Agrosilvopastoril v 19.1: Modeling Cattle Production and Environment Contribution of Silvopastoral Systems in the Peruvian Tropics

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Abstract. Simulation tools can be helpful for supporting implementation of livestock production systems and exploring ways of improvements. The aim of this paper is to present a support tool for implementation and evaluation of silvopastoral systems in the Peruvian Amazon Region. This approach is based on the design of a decision support model called Agrosilvopastoril v 19.1. It calculates livestock production using integrated information on climate, soil, crops, forestry, pastures and cattle herds collected from secondary sources and on-field work conducted at the Peruvian Northern Amazon Region. The model was tested to estimate carbon sequestration and enteric methane emissions in 10 has of silvopastures with different proportions of forest and pasture, showing an increase in carbon sequestration with a small reduction in the number of animals and similar methane emissions.

Keywords: livestock; simulation model; Amazon region; CO_2 emission; carbon sequestration.

1 Introduction

Modelling farming livestock systems may vary according to: (i) system definition, (ii) the intended use of the model and (iii) the way in which farmers' decision-making processes were represented and how agricultural experts and farmers were involved in the modelling processes (Gouttenoire et al., 2011). In the last decades, several simulation models have been built for describing specific components of a livestock systems, such as forage, nutrition or reproduction, and other ones for simulating the whole farm (Crosson et al., 2011; Schils et al., 2007; Duru et al., 2012). The latter are more complex, since they are focused on a better understanding of the possible existing interactions between the farming system and its environment.

Silvopastoral systems (SPS) are production systems that deliberately integrate trees, livestock, and forage production on the same unit of managed land (Peri et al. 2016). Silvopastures have potential to provide multiple benefits in terms of economic and

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environmental responses (Nuberg et al. 2009). Their potential economic benefits include income diversification to landowners through the sale of forest products, such as fuelwood, and agricultural products such as milk and cheese from livestock production, crops such as tropical fruits (Cotta 2017), coffee (*Coffea spp*.), and cacao (*Theobroma cacao L.*) (Sommariba et al. 2012). Research conducted in Latin America pointed out the potential for mitigation of greenhouse gas emissions and Carbon sequestration in SPS when livestock grazes forages with high digestibility and tannin concentrations (Montagnini et al. 2013; Villanueva et al. 2018). Despite the potential of SPS as a sustainable system for livestock production, there is a lack of a whole-farm simulation models designed to explain differences between SPS and prevalent land use systems to raise cattle in degraded land under the Amazon Region conditions. This situation limits the Peruvian government capacity to take sustainable decisions on land use or to establish strategies to incentivize SPS implementation. The main objectives of the present study are to (i) present a decision support model (Agrosilvopastoril v 19.1) designed to calculate the productivity, economic, and environmental impacts of the use of silvopastoral systems; and (ii) illustrate the model application with the results of the environmental contribution of silvopastoral systems based on a simulation in a 10-ha farm in the Peruvian Amazon.

2 Model description

Agrosilvopastoril v 19.1 represents cattle farm systems from the Peruvian tropical region, including its components, processes and interactions. It was developed using Microsoft Excel 2010 and then designed as a computer program with a user-friendly Java interface. Agrosilvopastoril v 19.1 is based on integrated information on climate, soil, crops, forestry, pastures and cattle herds collected from secondary sources and on-field work conducted during 2017 and 2018 in 30 different farms of Amazonas and San Martin at the Peruvian Northern Amazon Region.

2.1 Model structure and inputs of the model

Agrosilvopastoril v 19.1 is composed of 08 components describing the functions of the silvopastoral systems. Each component has the following parameters:

1. - Farm: Location, total area, land use (pasture, crops, forestry in hectares).
2. - Crops: Type, area, crop yield per ha.
3. - Forestry: Type, distribution, area, density, age and diameter at breast height.
4. - Livestock: Categories, average age, breed.
5. - Feeding: Forage biomass, level of supplementation and nutritional composition for dry and rainy season.
6. - Soil: Type, soil composition, erosion rate.
7. - Weather: Temperature, humidity, rainfall, wind velocity.
8. - Bio-economy: Production costs and average prices for meat, dairy, trees and crops sold.

Interactions between components were analyzed, considering inputs, state, and output variables. Population growth was simulated to determine the number of weaning, fattening, adults and sales of animals. Forage availability was obtained calculating the effect of rainfall, temperature, soil nutrients and erosion on growth rate (kg DM). Prediction of cattle nutritional requirements, consumption and milk or meat production were calculated using the model of the National Research Council for beef (NRC, 1996) and dairy (NRC, 2001). Dry matter intake regulation was adjusted according to weather conditions, using the temperature-humidity index suggested by Habeeb et al., 2018:

$$THI = 1.8*T+32-(1-H)*(T-14.3) \quad \textbf{(1)}$$

Where: THI = Temperature-humidity index
T = Temperature
H = Humidity

and the following equation:

$$F\ decreased = -28.19+0.391*THI \quad \textbf{(2)}$$

Where a decreased dry matter feed intake is expected in the animal if a positive value is obtained.

Incomes were obtained from milk, meat, crop and wood sales. They were estimated based on the yield of each product multiplied by the average sell price minus their production costs. Determination of methane production and carbon sequestration were calculated following the 2006 IPCC guidelines for National Greenhouse Gas inventories for Agriculture, Forestry, and Other Land Use sector.

2.2 Results of the model

Results are presented based on the input information filled by the user. However, default values are considered for each component. Results are showed in two separated modules called: Farm information and Scenarios. The farm information module calculates average farmer revenues and methane production and carbon sequestration. The Scenario module allows an analysis of two or more scenarios. Changes compared with the baseline scenario are presented in figures and tables to compare easily the effect of a variable on the system.

3 Model application

Agrosilvopastoril v 19.1 was tested to estimate carbon sequestration and enteric methane emissions. Table 1 presents the outputs of the modelling exercise for a 10 ha farm in the Peruvian Amazon as a function of the proportion of the area dedicated to tree and pasture components of a SPS with trees arranged in alleys. The tree component was *Cedrelinga catenaeformis*, and the forage component was *Brachiaria decumbens*. Increasing the area covered by trees without reducing area dedicated to forage resulted in greater carbon sequestration and marginal differences in methane emissions.

Table 1. Simulation of the effect of the increase in the area of silviculture on carbon sequestration and methane emissions on SPS in the northern Peruvian Amazon

Scenario	Stocking rate (LU/ha)	Number of LU	Total area (10 Ha)		Carbon sequestration (Mg/ha/yr)	Methane emissions (Mg/ha/yr)
			Forest* (ha)	Pasture (ha)		
A	1	9.9	0.5	9.5	0.20	1.79
B	1	9.0	1	9	0.40	1.64
C	1	8.2	2	8	0.85	1.35

*Tree arrangement in alleys
LU: Livestock unit (450 kgs cow)

In carrying out the simulation, an increase in the area destined for silviculture from 0.5 to 2 ha was considered, maintaining silvopastoral design (alleys), the tree species, the stocking rate in pasture area (LU/ha) and other information necessary for the simulation. It is important to mention that for the construction of the scenarios we only considered the area related to pasture as area available for cattle. We obtained, as expected, an increase in carbon sequestration with a small reduction in the number of animals and a similar methane emission. These estimates show that carbon neutral animal production systems could be designed since carbon emissions may be compensated by the carbon sequestration potential of SPS. Brazil has advanced this concept, as described by de Almeida et al. (2016), and Doran-Browthe et al. (2017) in Australia.

This exercise provided us first insights related to the environment contribution of silvopastoral systems in the Peruvian tropics. However, we recognize the need to increase the precision of results from the simulation tool, since there are effects that need to be better understood first before modelling i.e. evaluating how shade of trees could potentially impact understory forage productivity and ultimately carbon sequestration on a systems level or estimating how the type of tree could influence methane emissions if the tree component was a legume consumed by livestock versus a timber tree.

4 Conclusions

In this paper we present an overview of Agrosilvopastoril v 19.1, a decision support system for implementation and evaluation of silvopastoral systems in the Peruvian Amazon Region. We demonstrated that Agrosilvopastoril v 19.1 can be used to estimate the capacity of carbon sequestration of SPS and the level of enteric methane emission of livestock production systems on different scenarios.

The next step is to validate Agrosilvopastoril v 19.1 and use it in real case studies, where in collaboration with the policy makers and the stakeholders, different scenarios may be drawn to design carbon neutral animal production systems (a balance between cattle methane emissions and carbon sequestration of SPS).

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References

1. Cotta, J. N. (2017). Revisiting Bora fallow agroforestry in the Peruvian Amazon: Enriching ethnobotanical appraisals of non-timber products through household income quantification. Agroforestry systems, 91(1), 17-36.
2. Crosson, P., Shalloo, L., O’Brien, D., Lanigan, G. J., Foley, P. A., Boland, T. M., and Kenny, D. A. (2011). A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems. Animal Feed Science and Technology, 166, p.29-45.
3. De Almeida, R. F., Silveira, C. H, Mota, R. P., Moitinho, M., Arruda, E. M., Mendonça, E. D. S., La Scala, N. and Wendling, B. (2016). For how long does the quality and quantity of residues in the soil affect the carbon compartments and CO2-C emissions? Journal of Soils and Sediments 16(10): p.2354-2364
4. Doran-Browne, N., Wootton, M., Taylor, C. and Eckard, R. (2018) Offsets required to reduce the carbon balance of sheep and beef farms through carbon sequestration in trees and soils. Animal Production Science 58(9): p. 1648-1655
5. Duru, M., Felten, B., Theau, J. P., and Martin, G. (2012). A modelling and participatory approach for enhancing learning about adaptation of grassland-based livestock systems to climate change. Regional environmental change, 12(4), p.739-750.
6. Gouttenoire, L., Cournut, S. and Ingrand, S. (2011). Modelling as a tool to redesign livestock farming systems: a literature review. Animal, 5(12), p.1957-1971.
7. Montagnini, F., Ibrahim, M., and Murgueitio, E. (2013). Silvopastoral systems and climate change mitigation in Latin America. Bois et Forêts des Tropiques, 316(2), p.3-16.

8. Habeeb, A., Gad, A., and Atta, A. (2018). Temperature-humidity indices as indicators to heat stress of climatic conditions with relation to production and reproduction of farm animals. International Journal of Biotechnology and Recent Advances, 1, p.35-50.

9. IPCC, I. (2006). Guidelines for national greenhouse gas inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. Published: IGES, Japan.

10. Nuberg I., George B., and Reid R. (2009) Agroforestry for natural resource management. CSIRO, Collingwood.

11. National Research Council. 1996. Nutrient Requirement of Beef Cattle. 7th Rev. Ed. National Research Council. Nat. Acad. Sci., Washington, DC.

12. National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th Rev. Ed. National Research Council. Nat. Acad. Sci., Washington, DC

13. Peri, P. L., Dube, F. and Varella, A. (Eds.). (2016). Silvopastoral systems in southern South America (Vol. 11). London, UK: Springer.

14. Schils, R. L. M., Olesen, J. E., Del Prado, A., and Soussana, J. F. (2007). A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. Livestock Science, 112(3), p.240-251.

15. Somarriba, E., Beer, J., and Alegre-Orihuela, J. (2012) Mainstreaming agroforestry in Latin America. In: Agroforestry—the future of global land use advances in agroforestry, p.429–453

16. Villanueva, C., Casasola, F. and Detlefsen, G. (2018) Potencial de los sistemas silvopastoriles en la mitigación al cambio climático y en la generación de multiples beneficios en fincas ganaderas de Costa Rica. Boletín técnico 87. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica.