Short Term Scientific Mission (STSM) on "Calibration of Yield-SAFE model and analysis of the competition algorithms under multiple harvesting practices in pastures"

COST Action FP1203: European Non-Wood Forest Products (NWFPs) Network

Dates of the mission: 01/05/2015 to 31/05/2015

Fellow: Nuria Ferreiro Domínguez

Sending organization and supervisor: University of Santiago de Compostela, Maria Rosa Mosquera-Losada

Host organization and supervisor: Forest Research Centre, School of Agriculture, University of Lisbon, João HN Palma

1. Purpose of the STSM

The establishment of agroforestry systems is a practice common around the world, being the silvopastoral systems the oldest agroforestry system used in the temperate regions, which are characterized by integrating trees with forage and livestock production (Mosquera-Losada et al. 2009). During the last decade, the establishment of agroforestry systems has been actively promoted in EU (Council Regulation 1305/2013 (EU 2013), mainly because these systems diversify and sustain production with increased social, economic and environmental benefits for land users at several levels compared with exclusively agricultural systems (Nair et al. 2010). Moreover, the reform of the EU's Common Agricultural Policy (CAP), has also created renewed interest in agroforestry and silvopastoral systems.

The benefits of agroforestry systems are highly difficult to predict due to the interaction of many factors. Furthermore, research through field experiments is expensive and time consuming when tree and crop measurements have to be taken into account (Poulton 1995, Palma et al. 2007). One option to determine the benefits of agroforestry systems could be the use of models like Yield-SAFE that provides a method for overcoming these drawbacks (van der Werf 2007). The Yield-SAFE model is available for different tree species and crops (Palma et al. 2007). However, the Yield-SAFE model was not yet ready to work with data of pasture production and stocking rate, mainly due to the data from long-term experiments are scarce.

The research group of “Silvopastoral Systems” of the University of Santiago de Compostela (Spain) in which the candidate is involved since 2008 follows a line of research in this context with a large number of experiments established in different conditions of soil fertility and with different forest species, being some of these studies established 19 years ago. Within the Short Term Scientific Mission (STSM), the candidate was integrated in a group of the Forest Research Centre (University of Lisbon, Portugal) with a wide experience in the development and implementation of forest and agroforestry models, a field where the candidate started to work the last year through the 1st call for STSM. The STSM allowed the candidate to continue with the same research line thereby increasing the European knowledge about modelling in agroforestry systems.

The general objective of the STSM was the calibration of the Yield-SAFE model and analysis the competition algorithms under multiple harvesting practices in pastures to initiate the assessment of the potential environmental and economic benefits of the silvopastoral systems.

2. Description of the work carried out during the STSM

2.1. Experimental plots and field samplings

During the STSM, the parameter calibration of the Yield-SAFE model was performed with pasture data from a plot established in Lugo (Galicia, NW Spain, European Atlantic Biogeographic Region) at an altitude of 452 m above sea level. The experiment was conducted in a soil with a pH in water of 6.5 and a low percentage of organic matter (2.63%). The field experiment was located in the Atlantic Biogeografic region where the climate is influenced by Atlantic climatic patterns, with long cool moist winters and warm dry summers. Soil moisture becoming limiting in late summer (EEA 2006).

The study was initiated in 1997 when land ploughing was carried out and the experimental plots were established. The experimental design was a randomised block with twenty two treatments and four replicas (8 m^2 per replicate). We selected one of twenty two treatments consisted of sowing with a mixture of *Dactylis glomerata* L. var. Artabro (25 kg ha^{-1}) and *Trifolium repens* L. var. Huia (3 kg ha^{-1}) without fertilisation. This treatment was selected due to the high proportion of *Dactylis glomerata* L. in the botanic composition of the pasture (above 80% in some harvests) because the Yield-SAFE model is not yet prepared to work with a multispecific pasture composition with different light and humidity requirements.

For parameter calibration of Yield-SAFE model, pasture production was determined in each plot from 1999 to 2006. The pasture was harvested using a hand harvester in May, June, July and December, as is traditional for the area, when the pastures reached about 20 cm. Fresh pasture was weighed in situ and a representative subsample was taken to the laboratory. Once in the laboratory, the subsamples (100 g each) were dried (72 hours at 60ºC) and weighed to estimate dry matter production. Annual pasture production was calculated by summing the consecutive harvests of the pasture production in that year. From the annual pasture production we estimated the carrying capacity that the system would be able to support through the following equation:

$$CC_p = (PP) / (G_p \; x \; C_p)$$

Where: CC_p is the carrying capacity or number of animals per hectare feeded by the produced pasture on a hectare basis (sheep ha^{-1}), *PP* is the annual pasture production (kg DM ha^{-1}), G_p was the duration of grazing period (365 days per year) and *Cp* is the consumption of sheep quantified at 1.74 kg DM $sheep^{-1}$ day^{-1} (Zea-Salgueiro 1991).

On the other hand, during the STSM, we also tried to calibrate the Yield-SAFE model to the carbon accumulated in the soil with data from a silvopastoral system established in Castro Riberas de Lea (Lugo, Galicia, NW Spain, European Atlantic Biogeographic Region) at an altitude of 439 m above sea level. The experiment was conducted in a soil classified as Gleyic Umbrisols (FAO classification) and Inceptisols (USDA system), with a sandy-loam texture (61.14% sand, 33.79% silt and 5.07% clay), with an increase in clay below 50 cm; organic horizons reaching down to 40 cm; and acidic with no accumulations of inorganic carbon (Fernández-Núñez 2007). As it was described in the previous study, the field experiment was also located in the Atlantic Biogeografic region.

The experiment was initiated in 1995 when land ploughing was carried out and the experimental plots were established. The experimental design was a randomised block with twelve treatments and three replicas. We selected one of twelve treatments consisted of the evaluation of *Pinus radiata* D. Don (transplanted in soil from paper pots) that was established at a density of 833 trees ha^{-1}, with a planting distance of 3m×4m and an area of 192 m^2 per replicate. In each experimental unit, 25 trees were planted with an arrangement 5×5 stems. After plantation, the plots were sown with a mixture of *Dactylis glomerata* L. var. Saborto (25 kg ha^{-1}), *Trifolium repens* L. var. Ladino (4 kg ha^{-1}) and *Trifolium pratense* L. var. Marino (1 kg ha^{-1}). Fertiliser was not applied to replicate traditional reforestation practices for agricultural land in this area. A low pruning was performed on *Pinus radiata* D. Don at the end of 2001.

For parameter calibration of Yield-SAFE model, a composite soil sample per plot was randomly taken using a drill at a sampling depth of 25 cm, where the most organic matter accumulates, every December from 1995 to 2013, with the exception of 1996, 1999 and 2000 when soil samples were not collected. Once the samples were collected, they were taken to the laboratory, air dried and sieved through a 2mm screen. After this preparation, we determined the total C in the soil using the Saverlandt method (Guitián-Ojea and Carballás-Fernández 1976).

2.2. Yield-SAFE calibration

The initial estimation of the model parameters was based on an extensive literature review and on existing data sets with pasture and soil measurements. Climate data (daily maximum and minimum temperature and daily precipitation) were taken from a nearby weather station to the study area. In the case of the radiation and the relative humidity, the data were estimated through the CliPick tool (Palma 2014) due to the lack of data in the nearby weather stations to the study area.

The parameter calibration of the Yield-SAFE model and the graphic interpretation of the results was made with an MS Excel© implementation of the model (Graves et al. 2010).

In the case of the carbon accumulated in the soil, the calibration of the Yield-SAFE model was carried out according the RothC model which has been widely used in soil science (Ludwig et al 2011). The RothC model includes the following pools: decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO), humified organic matter (HUM) and inert organic matter (IOM) to calculate the carbon dynamics in the long-term treatments. The decay of the pools DPM, RPM, BIO and HUM follows first-order kinetics and the decomposition rate constants (year^{-1}) are set to 10.0 (DPM), 0.3 (RPM), 0.66 (BIO) and 0.02 (HUM) as suggested by Coleman and Jenkinson (1999). However, in our case, to get a good calibration of the Yield-SAFE model, these constants were modified following the recommendations established by Shirato (2010). The values established to the decomposition rate constants were 1 (DPM), 0.06 (RPM), 0.132 (BIO) and 0.004 (HUM).

3. Description of the main results obtained

As mentioned previously, *Dactylis glomerata* L. was the dominant specie in the botanic composition of the pasture. Therefore, the pasture parameters resulting from the calibration process are for this herbaceous specie (Table 1). In all cases, the parameters were found in literature review or derived from existing data measurements, confirming the ease of usage of the Yield-SAFE model.

Table 1: Pasture parameters (*Dactylis glomerata* L.) used in the Yield-SAFE model.

Bio-Parameters		Description	Value
Management	T_o	Temperature threshold (ºC)	5
	Tsumemerge	Temperature sum to emergence (ºCd)	0
	TsumR	Temperature sum at which partitioning starts to decline (ºCd)	1000
	TsumRE	Temperature sum at which partitioning to leaves=0 (ºCd)	1100
	Tsumharvest	Temperature sum to harvest (ºCd)	1000000
Initial conditions	$(Bc)_0$	Initial Biomass (g)	10
	LA	Initial leaf area (m^2 m^{-2})	0.18
	$(p_l)_0$	Partition to the leaves at emergence	0.8
Parameters	epsc	Potential growth (g MJ^{-1})	2
	gammac	Water needed to produce 1 g of crop biomass (m3 g^{-1})	0.0003
	$HIcrop_1$	Harvest index (g g^{-1})	0.9
	$HIcrop_2$	Harvest index (g g^{-1})	0.1
	k_c	Radiation Extinction Coefficient	0.7
	$(pF_{crit})_c$	Critical pF value for crop (log(cm))	3.2
	PWP_c	Permanent Wilting Point for Crop (log(cm))	4.2
	$Thetacrop_1$	Moisture content of the crop (wet basis)	0
	$Thetacrop_2$	Moisture content of the crop (wet basis)	0
	SLA	Specific Leaf Area (m^2 g^{-1})	0.0015

Figure 1 shows that in the most harvests the Yield-SAFE calibration procedure was successfully performed for pasture production (*Dactylis glomerata* L.) and it allows us to predict pasture response to different situations. The Yield-SAFE model has been also successfully calibrated for other crops as wheat, oats or oilseed rape established in different conditions in Europe (Graves et al. 2010). However, in some harvests the

Yield-SAFE model did not estimate adequately the pasture yields probably due to the increase of the proportion of other spontaneous species in these harvests with different light and humidity requirements than *Dactylis glomerata* L. Therefore, the adaptation of model structure for multiple arable component species is needed to improve estimations.

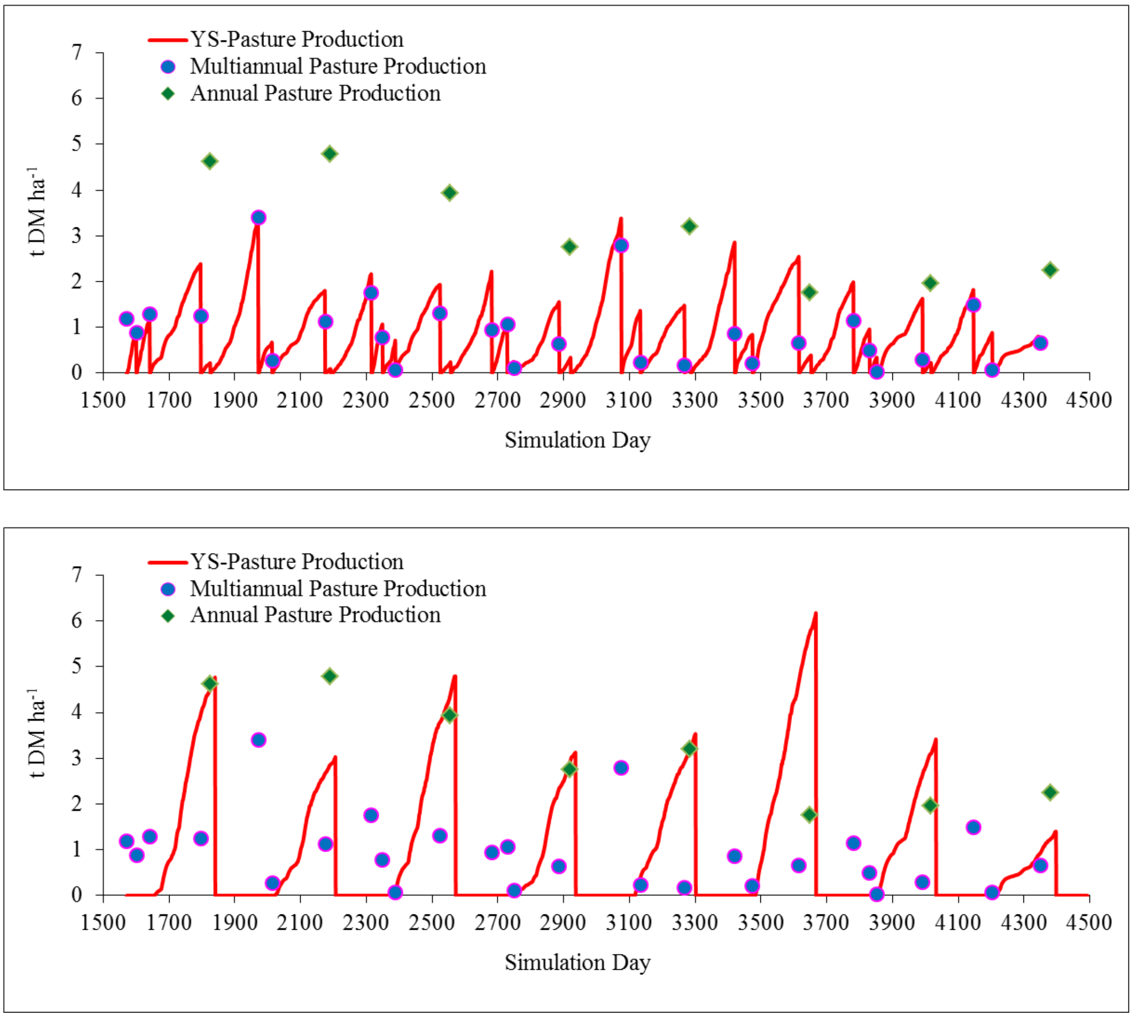

Figure 1: Calibration results of Yield-SAFE model for pasture production (*Dactylis glomerata* L.).

On the other hand, the carrying capacity parameters resulting from the Yield–SAFE model calibration process are presented in Table 2.

Table 2: Carrying capacity parameters used in the Yield-SAFE model.

Bio-Parameters	Description	Value
LU	Livestock units	0.1
LUER	Livestock unit energy requirement (MJ LU^{-1} $year^{-1}$)	37668
SLER	Selected Livestock Energy requirement (MJ LU^{-1} day^{-1})	20.88
SReq	Shade Requirements (m^2 LU^{-1})	0.325
Hts	Height Threshold for Shade (m)	2
LUERshaderatio	Max Proportion of LUER needed under shade (ratio)	0.9
Luw	LU weight (kg)	50

The Yield-SAFE model was adequately calibrated for the carrying capacity (Figure 2) yielding similar carrying capacities than those reported in Zea-Salgueiro (1991). This result is very important because it allows us to establish management techniques in agricultural and silvopastoral systems to maintain an adequate carrying capacity. In general, in the silvopastoral systems, the carrying capacity decreases over time due to the effect of the tree on the pasture production (Rigueiro-Rodríguez et al. 2012).

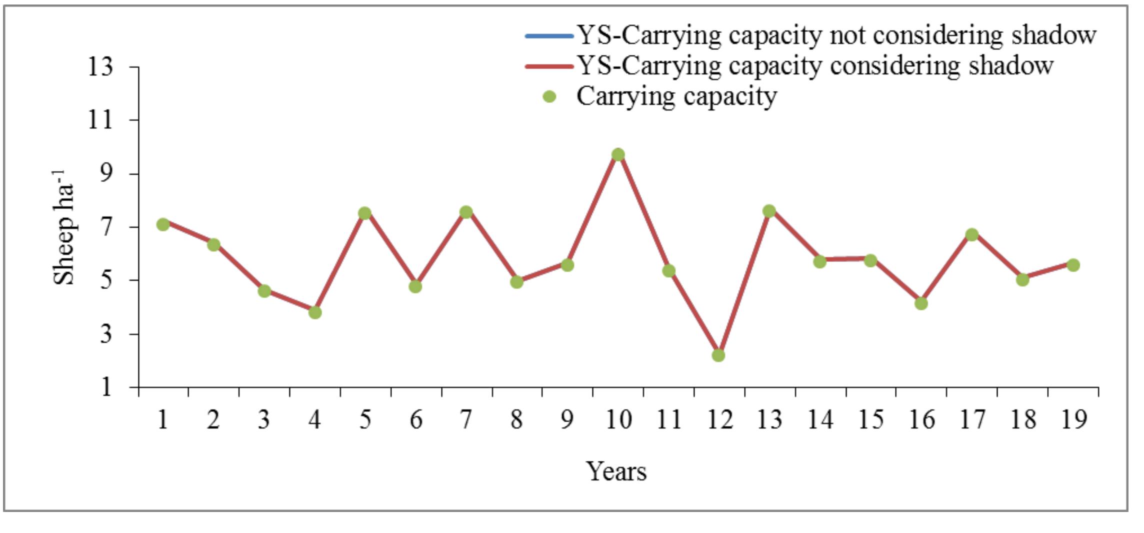

Figure 2: Calibration results of Yield-SAFE model for carrying capacity.

Finally, despite the decomposition rate constants were modified, the RothC model implemented in Yield-SAFE did not properly reacted to the carbon fluctuations accumulated in the soil (Figure 3). Probably, it would be necessary introduce new parameters in the model as the soil temperature and its variation with the tree canopy to improve estimations. In general soil temperature is one of the most important environmental factors known to affect the biological activity of soils (Pietikäinen et al. 2005) and therefore to the accumulation of carbon in the soil. We will probably continue calibrating the model for the carbon accumulated in the soil.

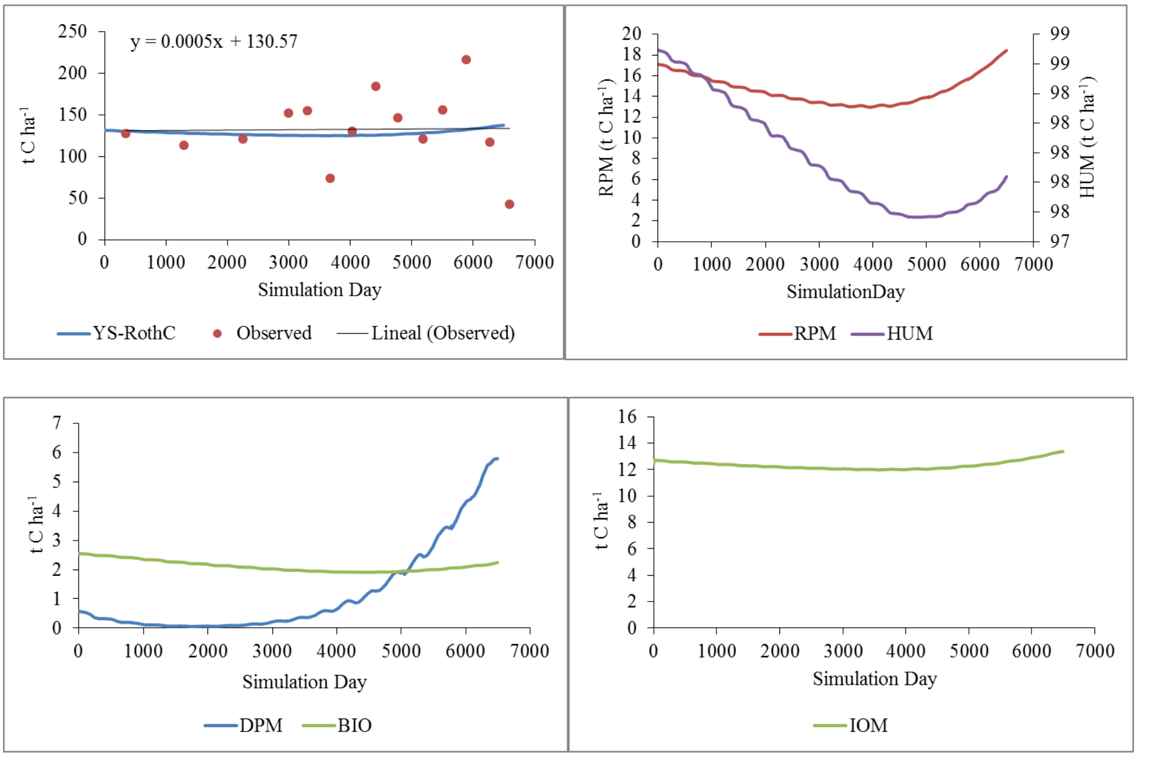

Figure 3: Calibration results of Yield-SAFE model for carbon accumulated in the soil. RPM: resistant plant material; HUM: humified organic matter; DPM: decomposable plant material; BIO: microbial biomass; IOM: inert organic matter.

4. Future collaboration with host institution

The STSM allowed the connection of both research institutions, University of Santiago de Compostela and University of Lisbon, as well as increase the European knowledge about modelling in agroforestry systems. In the future, the collaboration between these two Institutions will continue through the already funded European project "AGFORWARD" in which both Institutions are involved. The link with the European project "AGFORWARD" will allow us to continue with the research in this field.

5. Foreseen publications/articles resulting or to result from the STSM

The results from the STSM could be published in highly relevant journals due to the knowledge about modelling in agroforestry systems is scarce. A first paper could include the Yield-SAFE calibration procedure and in a second paper could be published the results obtained when Yield-SAFE model is used to predict tree and pasture response to different situations, mainly related with climate change.

6. Confirmation by the host institution of the successful execution of the STSM

A confirmation letter is attached to this report as Annex I.

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Annex I

INSTITUTO SUPERIOR DE AGRONOMIA
Universidade de Lisboa
Hinc Patriam Sustinet

Lisbon, 1st June 2015

To the STSM Coordinator of the COST FP1203,

I hereby confirm the successful execution of the STSM granted to Dr. Nuria Ferreiro-Domínguez from Universidad de Santiago de Compostela (Spain) to Instituto Superior de Agronomia, Universidade de Lisboa (Portugal) which was carried out from 1st May to 31st May 2015. Dr. Nuria Ferreiro-Domínguez provided well prepared data and showed a great interest in calibrating the YieldSAFE model, resulting in interesting and new scientific results.

I will certainly embrace Dra. Nuria Ferreiro-Domínguez for future collaborations, which are envisaged under the context of the current EU project AGFORWARD (www.agforward.eu).

Yours sincerely

Dr. João HN Palma