Integrated farming and global warming mitigation in Brazil

Using land-use change projections of integrated crop-livestock-forestry systems expansion in Brazil within the context of the Paris Agreement

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Abstract

One of the targets predicted in Brazil's Nationally Determined Contribution (NDC) to the Paris Agreement is the expansion of 5 million hectares of integrated crop-livestock-forestry systems (ICLFS) until 2030. Although there is some scientific notion of the extent where this expansion could take place, there is no systematic accounting on the role of soil carbon to bring this agricultural system at least close to carbon neutrality, or even to be a sink of carbon. In that context, the objective of this research plan is to produce spatially-explicit projections of the expansion of ICLFS predicted in Brazil's NDC and estimate the carbon balance, the provision of other ecosystem services and financial revenue according to different land management scenarios. This will be done with the use of ad-hoc scenario building applied to land-use modeling framework, comprised of a land-use change model and a crop-productivity and carbon-storage model. The final results of this study will represent practical information for decision makers, at any governance level, for guiding the implementation of ICLFS across Brazil in the context of the country's NDC.

Keywords: Land-use systems, Carbon budget, Ecosystem services, Global warming

1 Introduction

It is well known that AFOLU (Agriculture, Forestry and Land Use) and BECCS (Bioenergy with Carbon Capture and Storage) sectors are key to slow down the increase of CO_2 concentration in the atmosphere, by reducing emissions and also fixing carbon (IPCC 2018). As part of the Paris Agreement, Brazil pledged to stop illegal deforestation and to reforest 12 million of hectares by 2030 to help mitigating global warming, in addition, it also committed to restore 15 million hectares of pasturelands and expand the area of ICLFS to 5 million hectares.

The enhancement of agriculture intensification and efficiency are expected to have a high potential in the mitigation of climate change, which goes from smart land-use allocation planning (Searchinger et al. 2018), to the improvement of agricultural management systems and technology (Burney, Davis, and Lobell 2010; Campbell et al. 2014). The expansion of ICLFS in Brazil is considered promising for the development of a sustainable intensification of the agricultural production, it based on the combination of different species in the same area, aiming for higher revenue than traditional systems, while in the same time improving soil conservation (Balbino, Oliveira Barcellos, and Stone 2011). However, there is a significant knowledge gap regarding ICLFS in Brazil, as a relatively novel technology, there is still a scarcity of long-term field experiments (Garrett et al. 2017), which impacts in the understanding of many aspects of this production systems, such as economic revenue, provision of ecosystem services, overall productivity and its interaction with climate change (as an agent of mitigation, but also as an affected system).

In this context, modelling approaches may prove useful to explore the potentials of ICLFS expansion in Brazil. The use of process based models to simulate carbon exchange and productivity of ICLFS, as also projections of its expansion in the future, can provide valuable information for policy makers. The proposal of this work is to generate spatial estimates of ICLFS productivity, and projections of its expansion by 2030 and 2050. This data will then be used to support the quantification of ecosystem services and revenues of the integrated management systems.

2 Objectives

The main objective of this research plan is to produce spatially explicit projections on the expansion of 5 million hectares of ICLFS in Brazil and its associated carbon budget and synergistic provision of ecosystem services according to different land management scenarios. This will be done both for times horizons of 2030, which is relevant for the Paris Agreement, and a longer time horizon of 2050, which is relevant for any posterior intergovernmental agreement and for longer-term soil carbon storage.

The project aims at answering the following research questions as specific objectives:

- **Question 1**: What are the management practices that lead to the best compromise between carbon sequestration and financial revenue for agricultural land under ICLFS?

  Hypothesis: The ICLFS management systems are very diverse, and they can provide different results in relation to financial revenue and the capacity to store carbon. Thus it is important to find which of these systems are be more suitable for implementation, so that they can have a significant effect on climate change mitigation, while still economically viable.

- **Question 2** Can indirect land-use and land-cover changes, especially land sparing under expansion of ICLFS, improve the net carbon budget of this agricultural system?

  Hypothesis: The expansion of ICLFS will likely affect other areas indirectly, such as land sparing or increasing pressure for resources. Indirect effects of land-use are often underestimated, although they can represent a significant share of impacts associated with land-use change.

- **Question 3** Does the prioritization of the provision of ecosystem services other than carbon storage imply in changes of productivity of ICLFS?

  Hypothesis: ICLFS can provide other ecosystem services beyond carbon storing. If an integrated production system is developed to focus on the provision of another ecosystem service, there can be a significant difference in the system productivity.

- **Question 4** Can further expansion of ICLFS, beyond Brazil's NDC target, replace the afforestation targets pledged in the scientific literature for the tropics in terms of carbon storage, provision of ecosystem services and economic revenue?

  Hypothesis: There is a large demand over tropical countries for afforestation, however, there are great socio-economic challenges to implement this solution in large scale. If a ICLFS management system shows positive results for storing carbon, than it may be a potential substitute for afforestation programs.

3 Theoretical Foundation

3.1 Integrated production systems

In the reference document of ICLFS from Brazilian Agricultural Research Corporation (Embrapa), Balbino, Oliveira Barcellos, and Stone (2011) states the importance if agriculture intensification for sustainable development, but warns that this should not be taken as synonym to indiscriminate use of production resources.

They point that the sustainability is achieved if a system is technically efficient, environmental friendly, economically feasible, and socially accepted. The same authors describes that ICLFS meet the above requirements in implemented properly, being seen as a promising solution for developing a sustainable agriculture in Brazil. The ICLFS can be described as a system integrating crop-livestock-forestry in the same area in inter-cropping, succession and rotation, there is a wide possible system managements, from less to more complex productions (Balbino, Oliveira Barcellos, and Stone 2011).

There has been a raise in the studies concerning ICLFS in the last decade. They range from studies analysing soil properties in integrated systems (Moura Oliveira et al. 2017), biomass productivity (Sarto et al. 2020), water infiltration and erosion (Sone et al. 2019), and economic viability (Reis et al. 2020). These studies show advantages in implementing integrated systems over traditional practices. However there are still great challenges that hampers the widespread adoption of ICLFS, which are still relatively low (Garrett, Gil, and Valentim 2014; Gil, Siebold, and Berger 2015; Gil, Garrett, and Berger 2016), some factors such as labor demand, implementation costs and technical knowledge are common difficulties faced by producers in implementing ICLFS (Gil, Siebold, and Berger 2015).

There are also many gaps of knowledge over integrated systems, such as scarce information about spatial distribution, ecosystem services trade-offs and key knowledge to encourage ICLFS adoption (Garrett et al. 2017). The lack of field observations (specially in long term experiments) is also a great caveat for the area development, it forces some studies to rely on modelling, which is also deficient and limited due to low data availability (Garrett et al. 2017).

3.2 Modelling framework

3.2.1 Land-use modelling

There is a wide range of land-use change models are available from the literature of different disciplines. The characteristics of the models are also diverse, in which each different approach to predict land-use changes presents advantages and disadvantages. Verburg et al. (2004) classified land-use change models according to six characteristics: level of analysis, cross-scale dynamics, driving factors, spatial interactions and neighborhood effects, temporal dynamics and level of integration. These characteristics determines the suitability of each model for a certain application, since they dictate how the model will represent the land-use change process and its underlying principles (van Schrojenstein Lantman et al. 2011).

In a review of continental to global scale land-use models, Heistermann, Müller, and Ronneberger (2006) compared the weakness and strengths between geographic models (focused on spatial patterns and interactions) and economic models (driven by demand-supply structures). They pointed to deficits in the integration between the two approaches, and called for further efforts on the inclusion of interactions between environment and society.

In this context, Schaldach et al. (2011) proposed an integrated land-use model named LandSHIFT, which is able to represent socioeconomic and environmental interactions from continental to global scale. The LandSHIFT model is driven by variables in multiple spatial scales, using environment (terrain, climate and productivity) and socio-economic data (product demand, infrastructure, demography and land-use policies) to predict land-use transitions. The land-use allocation is based on Multi-Criteria Analysis and Multi Objective Land Allocation, which allows the calculation of the suitability of a land-use type to occupy a grid cell, by using variables from different dimensions in a rule-based process.

The LandSHIFT model have already been applied in numerous studies for Brazilian territory, specially in short to mid-term projections of possible scenarios. Lapola et al. (2010) analysed the impact of indirect land-use changes related to the expansion of biofuel crops in Brazil. Göpel et al. (2018) projected different scenarios of development pathways of Southern Amazonia from 2010 to 2030, showing the effects of products demand, land-use policies and intensification of agriculture on emission and fixation of greenhouse gases. Schaldach et al. (2018) used to model to predict the effects of land-use change and climate change over soil organic matter, soil erosion and water balance, they showed how environmental policies and agriculture intensification are key to reduce environmental impacts from land-use change.

3.2.2 Productivity modelling

One of the inputs required in the LandSHIFT model is gridded values of crop yield and grassland productivity, which have the key role of representing the effects of climate, soil, and management practices in productivity, and therefore, in the allocation of land-use by LandSHIFT (Schaldach et al. 2011). Alcamo et al. (2011) discussed the uncertainties of land-use modelling related to the productivity input, which can have significant impact in the final land-use estimates. A wide variety of models have been used to provide productivity information to LandSHIFT, but usually they share some common characteristics, they are process-based models which simulates carbon, water and energy fluxes between surface and atmosphere.

The DayCent model (Parton et al. 1998), is a possible option to provide productivity data as input to LandSHIFT, it simulates carbon and nitrogen fluxes between atmosphere, surface and soil based on air temperature, precipitation, soil characteristics and land-use (Parton et al. 1998; Del Grosso et al. 2009). The plant production is affected by species (genetic potential and phenology) and environment characteristics (nutrients, water availability, temperature, and solar radiation), and is allocated to different plant components above and below ground (Del Grosso et al. 2009; Necpálová et al. 2015).

4 Methodology

In order to achieve the proposed objective, the work will be divided in four major parts:

1. ICLFS management scenario elaboration;
2. Adaptation and application of the modeling framework to ICLFS;
3. Estimate the carbon balance, ecosystem services, and economic evaluation based on outputs from modeling framework;
4. Results consolidation and analysis;

A simplified scheme of the methodology activities and sequence is shown in Figure 1.

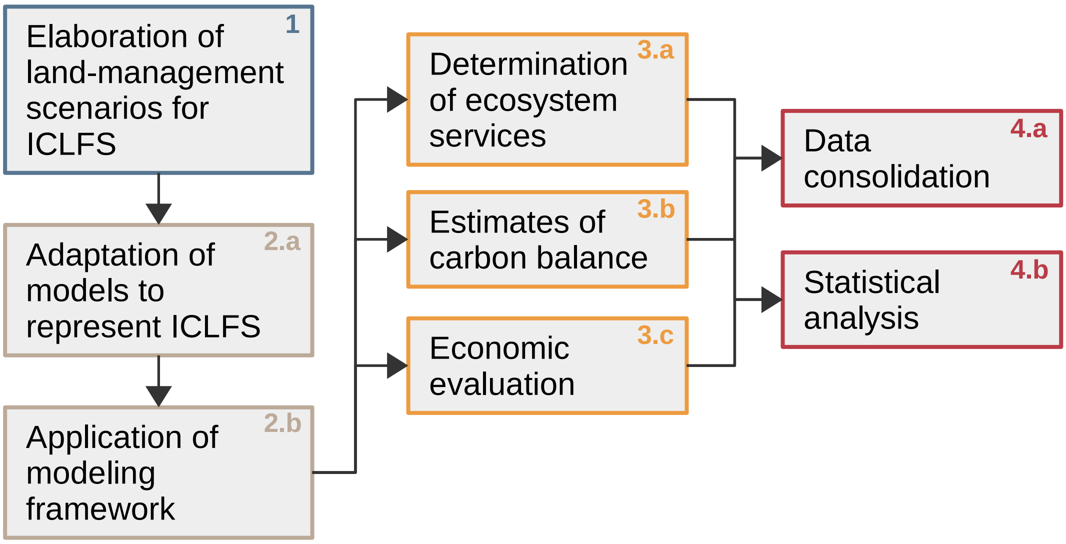


Figure 1: Flowchart of the activities to be performed to accomplish the proposed objectives. The color of box margins represents a different part of the methodology.

4.1 ICLFS management scenario elaboration

The ICLFS management scenarios will be elaborated trough different combinations of production systems, soil management practices, crop types, livestock and forestry species. These scenarios will be characterized according to their costs and complexity of implementation.

The choices to construct each scenario will be based on information provided by literature review and experts evaluations. The literature review will be performed over an exhaustive search for any material (from peer reviewed articles to grey literature and technical documents) with ICLFS as subject, searching for relevant keywords such as "crop-livestock-forestry", "agroforestry" and "integrated cropping systems", in both English and Portuguese language. Different databases will be used in the search, including well known international scientific databases (Google Scholar, Web of Science, AGRICOLA and AGRIS), but as well national institutions repositories (Alice-EMBRAPA). Works performed outside the Brazilian territories may or may not be included in the analysis.

With the literature review information at hand, a initial version of set of scenarios will be elaborated with the most common system managements found in the literature. These scenarios will be then submitted to experts scrutiny, which the plausibility of each one in future projections in Brazil will be evaluated. The most suitable scenarios will then compose the final set of management systems, which will be used in the modelling framework.

The workflow of scenarios elaboration is shown if Figure 2.

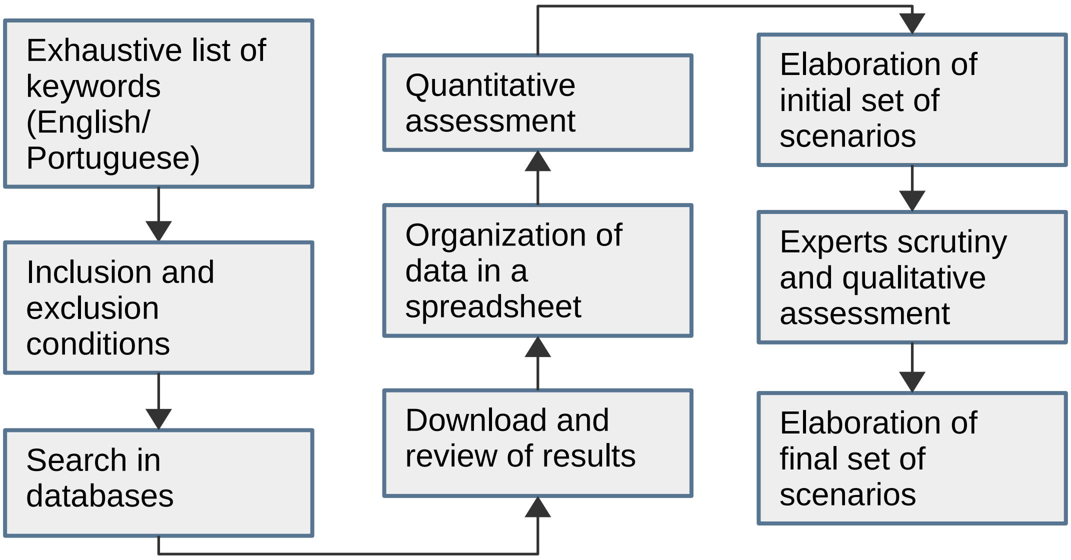


Figure 2: Flowchart of the process to elaborate the ICLFS managament secenarios.

4.2 Adaptation and application of the modeling framework

The modeling framework to be used is comprised of two spatially explicit models: the LandSHIFT land-use change model and the DayCent crop productivity and carbon dynamics model. It will be necessary to adapt both to represent the ICLFS from the scenarios, in order to answer the proposed questions of the study.

The DayCent model will be responsible to generate spatial values of productivity from ICLFS, which will be provided to LandSHIFT as an input for land-use forecast (Figure 3).

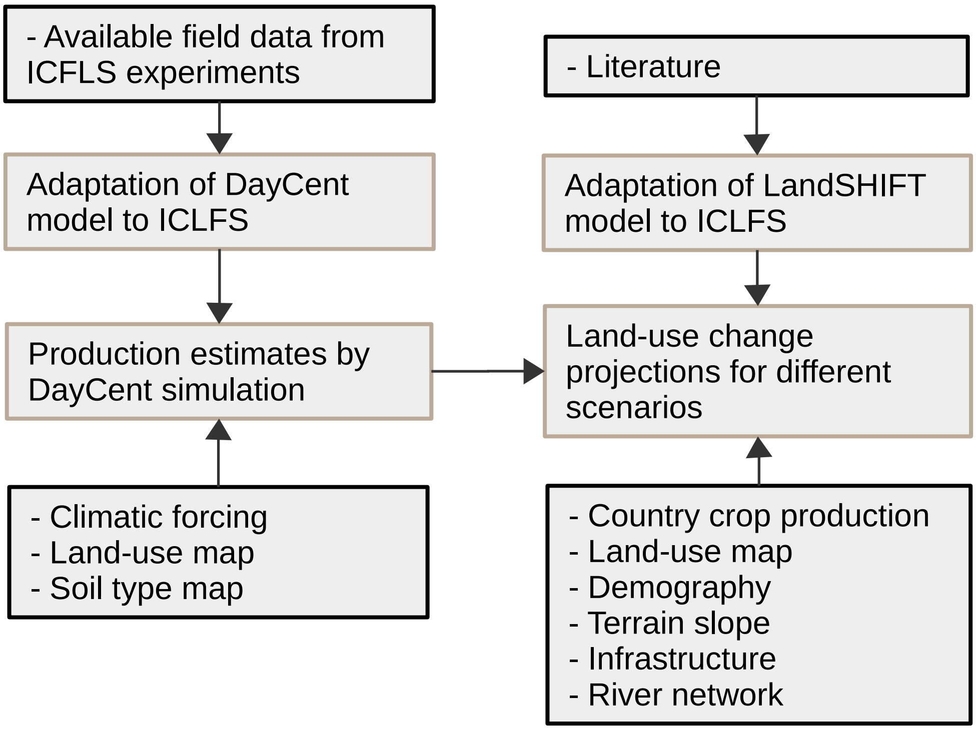


Figure 3: Flow chart of the adaptation and application of the modelling framework. Black margin boxes are the additional data that will be used in the activities of this section.

4.2.1 LandSHIFT

The LandSHIFT model is composed by different modules to address each land-use systems (settlement, crop, grassland). The representation of the ICLFS can be performed by the development of a new module, which will aggregate the processes inside the crop and grasslands modules, with some specific characteristics.

The new module will have to be adapted to take into account forestry productivity, and its cycle, which will demand the use of rules to avoid its transition to other land-use before the end of a forestry production cycle. The transition to ICLFS will also be favoured by specific conditions, such as the presence of old pastures, which can indicate a possible level of degradation.

4.2.2 DayCent

The DayCent model will be calibrated based on field observations from ICLFS experimental areas. It will be also adapted to represent carbon dynamics in areas occupied by multiple species, presenting different production cycles.

The forcing climatic data used to run DayCent will be obtained from an ensemble projection of climatic change derived from the global climatic models of the Coupled Model Intercomparison Project 6 (CMIP6) that will be part of the next IPCC report (Eyring et al. 2016).

4.3 Estimation of carbon balance, ecosystem services, and economic evaluation

The carbon balance, ecosystem services and revenue from ICLFS will be estimated based on the output from the modelling framework.

4.3.1 Carbon balance

The carbon balance will be calculated as the aggregation of net results of carbon uptake and loss by 2030 and 2050. The net production of ICLFS will be partitioned into above and below ground accumulation of biomass.

4.3.2 Ecosystem services

The outputs from LandSHIFT projections and the characteristics for each ICLFS management scenario will provide the input for quantification of ecosystem services. Additional datasets may also be used to estimate other ecosystem services no recognizable through land-use maps. Ecosystem services classification will follow the Common International Classification of Ecosystem Services (CICES; https://cices.eu/).

4.3.3 Economic evaluation

The results from general equilibrium models of the world economy will also be used to provide future demands for agricultural products. This information will be used to quantify the revenue from each ICLFS management scenario.

4.4 Results consolidation and analysis

The last part of the methodology will be composed by the the organization and the storage of the all the resulting data from previous processes, and by the statistical analysis that will support the interpretation of the results to answer the proposed questions.

4.4.1 Data consolidation

The data consolidation will attend to the main objective of the work, in which all the modelling projections, the estimates of carbon balance, ecosystem services and revenue, as also supporting data, will be presented in a systematic way. It will be performed in two stages, the first will be the organization of all the data created throughout the processes described in Figure 1, and the second will be the persistence of the data in a convenient way for accessibility and sharing.

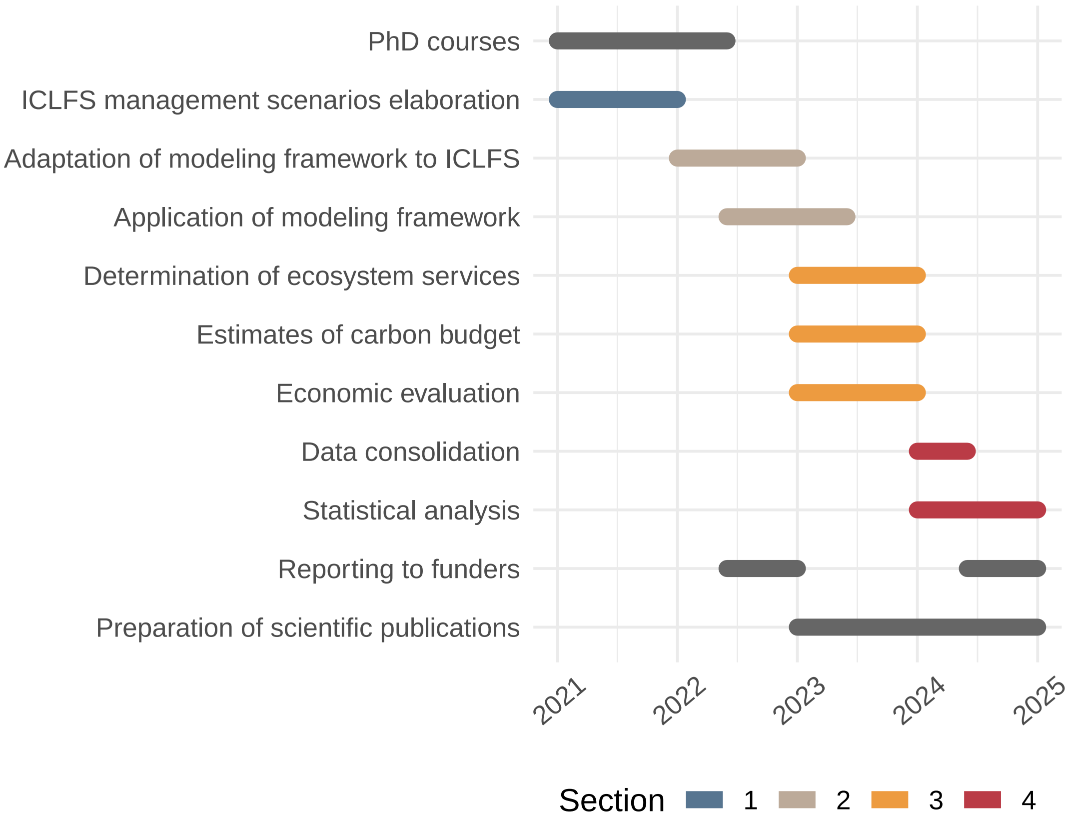
In the first stage, all data will be organized in an integrated way, they can be merged or split when appropriate, will follow naming and units conventions, and will present common indexes between them. The spatial data will be written into a convenient file format (e.g. NetCDF, HDF5, TIFF, or delimited text files) with explicit spatial representation, and may be written as a single file or a set of many files, the choices will depend on the data properties (number of variables and dimensions) and its size. Non spatial data will be written as delimited text files. The data files will be accompanied by their documentation, metadata, licensing information and source code.

In the second stage, data should be stored and made available for public access. The data storage can be performed in a database management system, which can be a relational database or a document database. The accessibility of the data will depend on local structure, and the documentation and source code will be made available trough public repositories (e.g. GitHub, Zenodo).

4.4.2 Statistical analysis

The statistical analysis of the results will be performed to answer the proposed questions. The methodology approach in the analysis will be heavily affected by the design of the scenarios. If each scenario represents the projected extent and production of only one ICLFS production system, than the analysis can rely only in the comparison of aggregated values between scenarios. But in the case that each scenario is a possible projection of the interactions between many ICLFS production systems, than a series of samples can be extracted from the scenarios to make statistical inferences over the differences between these production systems.

5 Schedule



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