MODELLING INTEGRATED CROP-LIVESTOCK SYSTEMS: PRELIMINARY RESULTS FROM AN AGROECOSYSTEM MODEL

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ABSTRACT
Integrated Crop-Livestock Systems (ICLS) are being considered to improve food production sustainability and are of increasing interest to the modelling community worldwide. Our goal was to evaluate the ability of an agroecosystem model simulator (ECOSMOS) to predict plant growth and yield, and water dynamics in an ICLS in the Western region of São Paulo State, Brazil. Four fields of approximately 50 ha each were monitored after the implementation of the ICLS at the end of 2018. Soybean yields (two seasons), mixed-pasture aboveground dry biomass and soil water content (for the pasture only) measurements were contrasted with predictions from ECOSMOS with recently implemented soybean and pasture sub-models. Preliminary results from a generic simulation for the whole farm showed that the model was able to capture fairly well the seasonal variation in growth and water dynamics. Such results suggest that the existing knowledge and modelling approaches embedded in the model are robust. Future steps toward modelling the ICLS will involve to parameterise the model for Brazilian cultivars of the system using data from controlled/manipulative experiments, develop a framework to simulate two plants concomitantly, and then assess its capability to predict environmental variables of interest, such as carbon dynamics.
Key words: Agriculture (Soybean); Pasture; Intensification

INTRODUCTION

Integrated crop-livestock systems (ICLS) have been replacing traditional agricultural and extensive/degraded pastureland areas as an alternative for sustainable food production intensification (BALBINO et al., 2019). Estimates indicate that ICLS is adopted over 9.5 M ha across production lands in Brazil in 2015/2016, representing ~ 83% of the integrated systems (REDE ILPF, 2021). One possible way to predict the performance of such systems, both in terms of productivity and environmental aspects, is by using dynamic simulation models. Agricultural, forestry and pasture process-based models have been used to analyse and simulate the performance of food, energy and fibre production systems worldwide (BOOTE, 2020). However, little is developed in the modelling community for integrated systems that combine different species growing concomitantly.

In this context, we evaluated as a preliminary analysis, the capability of the ecosystem model simulator (ECOSMOS) with recently included soybean and pasture submodules to predict soybean yields, pasture aboveground dry biomass and soil water dynamics in a commercially managed ICLS, recently implemented, in the Western region of São Paulo (SP) State, Brazil.

MATERIAL AND METHODS

1) Study area and measurements descriptions

The study area is a commercial farm with approximately 200 ha located in Caiuá, Western SP (21º38’15” S; 51º54’57” W, 310-380 m). A detailed description of the area and management can be found in Dos Reis et al. (2020), and here we highlight only the main features. The soil texture is predominantly sandy loam with clay contents ranging from 22 to 241 g/kg. Long-term annual averages for rainfall and temperatures (1950-1990) in this region are 1246 mm/year and 22.4 ºC/year, which is characterised as a tropical Aw climate according to Köppen’s climate classification (ALVARES et al., 2013).

The ICLS was implemented in 2018 after an extensively managed pasture (*Urochloa brizantha* cv. Marandu) since Aug. 2007. The area was then split into four fields of approximately 50 ha each, and soybean (*Glycine max*) was sown (cultivars BRS 7380 RR, AS 3730 IPRO, and NS 6700 IPRO) under no-till between 17th-23th November. Harvest took place between 28th March and 6th April 2019. After the first soybean harvest, the area was split into 13 paddocks, and a mixed-pasture of millet (*Pennisetum americanum*) and ruzigrass (*Urochloa ruziziensis*) was established to feed farm animals (primarily cattle), in a rotational management operation, until ~ 16th November 2019. Animals grazed on two occasions, from May to June and from August to October. The remaining pasture was then mowed and desiccated for the second soybean season. Between 7th-10th December 2019 the same three cultivars previously mentioned were sown under no-till and harvested last from 29th Mar to 5th April 2020.

Commercial soybean grain yields were measured at harvest (at 13% moisture). Point-based measurements of yields in the first soybean season were taken (100 points), while the data from a harvesting machine with a yield monitor embedded were used for the second season. Point-based measurements of aboveground (dry) biomass were taken on six occasions in the mixed pasture (100 points; roughly monthly). An automatic weather station (METOS®, Pullman, USA) was installed on 17th June 2019 in the area. Climate variables prior to this date and eventual gaps on records were filled with a nearby station (~ 21 km). On that same day, 20 locally calibrated soil water sensors (Teros 10 model; logger EM 5b; METER®) were distributed in the pasture area and installed at 20 cm depth in the soil to measured volumetric soil water content til before sowing the second soybean season. These collected data were then benchmarked with the ECOSMOS predictions after proper configuration of the system in the model, as described in the next section.

2) Modelling

ECOSMOS is a biophysical model that relies on the Agro-IBIS model (FOLEY et al., 1996; KUCHARIK; BRYE, 2003). Researchers from EMBRAPA (Brazilian Agricultural Research Company) have been improving the original model and implementing the most important cultivated plant species in Brazil. The model solves biophysical processes, such as photosynthesis, energy balance, and soil-related processes dynamics. The CROPGRO (BOOTE et al., 1998) and CROPGRO-Perennial Forage (PFM; RYMPH et al., 2004) models were brought from the DSSAT (HOOGENBOOM et al., 2019) and implemented (code rewriting) in the ECOSMOS framework. The previously mentioned biophysical processes (the core of the land surface module) were kept as in the ECOSMOS, and the soybean and pastures now develop and grow following the modelling approaches of CROPGRO and CROPGRO-PFM. Nitrogen deficiency is not allowed yet as in DSSAT, although the biogeochemical model in ECOSMOS simulates such nutrient dynamics. We lack at the moment of nitrogen-related data for a proper evaluation.

Soil properties for generic sandy loam type from Agro-IBIS database were used at this stage. The CROPGROs are well-known and have some cultivar calibrations for Brazilian soybean (BATTISTI; SENTELHAS; BOOTE, 2017) and single pasture experiments (BOSI et al., 2020; PEQUENO; PEDREIRA; BOOTE, 2014), which can be leveraged until we have a fully parameterised model for the cultivars in the ICLS we simulated. Genotype coefficients from Pequeno et al. (2014) for the pasture and from CROPGRO for soybeans representing the generic maturity group 7 were employed.

Simulations were performed for the whole area in this study. Soybean sowing dates in both seasons considered were set as the earliest among the four fields. Implementation of the mixed pasture was set on the posterior day of the latest harvest date in 2019. Simulations for the mixed pasture comprised only the single plant of CROPGRO-PFM. Grazing was mimicked by using the 'mowing' approach as used currently in the DSSAT. It is worth mentioning that the model does not take into account pests and nutrients deficiencies (apart from nitrogen, to be evaluated in future).

The evaluation at this stage was made by visually analysing the time-series graph for predicted and measured dry yields at harvest (soybeans) and aboveground biomass (mixed pasture), and soil water measurements built with the *ggplot2* (WICKHAM, 2016) package in the *R* environment (R CORE TEAM, 2018).

RESULTS AND DISCUSSIONS

Daily meteorological conditions throughout the period monitored and modelled is presented in Figure 1A. Accumulated precipitation in the soybean cycle in 2018-2019 was 642.1 mm, and averages of maximum and minimum air temperatures were 33.2 ºC and 21.6 ºC, respectively. For the pasture phase, accumulated precipitation reached 504.8 mm with temperatures averages of 31.5 ºC and 17.9 ºC for maximum and minimum values recorded. In the second soybean season, total precipitation was 438.8 mm, and the averages of maximum and minimum air temperatures were 33.5 ºC and 21.1 ºC, respectively.

The simulation for the ICLS in Western SP reproduced fairly well the crop yields and pasture growth, given that practically any parameterisation at this stage was done (Figure 1BC). It suggests that the existing knowledge and modelling approaches embedded in the ECOSMOS and plant models CROPGRO and CROPGRO-PFM are robust. Despite the reasonable performance, there are a few points of parameterisation that needs to be addressed, such as soybean phenology and grazing management (Figure 1B). Because the soybean fields were not monitored frequently, phenology may not be accurately simulated. Matching cycle length by manipulating genotype parameters for each soybean cultivar at least will be necessary. The mowing events to represent grazing perhaps will need to be replaced for another modelling approach that takes into account the grazing intensity imposed by the number, type and living weight of the animals to some extent. The slow pasture regrowth, now predominated by ruzigrass, predicted by the model (see the last measurement in Figure 1B) after the second grazing during springer also deserves attention. Such behaviour may be related to excessive grazing imposed by us, an excessive water stress penalisation in winter by the model, and/or the different ability of the ruzigrass to respond to the environment not captured by the genotype traits adopted.

Simulations accounted quite well for the variations in the soil water content at 20 cm (Figure 1C), considering the standard deviation from the mean values. It is expected that the simulations for each paddock with their respective soil properties as well as calibrated genotype parameters and specific grazing events will give more confidence to the modelling; nevertheless, there are a few steps before fully modelling the ICLS.

Future steps toward modelling of integrated systems will involve first to parameterise and evaluate the model for each species (crops and pastures) with fluxes in the agroecosystem (CO_2, energy and water), phenology and biometric data from manipulative and/or controlled experiments in diverse agricultural production systems. Another plant model is under implementation for maize, millet and sorghum in single production systems. Then we will develop and test a framework based on the existing approach of the ECOSMOS to simulate intercropping and mixed systems (two species competing for resources such as light and water). The simulations will be paddock-specific at this stage for the ICLS that was monitored for this study. We will parameterise and evaluate a grazing modelling approach and the biogeochemical submodule to predict carbon dynamics in such an integrated system.

A mixed pasture system was implemented after the soybean harvest in 2020, but monitoring was paralysed in most of 2020 when restrictions due to COVID-19 pandemic were imposed. Measurements have been resumed following the farm, local and state guidelines in 2021, and further data will be used to evaluate the modelling performance of the ECOSMOS.

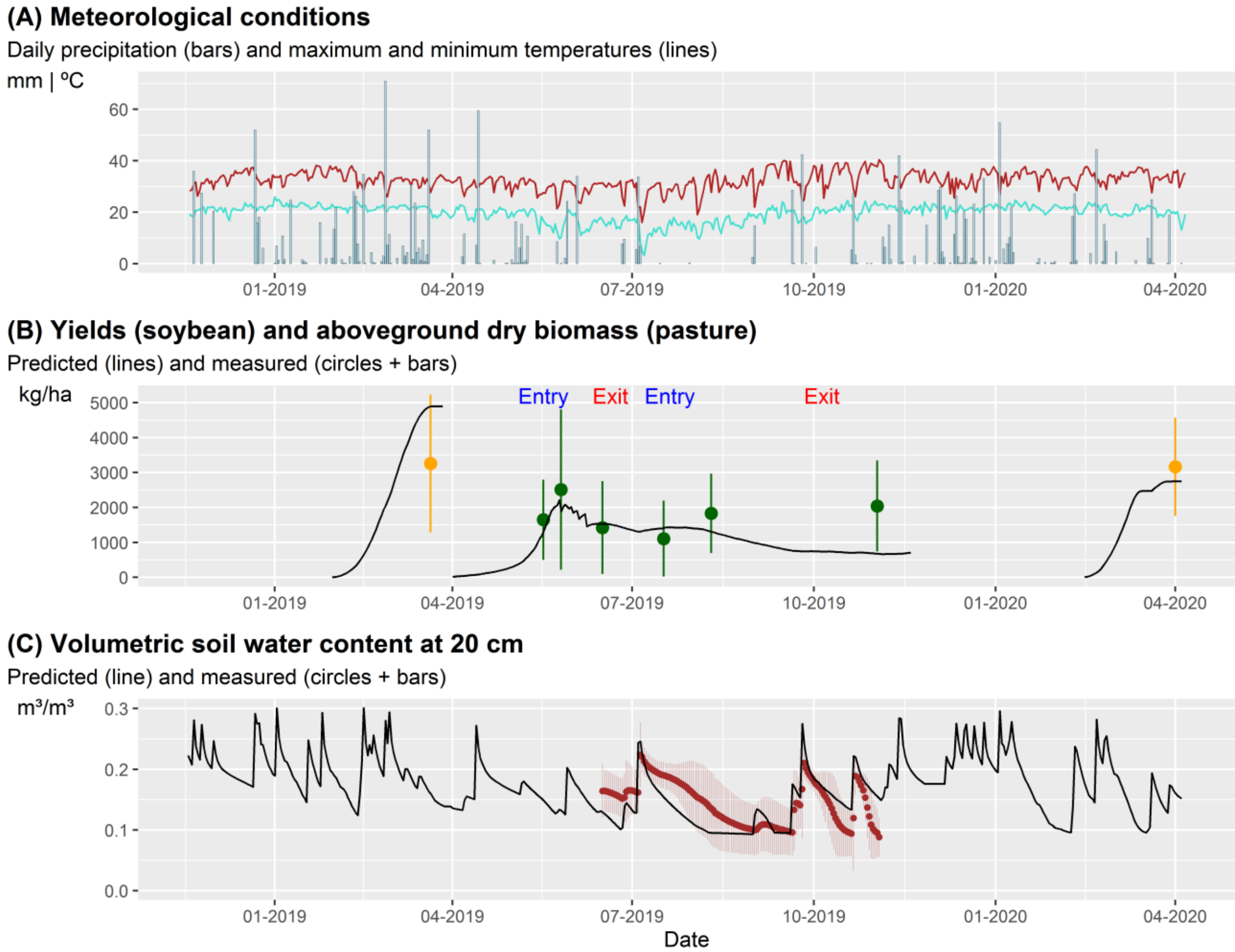

Figure 1. Meteorological conditions and the simulation by the ECOSMOS model for the ICLS in Western SP, Brazil, between November 2018 and April 2020. A) Daily precipitation and maximum and minimum air temperatures throughout the monitored period. B) Predicted (line) and measured yields at harvest for soybean seasons (orange circles plus bars; 2018/2019 and 2019/2020) and aboveground dry biomass for the mixed-pasture of millet and ruzigrass (dark green circles plus bars; 2019). Harvest soybeans at 13% moisture. Grazing intervals (earliest entries and latest exits) are also indicated. C) Soil water content at 20 cm measured (red points plus bars) and predicted (line) for the pasture phase. Bars represent the standard deviation from the mean values.

CONCLUSIONS

The preliminary simulation indicated that the ECOSMOS model reproduced reasonably well the aboveground biomass of a mixed-pasture and yields of two soybean seasons, as well as the soil water content (during the pasture phase) of an ICLS in the environmental conditions of Western SP, Brazil.

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