing the need of fertilizers.

5.7 Summary of the case studies

Case #		**1**	**2**	**3**	**4**	**5**	**6**
Production system		Beef finishing	Dual purpose	Tropical dairy	Tropical dairy	Cattle breeding	Dual purpose
Reference year		2013	2013	2013	2014	2014	2015
Region		Cesar	Valle del Cauca	Valle del Cauca	Quindio	Valle del Cauca	Caqueta
Breed		Zebu (crosses)	Cross-breeds	Lucerna	F1 (Holstein x Zebu)	Brangus	Cross-breeds
Area	Productive	140	30	135	50	37	170
	Total SPS	140	14	94	50	25	100
Number of animals	Baseline	71 (2)	35 (1)	230 (1)	108 (1)	7 (2)	70 (1)
	SPS	710 (2)	58 (1)	307 (1)	148 (1)	85 (2)	181 (1)
Feed production	Baseline	3	14	24	40	2	5
	SPS	25	16	28	28	11	25
Stocking density	Baseline	0,7	1,9	3,1	3,6	0,2	0,8
	SPS	4,0	4,5	4,5	4,9	1,5	1,8
Productivity	Baseline	370 (2)	2.346 (1)	2.644 (1)	2.744 (1)	342 (2)	872 (1)
	SPS	614 (2)	3.084 (1)	3.010 (1)	4.240 (1)	685 (2)	2.400 (1)
Land Productivity	Baseline	126 (1)	3 (3)	4 (3)	6 (3)	85 (2)	0,2 (3)
	SPS	1.187 (1)	6 (3)	6 (3)	13 (3)	1.034 (2)	2,0 (3)
Land productivity – milk prod. area	Baseline	--	7	11	14	--	0,4
	SPS	--	12	13	24	--	11
Farm net income	Baseline	-25.277	-1.251	-50.749	-76.192	-27.082	8.633
	SPS	192.444	43.058	240.850	155.640	30.995	97.212
CO_2 Emissions		reduce	reduce	reduce	reduce	reduce	reduce

Units

Area	Hectares (ha)		
Number of animals	(1) productive cows	(2) sold / year	
Feed production	t dry matter / ha		
Stocking density	LU / ha		
Productivity	(1) kg / cow & year	(2) gr / day	
Land Productivity	(1) kg CW / ha	(2) kg LW / ha	(3) t ECM / ha
Land productivity – milk prod. Area	t ECM / ha		
Farm net income	USD / year		

Regarding animal welfare, Silvopastoral systems have shown to offer optimal conditions to deliver animal welfare and avoid the current challenges of extensive cattle ranching such as poor body condition and heat stress as seen on comparison farms. They provide a large amount of green fodder that meets nutritional needs, as seen in the good body condition for most animals assessed.

The animals have freedom of movement and a diverse environment to express a wide range of behavior, and trees and shrubs provide shade during the hottest part of the day. Regular calm interactions with animals e.g. during movement between paddocks mean animals do not show fear of humans, with very short flight distances.

6 Conclusions

Analyzing the information gathered and results obtained, it is clear that silvopastoral systems represent a valid alternative for livestock production, fulfilling most of the current criteria for sustainability. Results provide evidence for the ability of SPS to create sustainable solutions for coping with future demand trends for livestock products.

Case studies over a period of ten years – even with different original production systems and from different regions - have shown better results for SPS-farms than for farms with traditional systems (baseline scenarios).

SPS provides a better supply of fodder in terms of quantity and quality. In previous works as well as current case studies, biomass production has significantly increased, which is one of the key factors for increasing animal production, allowing better stocking rates.

Assessing the environmental impact, this project has proven several advantages over traditional systems. A reduction from 11 to 40 percent in greenhouse gases emission was verified. A denser vegetation cover protects the soil from erosion, and there is a better use of groundwater. Trees and fodder shrubs' roots contribute to soil fixation, reducing the impact of erosive elements.

Silvopastoral systems have the potential to deliver optimal animal welfare, including good feeding, good housing, health and behaviour, especially where breeds are selected to be well adapted to the climate.

Despite the disadvantage of requiring large initial investments, economic results are favorable after a period ranging from 3 to 6 years, covering in all cases the costs of production.

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Annex I – Comparative tables (Baseline = 100)

Case #1

Region: Cesar / Prod. System: beef finishing / Area: 200 ha.

	Base line	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9
Forage production Tons DM/Ha.	100	129	177	254	349	445	540	636	696	731
Land Productivity Tons Milk/Meat/Ha.	100	100	149	218	331	468	599	732	813	943
Economic results Profitability (incomes–	100	-18	-19	-81	-31	84	218	356	560	969

	Base line	SPS
CO_2 Emissions Kgs CO_2/100 kg LW added/Milk	100	91

Case #2

Region: V del Cauca / Prod. System: dual purpose / Area: 39 ha.

	Base line	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9
Forage production Tons DM/Ha.	100	87	100	104	80	104	112	112	112	112
Land Productivity Tons Milk/Meat/Ha.	100	107	110	124	136	152	173	182	204	218
Economic results Profitability (incomes–	100	-2336	-416	84	-1247	1778	2688	3648	4798	5491

	Base line	SPS
CO_2 Emissions Kgs CO_2/100 kg LW added/Milk	100	99

Case #3

Region: V del Cauca / Prod. System: dairy / Area: 135 ha.

	Base line	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9
Forage production Tons DM/Ha.	100	99	99	101	104	107	109	112	115	117
Land Productivity Tons Milk/Meat/Ha.	100	103	109	113	123	130	135	138	145	152
Economic results Profitability (incomes–	100	173	199	204	281	360	477	558	677	773

	Base line	SPS
CO_2 Emissions Kgs CO_2/100 kg LW added/Milk	100	93

Case #4

Region: Quindio / Prod. System: dairy / Area: 76 ha.

	Base line	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9
Forage production Tons DM/Ha.	100	87	81	75	69	64	71	71	71	71
Land Productivity Tons Milk/Meat/Ha.	100	121	141	163	180	195	212	212	212	212
Economic results Profitability (incomes–	100	114	152	231	275	306	355	398	393	404

	Base line	SPS
CO_2 Emissions Kgs CO_2/100 kg LW added/Milk	100	52

Case #5

Region: V del Cauca / Prod. System: cattle breeding / Area: 45 ha

	Base line	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9
Forage production Tons DM/Ha.	100	158	288	419	549	680	753	753	753	753
Land Productivity Tons Milk/Meat/Ha.	100	100	200	414	657	886	1100	1214	1214	1214
Economic results Profitability (incomes–	100	73	78	129	154	192	221	239	245	252

	Base line	SPS
CO_2 Emissions Kgs CO_2/100 kg LW added/Milk	100	95

Case #6

Region: Caqueta / Prod. System: dual purpose / Area: 200 ha.

	Base line	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	year 11	year 12
Forage production Tons DM/Ha.	100	111	138	181	225,2	269	313	356	400	444	487	520	537
Land Productivity Tons Milk/Meat/Ha.	100	108	144	191	263,1	355	517	605	741	947	959	1003	1009
Economic results Profitability (incomes–	100	-35	-132	-298	-269,7	-245	-75	61,2	271	609	753	938	1050

	Base line	SPS
CO_2 Emissions Kgs CO_2/100 kg LW added/Milk	100	22