USING THE YIELD-SAFE MODEL TO ASSESS HYPOTHETICAL EUCALYPTUS SILVOPASTORAL SYSTEMS IN PORTUGAL

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Introduction

In the last Portuguese forest inventory, *Eucalyptus globulus* Labill became the species with the largest forest area. This species now occupies 812,000 ha in Portugal (ICNF 2013) and despite the area increase in recent years, it is anticipated that demand will increase in the next 30 years at an annual rate of 1.6% (AIFF 2013).
During 2014, the AGFORWARD project, sponsored by the European Union, supported about 40 stakeholders meetings on agroforestry across Europe. In one of the Portuguese meetings organized in Coruche (Cork production hotspot region in Portugal), stakeholders asked about eucalyptus agroforestry solutions. In Portugal, agroforestry with eucalyptus is not practiced but the system is promoted in South America where silvopastoral systems with eucalyptus combine pulpwood and forage production on the same area of land (Souza et al. 2000; Paula et al. 2013).
The future demand scenarios of pulpwood may suggest the possibility for considering this species within an agroforestry system, e.g. an alley cropping design. Currently, eucalyptus has an interesting economic return and these systems could be up taken by farmers, even without institutional financial support.
Taking advantage of process-based modelling tools, this paper investigates the anticipated yields under a hypothetical eucalyptus agroforestry system, with and without irrigation.

Material and Methods

The Yield-SAFE model (van der Werf et al. 2007), a process based modelling concept for agroforestry systems, was calibrated for eucalyptus, a ryegrass pasture, and used to determine the potential yields of hypothetical eucalyptus agroforestry systems, comparing scenarios of a) grassland (G), b) G+52 trees ha^{-1} (T), c) G+203 trees ha^{-1},and d) G+1000 trees ha^{-1}, in a location near Coruche (approx. Lat: 38.94°N, Lon:8.61°W). The projections were made considering two water scenarios: 1) irrigated (no water limitation) and 2) rain-fed.
For the calibration and simulation we used artificial climate retrieved from the CliPick tool (Palma 2015) for the locations of the tree measurements and near Coruche.
The tree calibration was made with data from experimental plots where eucalyptus trees were irrigated. Ryegrass was calibrated considering farmer potential yield references (7.5 Mg ha^{-1}) and, for comparison purposes, data from natural grassland from Moreno and Cáceres (2016).
The crop component module in Yield-SAFE needed to integrate a maintenance respiration cost to allow the reduction of biomass during the year. The integration was made using the equation proposed by Thornley (1970):

$$R_k = mW_{k-1} + g\delta Wact_{k-1}$$

While the equation of the daily actual growth in YieldSAFE was updated to consider this cost:

$$\delta Wact_k = f^{Wred} * \delta Wpot_k - R_k$$

Where R_k is the maintenance respiration (g m^{-2}) in day *k*, *m* is the maintenance coefficient representing the amount of carbon respired to maintain existing biomass (g g^{-1} d^{-1}), *g* is the amount of carbon respired per unit of carbon used in growth (g g^{-1}), *W* is the biomass of the crop (g m^{-2}),$\delta Wact$ is the actual biomass growth (g m^{-2} d^{-1}), f^{Wred} is the modifier for water reduced growth (ratio) and $\delta Wpot$ is the potential growth (g m^{-2} d^{-1}). Values of m = 0.037 g g^{-1} d^{-1} and g = 0.54 g g^{-1} were used as suggested by Reekie and Redmann (1987).
For the estimation of carrying capacity we considered 13765 MJ Mg^{-1} of metabolizable energy in ryegrass as suggested by Milford and Minson (1965) with a livestock unit needing a yearly value of 37668 MJ (Hodgson 1990).

To evaluate the efficiency of resource use, the land equivalent ratio (LER) was calculated as:

$$LER = \frac{crop\ biomass\ in\ agroforestry}{crop\ biomass\ monocropping} + \frac{stand\ biomass\ in\ agroforestry}{stand\ biomass\ in\ forestry}$$

Results and discussion

The tree calibration result was obtained using parameter values present in the literature, matching the observed values of the potential yield experiment. The model was able to capture the yield range variability by assuming climate and soil characteristics from two measurement areas (**Figure 1 –** top). The parameter set used for the ryegrass allowed the simulation of the yields indicated from farmer knowledge and literature.

The model was able to incorporate the maintenance respiration in the crop component. Not only was the model able to predict the ryegrass yield but also the characteristic fluctuations of grassland biomass throughout the year (Figure 1 – top right).

These first simulation results suggest that using irrigation on a design similar to a forest might increase growth up to 6 times (from about 100 kg tree^{-1} to 600 kg tree^{-1} at 12 years). This yield seems even higher than the yield obtained after 10 years in the potential calibration site (about 450 kg tree^{-1}). However, the average yearly radiation (not shown) received in Coruche (5401 MJ m^{-2}) was greater than that (4899 MJ m^{-2}) in the experimental plot and this could explain the higher yields in the Coruche simulation.

Moving further into unknown ground, the model estimates a tree size of about 1200 kg in an agroforestry system with a density of 52 trees ha^{-1}, which is twice the size of the trees in the density of 1000 trees ha^{-1}. Although a two-fold increase seems high, relations of this magnitude have been previously found in other temperate agroforestry systems (Balandier and Dupraz 1999; Cabanettes et al. 1999) and in other Eucalyptus species density trials, even at earlier ages (Cockerham 2004; Stape and Binkley 2010).

This relationship suggests that with 203 trees ha^{-1} under irrigation, the stand volume after 10 years could be about 400 m^3 ha^{-1}. The equivalent volume at a stand density of 1000 irrigated trees ha^{-1} would be 1000 m^3 ha^{-1} after 10 years. The model also suggests that with about 200 trees ha^{-1}, the grass yield under the trees is still higher than the yield of a rain-fed grass without trees.

Under a rain-fed system, with 203 trees ha^{-1}, the model predicts about 60% grass yield reduction at the end of the 10 year rotation. Graves et al. (2010) predicted a 40% reduction in crop yield after 10 years but for a density of 113 poplar trees ha^{-1}. With 50 trees ha^{-1}, the farmer could have about 20% reduction while harvesting about 50 m^3 ha^{-1} of wood after 10 years.

The carrying capacity of the grassland (not shown) without trees yielded an average of 2.7 LU ha^{-1} and 1.0 LU ha^{-1} for irrigated and rain-fed systems respectively. After 10 years, the systems with 52, 203 and 1000 trees ha^{-1}, had a carrying capacity of 2.4, 1.7 and 0.4 LU ha^{-1} for irrigated systems, while the rain-fed systems had a carrying capacity of 0.8, 0.5, and 0.1 LU ha^{-1} for the three tree densities. The carrying capacity in the Mediterranean grassland ranges between between 0.15 and 0.74 LU ha^{-1} (Reis et al. 2014). Therefore the model suggests that although the yields of rain-fed ryegrass under a forest system may be low, the agroforestry systems with 52 and 203 trees ha^{-1} could maintain a carrying capacity similar to natural Mediterranean grassland. Furthermore it is noticed in the simulation that irrigated systems not only increase the grass yield, but also increase the duration of grass production (Figure 1 – top right), which is important in livestock management. Although it is known that higher water availability can lead to longer growing seasons, the model can be used to explore the effect of trees on radiation interception, temperature, wind speed and evapotranspiration (see Palma et al. in this book of abstracts).

In terms of resource use efficiency, the predicted land equivalent ratios (not shown) were 1.2 and 1.1 for the rain-fed systems with 203 and 52 trees ha^{-1} respectively and 1.1 and 1.0 for the corresponding irrigated systems. Although these ratios are not as high as other agroforestry systems, there is a tendency to have higher efficiency in water limited systems, where lower soil evaporation due to the presence of trees might play an important role in water balance and availability to plants.

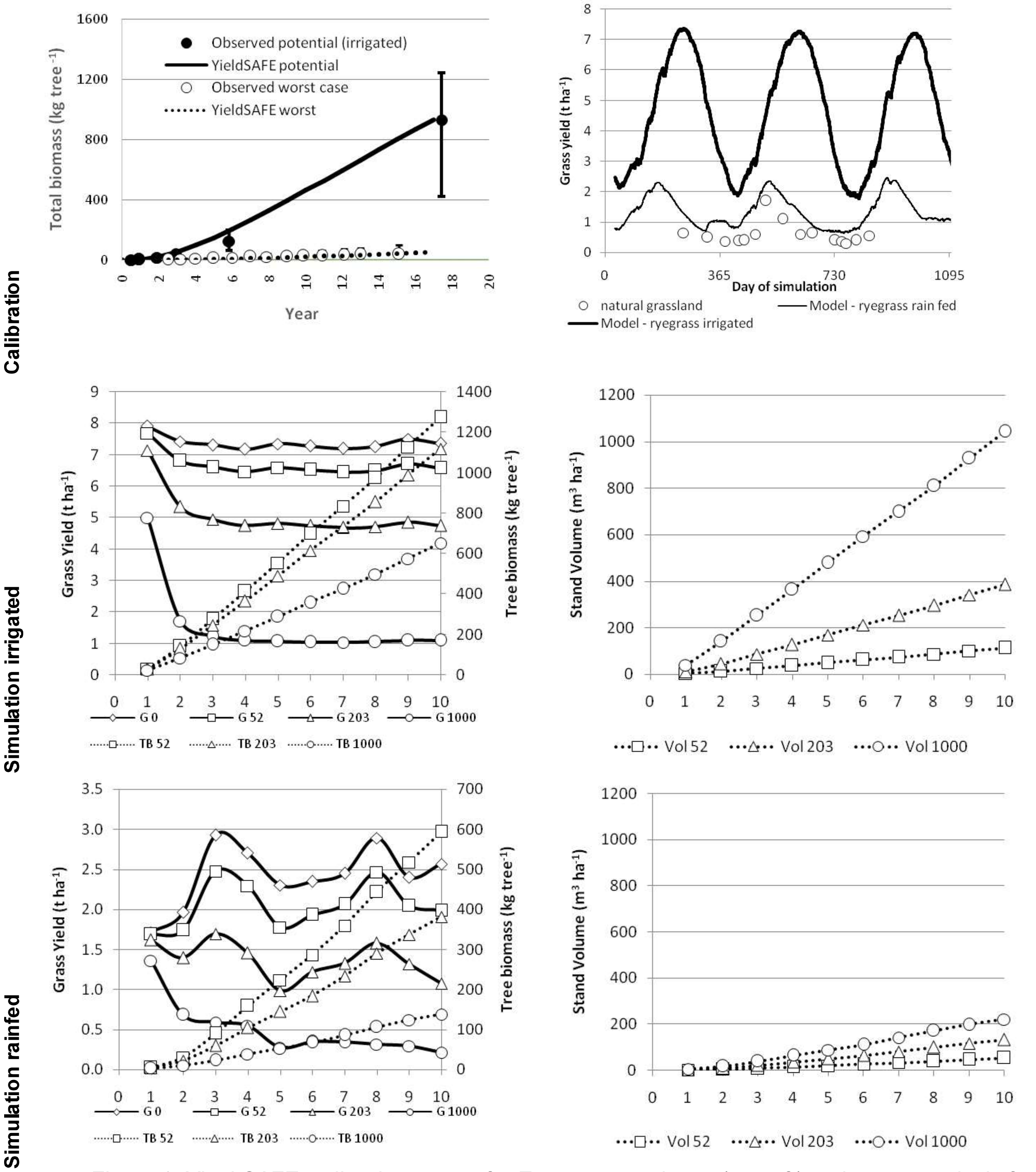

Figure 1: Yield-SAFE calibration results for Eucalyptus globulus (top-left) and ryegrass yields for irrigated, rain-fed and reference yields for natural grassland from Moreno and Caceres (2016). Simulated yields under irrigated and rain-fed regimes for grassland without trees (G0), grassland with 52, 203 and 1000 trees ha^{-1} with tree biomass (TB) for reference, and stand volumes.

Conclusions and further research

Yield-SAFE has been calibrated for the first time for eucalyptus in Portugal, and it predicts yields within the limits of existing observations and it seems to respond appropriately to the changes in soil and climate inputs. However the tree yields in the agroforestry systems seem high and, in the absence of an agroforestry trial, these results cannot be verified. However existing literature on eucalyptus forest trials, with densities similar to agroforestry, support the results of this work.

Eucalyptus globulus agroforestry systems are not currently practiced in Portugal but models such as Yield-SAFE can provide insights and increase our knowledge on relationships between trees and crops in terms of resource use.
Further tree and crop calibrations and model improvements are being developed under the modelling tasks of AGFORWARD project. The modelling of economic and provisioning of additional ecosystems services are currently being linked to Yield-SAFE with the aim of providing a consistent analysis of agroforestry systems and innovations throughout Europe.

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