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Title of the STSM: Modelling holm oak acorn production in southern Spain.

Applicant: Josep Crous-Duran. PhD student at the Instituto Superior de Agronomia (Portugal).

Dates: 18 / 05 / 2015 – 29 / 05 / 2015

Sending institution and responsible: Instituto Superior de Agronomia (Un Lisboa), João Palma

Host institution and responsible: Universidad de Extremadura, Plasencia (Spain). Gerardo Moreno

1. Purpose of the STSM

Dehesa is an agroforestry system typical of the south western quadrant of the Iberian Peninsula characterized by the presence of wooded pasture and by its main orientation to livestock extensive farming. The area of *Dehesa* in Spain is about 6 million ha (Pulido et al 2001) while in Portugal a similar system called *Montado* occupies 0.5 million ha (Joffre et al 1999).

In these systems there is a frequently mixed exploitation of different livestock species such as beef cattle sheep, Iberian pig and merino sheep which complement each other for a better use of the system's resources: while ruminants make use of pastures, stubble and fallow land, Iberian pigs, in their final phase of fattening, feed free range on the pasture mainly for acorns from holm (*Quercus ilex*) and cork oaks (*Quercus suber*).

Since old times the production of acorn by the oak trees has been of high interest for human and animal consumption (Fernández-Rebollo and Carbonero-Muñoz, 2008). But the acorn production is highly variable and can have significant differences between years, between geographic locations and even between nearby trees. Several studies have been conducted in order to acquire more knowledge about the variability in the acorn production but often the use of different methodologies make it difficult to extract clear conclusions (Carbonero-Muñoz 2011).

The main objective of this STSM is to include an acorn production estimation method into an agroforestry process-based growth model (Yield-SAFE) and relate it to its potential for transformation to meat (Iberian pig) production. The work plan presents several phases:

1) Collect (with the help of the host institution) the information available related to the acorn production and the grazing activity in the *Dehesas* system in Southern Spain.

2) Analyze this information and determine its possible implementation as a fruit module to an agro-forestry growth model, the Yield-SAFE (YS) model (van der Werf et al 2007), considering a general modelling approach framework to host other species

3) Use the Yield-SAFE model with the fruit module for the *Dehesas* system and validate de methodology with observed data.

4) Quantification of the metabolisable energy (ME) from the acorns produced, relating to the grazing activity (mainly for Iberian pig).

The results obtained are expected to provide:

- A method for quantifying acorn production according to the growth of the agroforestry system (holm oak and grass).
- A new tool to relate the agroforestry growth to the grazing activity.
- General improvement of the knowledge related to the economic viability of the *dehesas* by better estimating the potential provisioning of food and materials.
- Reinforcement of the concept of the *dehesas* as sustainable agroforestry systems

The proposal will be carried out in the Working Group 2: Tree products (WG2) and in Task force 2: NWFP data and models: state of the art, needs and improvements (TF2).

2. Description of the work carried out during the STSM and results obtained

2.1 Collection of information

The first phase of the STSM was to collect (with the help of the host institution) the information available related to: 1) the acorn production for the two most important tree species present in the *dehesa* system: *Quercus ilex* and *Quercus suber* and 2) the grazing activity requirements for the Iberian pigs in the *Dehesas* systems in Southern Spain.

Information found confirms that acorn production can be highly variable, both between and within years and individuals (Table 1). García-Mozo (2012) suggests a yearly tree mean value of 10 kg of acorns for trees aged between 50 and 70 years. Carbonero-Muñoz et al (2003) provides a maximum value of up to 155 kg $tree^{-1}$. In the northwest foothills of the Sistema Central Range (Spain), Álvarez et al (2002) reports ranges from 0.1 to 87.9 kg $tree^{-1}$, corresponding to an average of 19.0 kg $tree^{-1}$ giving similar results to previous studies such as Medina-Blanco (1963) with a tree annual production of 20.7 kg $tree^{-1}$ and slightly higher than other in the same area (15 kg $tree^{-1}$; Espárrago et al 1993).

In acorn production per area, values, of around 550 kg ha^{-1}, have been reported by several authors (San Miguel, 1994; Martín et al, 1998; Cañellas et al, 2007; Fernández-Rebollo and Carbonero-Muñoz, 2007) including Torrent (1964) that estimated a mean annual average of 586 ± 131 kg ha^{-1}. Gea-Izquierdo (2006), in the review of acorn production in Spanish holm oak woodlands suggests mean values in 50-

trees-per-hectare *dehesas* of around 250-600 kg ha^{-1}; an average value of 100 g m^2 of tree canopy and a mean acorn size and weight of around 3.5 × 1.6 cm and 3.5 g $acorn^{-1}$ respectively.

Related to the carrying capacity of the system, Lopez-Bote et al (2000) suggests a metabolisable energy content of 7.24 MJ per fresh acorn, 2.7 MJ kg^{-1} for fresh *dehesa* grass and daily energy requirements of around 51.2 MJ day^{-1} for an Iberian pig (48.7 MJ day^{-1} from acorn and 3.4 MJ day^{-1} from grass assuming daily consumptions of around 5 - 8.5 kg of acorn and 0.8 - 2 kg of grass. The energy requirements are calculated based on an Iberian pig with 125 kg of weight walking around 1 km day^{-1} at an average temperature of 6ºC Lopez-Bote et al (2000). As carrying capacity days are considered the number of sequential days available for selected livestock to graze/browse in the systems.

Table 1. Acorn production in *dehesas* systems in Spain according to different authors (includes *Quercus suber* and *Quercus ilex*).

Reference	**Location**	**Specie**	**Average acorn production**					
			g/m2		**kg/tree**		**kg/ha**	
			min	**max**	**min**	**max**	**min**	**max**
Vazquez (1998)		*Q.suber*			0.5	135		
Martin et al (1998)	Andalusia	*Q. ilex*	115.8	285,8				
Martin et al (1998)	Andalusia	*Q.suber*	19.5	171.1	0.6	16.9	82.7	399.2
Porras (1998)	Huelva	*Q.ilex*			22.9			
Cañellas et al (2001)	Huelva)	*Q.ilex*	0	94	0.8	42.5		
Fernández and Carbonero (2007)	Córdoba)	*Q.ilex*			8.5	20.7		
					0	203	414	978
Fernández and Carbonero (2007)	Sevilla	*Q.ilex/Q.suber*			3.7	12.2		
					0	371	414	1428
Fernández and Carbonero (2007)	Malaga	*Q.ilex*			9.3	31.9		
					0	77.3		
Cañellas et al (2007)	Badajoz	*Q.ilex/Q.suber*					530	890
Gómez et al (1980) in Gea et al (2006)	Salamanca	*Q.ilex*	86.6					
Escudero et al (1985) in Martin et al (1998)	Salamanca	*Q.ilex*	120.1					
Cañellas et al (2001)	Toledo	*Q.suber*	0.98	237.3				
Fernández and Carbonero (2007)	Cordoba	*Q.ilex*			8.5	20.7		
Fernández and Carbonero (2007)	Cordoba	*Q.ilex*			0	203		
Torrent (1964)	South Spain						455	717
Martin et al (1998)	Andalusia	*Q.faginea*	11.6	48	0.8	3.7	130.4	415
Medina (1956) in Laguna (1998)	Córdoba						670	
Medina(1963) in Martin et al (1998)	Extremadur a				20.8			

Garcia et al (2005) in Gea et al (2006)	Extremadura				6.32	19.4		
Alvarez et al (2002)	Salamanca		0.1	87.9	19		475	
Gea -Izquierdo (2006)			80	300			250	600

Another aspect to consider is how the tree density affects the acorn production. However scarce literature is available on this subject. Martín et al (1998) studied holm oaks under 23 and 59 trees.ha^{-1} that were producing similar yields per hectare (291 and 296 kg acorns ha^{-1} respectively) mainly due to low-density-stand tree producing more kilograms per tree than middle-density-stand trees as a result of increased light availability, and decreased intraspecific competition (Abrahamson and Layne 2003). With the same aim, Vázquez et al (1998) studied acorn production differences depending on tree densities (19, 56 and 133 trees ha^{-1}) resulting in the stand with middle density (56 trees ha^{-1}) having the highest acorn production per ha (21.3 ± 32.8 kg tree^{-1}), and the stand with lower density (19 trees ha^{-1}) had the highest acorn production per tree (31.5 ± 3.4 kg tree^{-1}). The high density stand produced on average 2.3 ± 0.6 kg tree^{-1}. As mentioned in Gea-Izquierdo et al (2006), it is noticeable that higher density forest yields are comparable to yields obtained by *dehesas* with much lower densities and commonly including areas with agricultural or pastoral activities indicating how efficient these traditional agroforestry systems are.

2.2 Implementation of a fruit module in Yield-SAFE

The Yield-SAFE model (van der Werf et al 2007) is a biophysical model that describes tree and crop growth in arable, forestry, and agroforestry systems according to light and water availability. The dynamic 'core' of the model comprises seven differential equations. These express the temporal dynamics of: (1) tree biomass; (2) tree leaf area; (3) number of shoots per tree; (4) crop biomass; (5) crop leaf area index; (6) heat sum, and (7) soil water content. The main outputs of the model are the growth dynamics and final yields of trees and crops. Daily inputs are temperature, solar radiation and precipitation. Planting density, initial biomass of different tree and crop species, and soil parameters must be specified. Yield-SAFE contains 21 parameters, i.e. six tree parameters (per species), nine crop parameters (per species) and six soil parameters (per location). A full description of the model, including its seven differential equations, 21 parameters, and the required inputs is provided by van der Werf et al (2007).

In Palma et al (2014), Yield-SAFE (YS) model was calibrated for *Quercus suber* in order to estimate cork oak biomass growth and determine the potential carbon sequestration using several implementation scenarios. Due to their biophysical similarity, for this study the parameter set used of Yield-SAFE model for both species would be the same (Table 2).

Table 2. Parameter set used in Yield-SAFE for *Quercus suber* and *Quercus ilex* in SW Spain.

Parameter	***Description***	***Quercus suber/Quercus ilex***
Pheight	Pruning height (m)	*3*
Pbiomass	Proportion of biomass removed per prune	*0.17*
Pshoots	Proportion of shoots removed per prune	*0.2*
maxPropbole	Maximum proportion of bole	*0.6*
Bheight	Maximum bole height (m)	*6*
sShoots0	Initial number of shoots	*1*
Biomass0	Initial tree biomass (g)	*12*
LA0	Initial tree leaf area (m2)	*0.0174*
Ap	Power function to describe relationship between tree height and diameter	*0.63*
Epst	Radiation use efficiency (g MJ1)	*0.21*
F	Form factor of the tree	*0.6*
Gammat	Water needed to produce 1 g of tree biomass (m3g-1)	*0.0004*
Kt	Radiation extinction coefficient	*0.8*
Kmain	Maintenance coeficiente	*0.0001*
LA max	Maximum leaf a´rea (m2)	*500*
Ratio branch	Ratio of branches to total biomass	*0.23*
Ratio timber	Ratio of branches to total biomass	*0.5*
Wood density	Wood density (g m-3)	*710000*
pFcrit	Critical pF value for tree (log(cm))	*3.5*
PWPt	Permanent Wilting Point for Trees (log(cm))	4.2
Dsigma/density	The change in Sigma height with density	*0.63*
Sigma height	Ratio of tree height to tree diameter for a free growing tree	*17.69*
Canopy width/depth	Ratio of maximum width to canopy depth	1.2

Following the suggestion of Gea-Izquierdo et al (2006) in the review of “Acorn production in Spanish holm oaks”, acorn production in *Quercus ilex* and *Quercus suber* stands will be predicted depending on the crown cover size as it seems the most reliable way to measure productivity and compare between stands and locations and states an average value of acorn production related to canopy cover of 100 g m^{-2}. This value would be considered for linking the biomass growth, and more precisely the canopy area occupied by the tree elements to the acorn production. Yield-SAFE currently calculates the canopy area as the proportion of the ground covered by tree canopies (%) by:

If ρ_t = 0, then $CanopyArea = 0$.

If ρ_t > 0, then, $CanopyArea = 100 \circ \pi \circ \left(\frac{H \circ C_{wd}}{2} \right)^2 \circ \rho_t$

If $CanopyArea$ > 100, then $CanopyArea = 100$.

While, C_{wd} is the ratio between the maximum canopies width related to canopy depth (unitless); H is the height of the trees (m), and ρ_t is the tree density of the stand (trees m^{-2}). In this case, the C_{wd} ratio was established in 1.2 (Palma et al 2014).

Using the Canopy Area estimation the *Canopy cover* per tree can be defined as the area of the ground covered by the vertical projection of the canopy of the tree (in m^2) . The estimation of $CanopyCover$ is included in YS as:

If $CanopyArea =$ = 0, then $CanopyCover = 0$.

If $CanopyArea =$ > 0, then $CanopyCover = \left(\frac{CanopyArea}{100 \cdot \rho_t} \right)$

While, $CanopyArea$ is the proportion (%) of the ground covered by tree canopies (state variable from YS) and ρ_t, also a state variable of YS, is the tree density of the stand (trees m^{-2}).

Another aspect to be considered is the falling seasonality of acorns. The seasonal distribution of the acorn fall for *Quecus ilex* and *Quercus suber* can be considered as 100 days, from 15th September (Day of year – DOY = 258) to 23th of December (DOY = 357) with peak values the 3rd of November (DOY= 307) (Cañellas et al 2007). The daily probabilities of acorn fall were calculated using a normal distribution function with the average value the 3rd of November, (DOY= 307) and a standard deviation of 25 days, meaning that 95% of the probability of acorn fall are included in 100 days (Figure 1).

For the calculation of the fruit fall probability using a normal distribution, a recalculation of the DOY is needed to consider end of the season after the 1st of January (DOY_{norm}):

IF (FF_{Peak} + FF_{Span}) > DOY + 365, then DOY_{norm} = DOY + 365

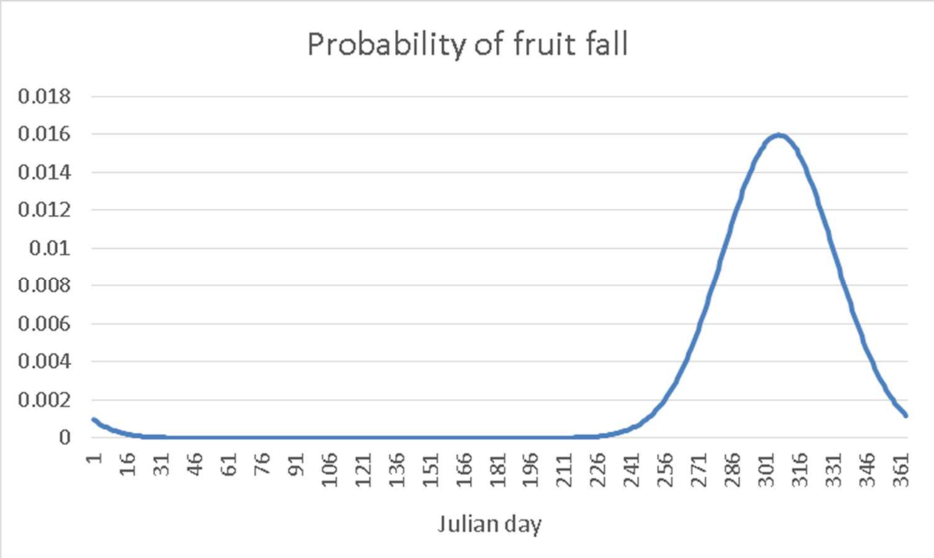
IF (FF_{Peak} + FF_{Span}) < DOY + 365, then DOY_{norm} = DOY

Then fruit fall probability (FFP_{DOY}) is calculated as:

$$FFP_{DOY} = \frac{1}{\frac{FF_{Span}}{4}\sqrt{2\pi}} e^{-\frac{(DOY_{norm}-FF_{Peak})^2}{2(\frac{FF_{Span}}{4})^2}}$$

Where the normal distribution mean is defined as FF_{Peak} and the standard deviation as $FF_{Span}/4$.[1]

Figure 1. Daily probability used for acorn fall with FF_{Peak} = 307 and FF_{Span} = 100 (based on Cañellas et al, 2007).



The daily fruit production can then be calculated as:

- Daily fruit production: DFP_{DOY} (kg ha^{-1} day^{-1})

  DFP_{DOY} = CanopyCover $_{DOY}$ * (F_P/ 1000) *(ρ_t * 10000)* FFP $_{DOYnorm}$

  Where DFP_{DOY} is the daily fruit estimation in kg ha^{-1} day^{-1}, CanopyCover $_{DOY}$ is the canopy cover in m^2 tree^{-1}, F_P is the Fruit production parameter (g m^{-2} canopy cover), ρ_t is the tree density of the stand (trees m^{-2}) and FFP $_{DOY}$ is the Fruit Fall probability (FFP) for DOY_{norm}.

Then the Annual fruit production: AFP (kg ha^{-1} year^{-1}) is calculated as the sum of the Daily fruit production for the period of time where there is a fruit fall (when FFP $_{DOYnorm}$ is > 0.00001) as:

If FFP $_{DOYnorm}$ < 0.00001, then, AFP = 0

If FFP $_{DOYnorm}$ > 0.00001, then, AFP = DFP $_{DOY}$ + DPF $_{DOY-1}$

[1] Implemented in MS Excel as NORM.DIST (DOY_{norm}, FFPeak,FFSpan/4)

Where FFP_{DOY} is the Fruit Fall probability (FFP) for DOY_{norm} and DFP_{DOY} and DFP_{DOY} are the daily fruit estimation in kg ha^{-1} day^{-1} for the day and the previous day respectively.

Also the number of fruits is calculated using the Daily Fruit Production (DFP_{DOY}) and the Fruit weight parameter (F_{Weight}):

- Daily number of fruits: NPF_{DOY} (pieces ha^{-1}):

  $NPF_{DOY} = (DFP_{DOY} * 1000) / F_{Weight}$

Also the Daily fruit production per tree ($DFP_{tree\ DOY}$) is calculated as in kg $tree^{-1}$ day^{-1} as a relationship between the Daily fruit production, DFP_{DOY} (kg $ha^{-1} day^{-1}$) and tree density of the stand (ρ_t, in trees m^{-2}) as :

If $\rho_t = 0$, then $DFP_{tree\ DOY} = 0$

If $\rho_t > 0$, then $DFP_{tree\ DOY} = DFP_{DOY} / (\rho_t * 10000)$

The Annual fruit production per tree ($AFP_{tree\ DOY}$) is calculated in kg $tree^{-1}$ $year^{-1}$ as:

If $FFP_{DOYnorm} < 0.00001$, then $AFP_{tree\ DOY} = 0$

If $FFP_{DOYnorm} > 0.00001$, then $AFP_{tree} = DFP_{tree\ DOY} + DFP_{tree\ DOY-1}$

The Daily fruit production, DFP_{DOY} (kg $ha^{-1} day^{-1}$) is related to the Fruit Energy Content parameter (F_{ec}) in order to estimate the Daily Utilisable Metabolisable Content, $DUME_{DOY}$ (in MJ ha^{-1} day^{-1}) and Annual Utilisable Metabolisable Content, $AUME_{DOY}$ (in MJ ha^{-1} $year^{-1}$) as:

$DUME_{DOY} = DFP_{DOY} * (F_{ec} / 1000)$

If $FFP_{DOYnorm} < 0.00001$ then $AUME_{DOY} = 0$

If $FFP_{DOYnorm} > 0.00001$ then $AUME_{DOY} = DUME_{DOY} + DUME_{DOY-1}$

The Daily Carrying capacity of Livestock units, $DCCLU_{DOY}$ - (in LU ha^{-1}) is calculated as:

$DCCLU_{DOY} = DUME_{DOY} / (LUER / 365)$

Where LUER is the Livestock Unit Energy Requirements in MJ LU^{-1} $year^{-1}$

The Daily Carrying capacity of Selected Livestock Units, $DCCSLU_{DOY}$ (in LU ha^{-1}) is:

$DCCSLU_{DOY} = DUME_{DOY} / SLUER$

Where SLUER is the Selected Livestock Unit Energy Requirements in MJ LU^{-1} day^{-1} (in this case $SLUER_{Iberian\ Pig}$ = 47.8 MJ LU^{-1} day^{-1}).

And finally the Carrying capacity Sequential Days, CCSD (in days per season) are calculated as:

If $DCCSLU_{DOY} >= 1$, then $CCSD_{DOY} = CCSD_{DOY-1} + 1$

If $DCCSLU_{DOY} < 1$, then $CCSD_{DOY} = 0$

For the implementation of the new fruit/acorn module, the previous described equations need a new parameter set (Table 3), while and several new state variables were introduced into Yield-SAFE. The new parameters offer the possibility to adjust parameter values depending on the stand, the region or on the information available.

Table 3. New parameters from fruit module implemented into Yield-SAFE

Name	***Unit***	***Parameter***	***Description***	***Q.ilex/ Q.suber***	***Reference***
Fruit name	-	-	Name of the fruit	acorn	-
Fruit energy content	MJ/t FM	F_{ec}	Utilizable metabolisable energy content in fruit	7230	Lopez-Bote et al (2000)
Fruit productivity	g/m^2 canopy cover	F_p	Production related to canopy cover	100	Gea-Izquierdo et al (2006)
Fruit falling days	Days	FF_{Span}	Number of days when 95% of fruit falls	100	Cañellas et al (2007)
Fruit fall peak day	Julian day	FF_{Peak}	DOY when peak is occurring	307	Cañellas et al (2007)
Fruit weight	g/piece	F_{Weight}	Weight of a single piece of fruit	3.5	Lopez-Bote et al (2000)

2.3 Validation of the fruit module in Yield-SAFE

2.3.1 Data

For the validation of the fruit/acorn module implemented in Yield-SAFE, results from Cañellas et al (2007) and unpublished data provided by the host institution (UEX) was used.

In Cañellas et al (2007), two different trials were performed in acorn production on *Quercus suber* and *Quercus ilex* at the Badajoz province (Spain). The study was carried out on five sites representative of the Spanish dehesa system in the southwest of the province of Badajoz (Extremadura). The soil texture is loam, with pH range of 6–6.9 and low organic matter content (range 0.7–1.9 %). The climate is semi-arid Mediterranean. Tree density varies from 20 to 45 trees ha^{-1} and acorn productivity was studied during the years 1997–1998 and 1998–1999. As it is not specified we considered a soil depth of 100 cm. During the second year (1998/1999) distribution was considered ideal (a progressive acorn fall) forming a Gaussian curve and near-uniformity throughout the year, while in the first year production was spread in intensity across the five study sites. The mean total annual acorn production for the second year was around 680 kg ha^{-1} while for both years ranged from 590 to 830 kg ha^{-1}. Weather information for the period for the specific sites was obtained with the Clipick tool (Palma 2014). Tree density considered was 32 trees ha^{-1} (as the average between 20 and 45 trees ha^{-1}). The trees were considered as being 70 years old.

Additionally, the validation of the fruit/acorn module was compared with the unpublished data provided by the host institution (UEX) from the Cáceres province. The study was carried out in Las Majadas del Tiétar (Càceres, Spain). The study is located at: 5°46’29’’ W, 39°56’26’’ N, at an altitude of 258 m a.s.l, with a maximum monthly temperature of 34.9 °C and a minimum of 1.4 °C. The annual precipitation is around 572 mm. Natural regeneration is acceptable and management is focused on grazing. Soil are Stagnic Alisols, with depths of more than 2 m. Soil texture is sandy loam and tree density is 20 trees ha^{-1}. The site presents 9 different plots where annual acorn production information was collected (Table 4).

Table 4. Average acorn produced in the experimental site of Las Majadas del Tiétar (Spain)

Year	***Fruit productivity (g DM/m²)***	***Acorn production (kg/ha)***
2003	308.5	617.0
2004	108.4	216.8
2005	218.5	437.1
2006	23.7	47.4
2007	187.2	374.4
2008	234.6	469.3
2009	123.1	246.1
2010	223.2	446.4
2011	215.6	431.3
2012	185.6	371.1
Average	182.8	365.7

2.3.2 Results and discussion

2.3.2.1 Yield-SAFE implementation of fruit production

Yield-SAFE was used to simulate cork oak stands growth for a period of 100 years for both sites from where data was available (Badajoz and Cáceres). The results obtained with Yield-SAFE (Figure 2. *Yield-SAFE estimation for height, tree biomass, dbh and canopy area in Badajoz and Cáceres sites. The latter is used for the tree fruit module.* for height (m); tree biomass (g $tree^{-1}$); diameter at breast height – dbh (cm) and canopy area (%) seem to be consistent with previous studies using Yield-SAFE for cork oak plantations (Palma et al 2014).

Yield-SAFE estimated an annual acorn production per hectare at year 70, of 596 kg ha^{-1} and 406 kg ha^{-1} for Badajoz and Cáceres sites respectively. These values are similar to the validation data between 590 and 830 kg ha^{-1} and an average of 365 kg ha^{-1}. Also the results are similar to results obtained in previous studies in *dehesa* systems. Gea-Izquierdo (2006), reported productions of around 250-600 kg ha^{-1} in *dehesa* system with 50 tree ha^{-1}, and other authors reported average values around 550 kg ha^{-1} (San Miguel, 1994; Martín et al, 1998; Cañellas et al, 2007; Fernández-Rebollo and Carbonero-Muñoz, 2007).

Related to acorn production per tree, the results obtained (

Figure 3), with values going up to 18.5 kg.$tree^{-1}$ and 20.3 5 kg.$tree^{-1}$ for the Cáceres and Badajoz respectively are also consistent with results stated in previous studies: Espárrago et al (1993), found an average value of 15 kg.$tree^{-1}$; Álvarez et al (2002) reported an average of 19.0 kg .$tree^{-1}$; Medina-Blanco (1963) a tree annual production of 20.7 kg.$tree^{-1}$; and Gea-Izquierdo (2006) a range from 15 to 21 kg.$tree^{-1}$.

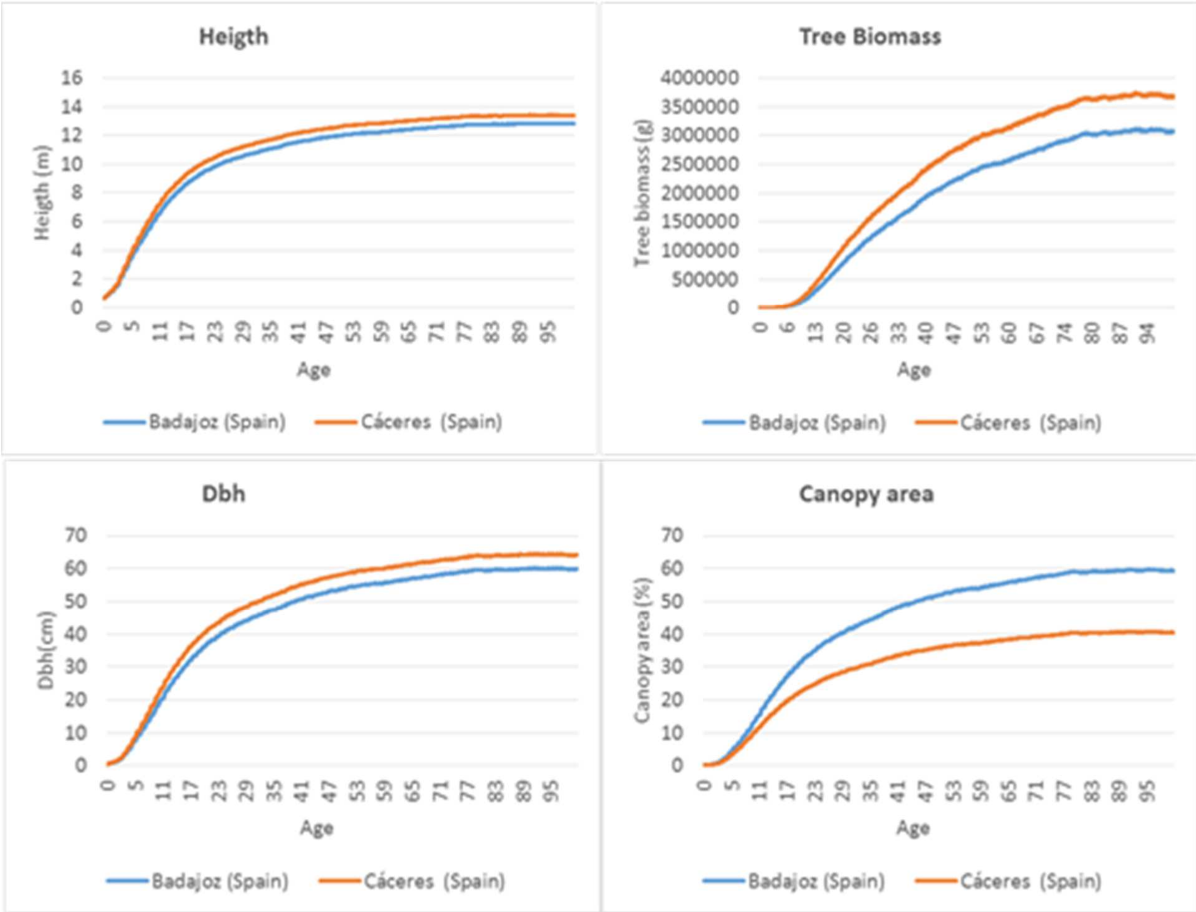


Figure 2. Yield-SAFE estimation for height, tree biomass, dbh and canopy area in Badajoz and Cáceres sites. The latter is used for the tree fruit module.

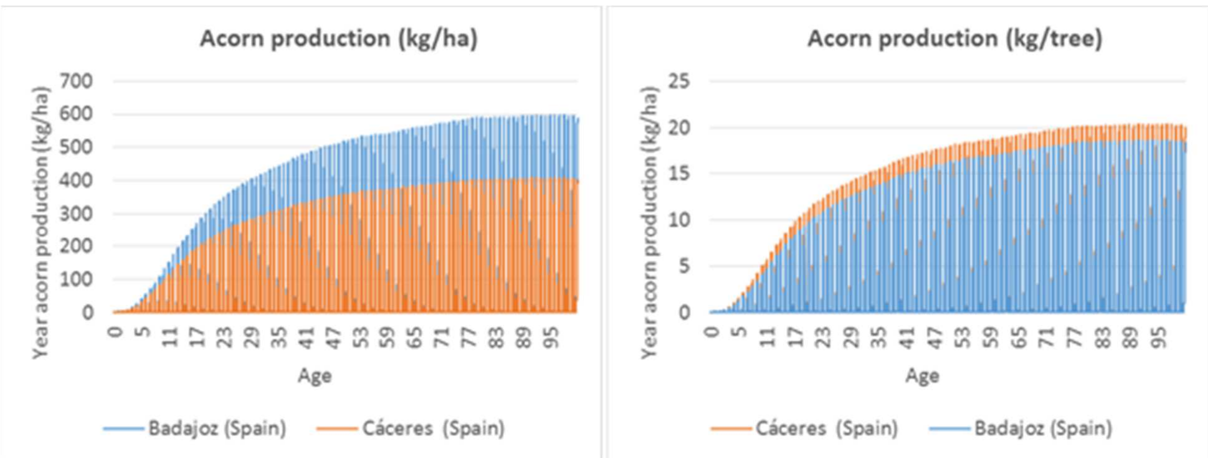


Figure 3. Yield-SAFE estimation of acorn production for Badajoz and Cáceres sites

2.3.2.2 Carrying capacity

Considering the energy requirements of an Iberian pig captured from acorn of 48.7 MJ day^{-1} (Lopez-Bote et al 2000), the *dehesa* system in Badajoz presents a carrying capacity for Iberian pigs up to 1.4 Iberian pigs ha^{-1} while the system in Cáceres presents just a maximum value of 0.96 Iberian pig ha^{-1} meaning that is needed more than one hectare to support the presence of an animal. The results seem consistent with the average carrying capacity reported for a good fruit productive *dehesa* of between 1 and 1.5 iberian pigs ha^{-1} (Lopez-Bote et al 2000).

The sequential days of carrying capacity expresses the potential number of following days the system is able to supply the energy requirements for the animal (what in Spanish/Portuguese is called *montanera/montanheira*). As the carrying capacity for Iberian pig of the system is over 1 pig ha^{-1}, the Badajoz system presents a maximum number of sequential days of 41. In the Cáceres system, as the carrying capacity for the Iberian pig is below 1 pig ha^{-1}, the sequential days of carrying capacity are not considered (Figure 4).

To receive the Protected Designation of Origin (PDO) certificate, farmers are required to provide to the pigs a minimum gain of weight during the browsing of 40 kg. Lopez-Bote et al (2000) considers a minimum browsing time of 40 days where the animal increases around 1 kg day^{-1} of weight from an initial weight of around 110 kg up to 150 kg at the end.

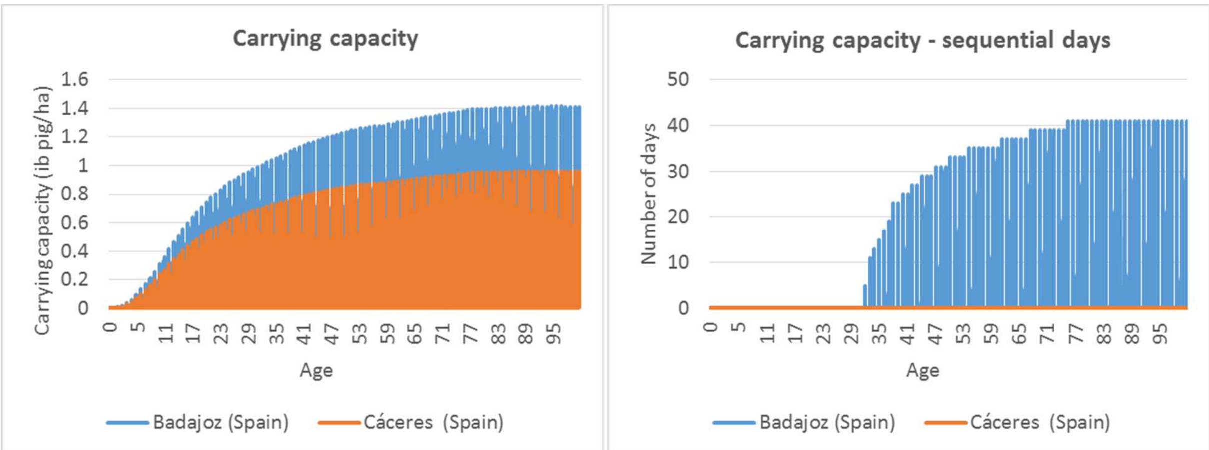


Figure 4. Carrying capacity for Iberian pigs and number of sequential days that the system can support at least one Iberian pig, for Badajoz and Cáceres sites

2.3.2.3 Validation with data

In Cáceres site, data of monthly acorn production of 9 plots was collected for ten years. The tree density average was around 20 tree ha^{-1}; the average diameter class, 45 cm and the average biomass per tree associated to that class was 1270 kg $tree^{-1}$. Following these values and using Yield-SAFE results we associated and average age of the stand of 23 years.

At the age of 23 years old in Cáceres, Yield-SAFE estimates a fruit falling distribution with acceptable resemblance to the measures data (Figure 5).

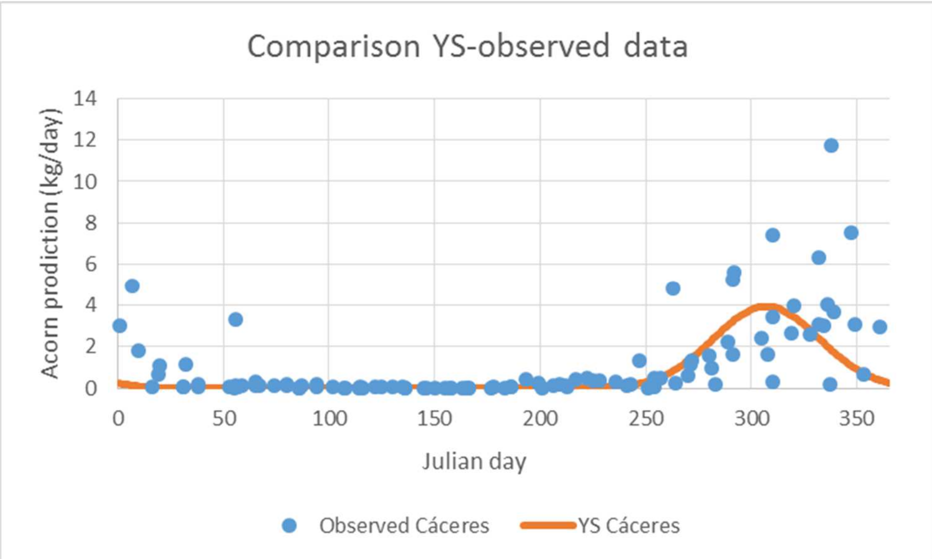


Figure 5.Comparison between Yield-SAFE results and observed data for the Cáceres site.

In Badajoz, in the absence of a stand age in Cañellas et al (2007), a mature stand of 70 years was assumed. Similarly to the Cáceres site, Yield-SAFE estimates of fruit production fall within the observed data from the 5 plots during the year 1998/1999. Yield-SAFE may seem to slightly underestimate the production, but the conservative approach is optional and can be corrected by adjusting the FF_{Peak} and the FF_{Span} parameters of the distribution according to the regional information available (Figure 6).

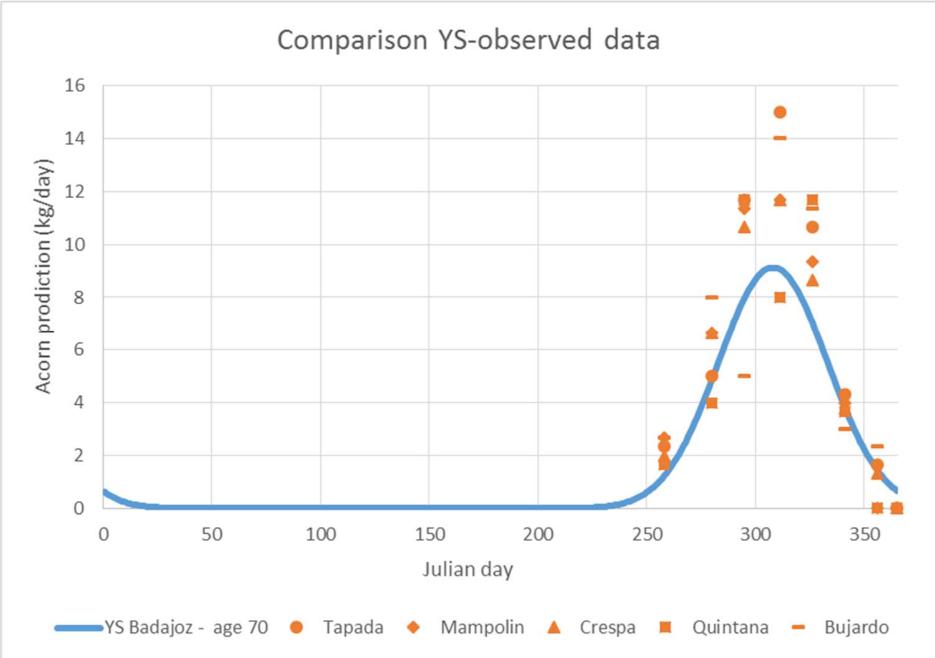


Figure 6. Comparison between Yield-SAFE estimation of acorn production for a tree with 70 years old with observed data from Badajoz site .

In both cases, Cáceres and Badajoz, the Yield-SAFE fruit module seem to estimate acceptable yields. Furthermore the integration of a small amount of parameters related to the fruit production offers the possibility to adjust productivity for local conditions. For example, in Cáceres site, delaying the standard fruit fall peak day (DOY=307) for 10 days could improve the precision of the model for that site (Figure 7). On the other hand in the Badajoz site reducing the “fruit falling days” parameter from 100 days to 70 days could also help to fit better the model into the observed data (Figure 8).

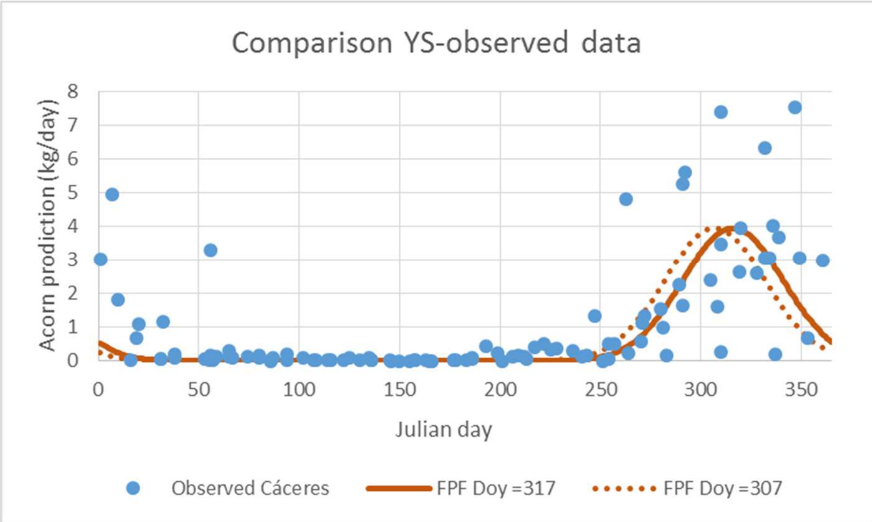


Figure 7. Comparison of the Yield-SAFE predictions by changing the Fruit Fall Peak DOY parameter on the Cáceres site.

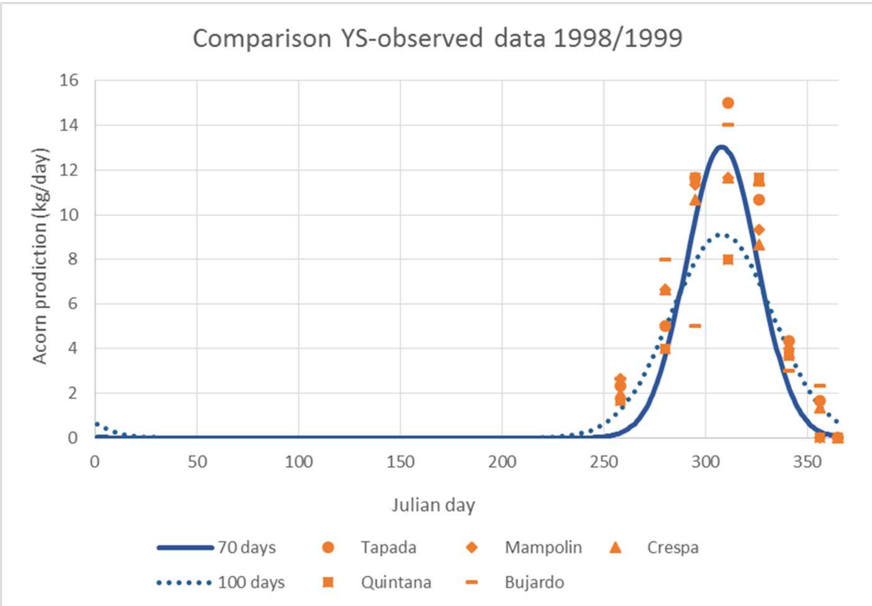


Figure 8. Comparison of the Yield-SAFE predictions by changing the number of fruit falling days parameter on the Badajoz site.

3. Summary and final considerations

- The first objective of this work was to gather information related to acorn production in order to propose a methodology to estimate fruit production linked to the process-based model Yield-SAFE. Several references were found and data supplied by the host institution (UEX) were used to support this work.

- The production of the fruit in Yield-SAFE is proposed by using the tree leaf area state variable of the model which is then related to the fruit productivity per leaf parameter (F_p). Additionally, a probability function (normal distribution) is proposed to define the fructification season with two parameters, namely: 1) the day of the year where the peak of fructification occur (FF_{Peak}) and 2) the time span the trees are on the fructification process (FF_{Span}). With this rationale, Yield-SAFE is proposed to provide fructification outputs for other species with three parameters.
- The methodology proposed seems to fit observed data from two sites in Spain (Cañellas et al 2007 and Moreno, personal communication, 2015), providing what seems a robust validation for fruit production modelling under agroforestry systems with Yield-SAFE under long-term predictions.
- However, the methodology does not account for the interannual or individual variability occurring in natural conditions (Perez-Izquierdo and Pulido, 2013). To take into account this variability more data is needed (e.g. daily climate data associated to acorn production) which is not available at present.
- The estimation of fruit production linked to data on utilisable metabolisable energy (UME) provided a good estimation on livestock unit carrying capacity and, more specifically with Iberian pigs. Additionally a good approximation of carrying capacity days (number of sequential days the system can support a livestock unit) was estimated by the model.
- In a future this new version of the Yield-SAFE model will be applied for other agroforestry systems present in Europe under the scope of the AGFORWARD project including chestnut plantations with Celtic pigs in northern Spain or olive trees plantations with chickens in Italy.

4. Future collaboration with host institution

The STSM allowed the connection of both research institutions, Universidad de Extremadura (UEX) and the School of Agronomy of the University of Lisbon, as well as increase the general knowledge about an agroforestry system (dehesa/montado) present in both countries and of great economic importance. 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 the research in this field.

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

The intention is that part of the first results obtained from this STSM will be published in a relevant research journal as the knowledge about acorn production and its modelling as a provisioning service in agroforestry systems is scarce. The paper would include the integration of the methodology used to quantify provisioning ecosystem services to Yield-SAFE and compare the results for the three agroforestry systems in Europe.

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

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

7. **Other comments (if any).**

No additional comments are included.

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