LIFE

Climate Change Mitigation

Deliverable C.3: Interface development of a software application for accounting tree crop carbon sequestration

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LIFE CLIMATREE (LIFE14 CCM/GR/ 000635)

A novel approach for accounting and monitoring carbon sequestration of tree crops and their potential as carbon sink areas

The **LIFE CLIMATREE** project “A novel approach for accounting and monitoring carbon sequestration of tree crops and their potential as carbon sink areas” (LIFE14 CCM/GR/000635) is co-funded by the EU Environmental Funding Programme **LIFE Climate Change Mitigation**.

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1. Introduction

In this section, the CO_2 sequestration model will be described, starting with the conceptual model, continuing with the equations and the dataset supporting the model, then outlining the implementation of the model in a package and in a web application and finally illustrating their usage.

2. Description of the CO_2 sequestration model

A model is a simplified description of a phenomenon that in real world is often complex and, in that process, it is decided what matters and what does not.

In the next stages, a simulation model of CO2 sequestration in tree crops will be described by defining the quantitative relationships among the state variables. The variables in our case are stocks which are system variables, representing quantities stored in a system over time, flows which represent the movement of stock among different part of the system and parameters that describe the overall state of the system and govern the relationship among stocks and flows. In a simulation model, a computer program is iteratively recalculating the state variables as it changes over time (Winsberg, 2009).

The model in this study, will consist by three pools (Figure 1). The first one will include biomass (BM), the second one, debris pool (DP) and the third one the soil organic matter (SOM).

The 1st pool is connected to 2nd pool though pruning, and crops left to ground. It is also connected through the roots to the soil directly. The material in DP decomposes and feeds the Soil. The conceptual description of the model can be seen in Figure 1.

The model is spatial, and can be run in NUTS 1, 2 or 3 level of detail. It is customized for the five species of perennial trees most common in Mediterranean area and are the olive, orange, apple, almond, peach trees.

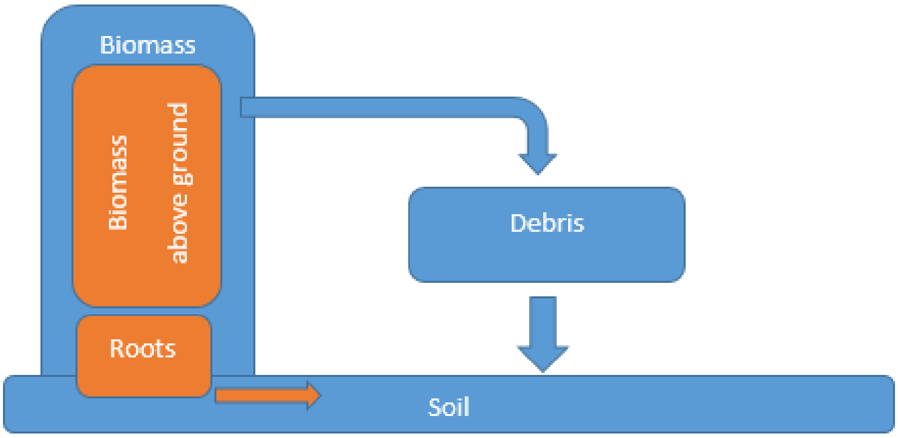


Figure1. Conceptual model.

3. Methodology and datasets

The three pools of the model will be described in detail along with the relevant datasets.

Biomass

The 1st pool consists from two sub-pools. The biomass above ground and the roots.

In our model, the trunk biomass grows at a variable rate given by the equation:

$$trunk\ biomass(t) = a * t^{b} \tag{1}$$

where t is the time and a, b are constants specified for each tree. So, by using the data for our species (above ground biomass stock in kg plant^{-1} and maturity in years) which are provided by measurements in C1 and Scandellari et al. (2016), constants a, b can be determined and in our case are given in Table 1.

	a	**b**
Olive	10.3	0.3
Orange	24.87	0.3
Apple	53.97	0.3
Almond	5.08	0.3
Peach	3.39	0.3

Table 1. Constant values for trunk growth rate.

So, the trunk carbon ($kg\ C\ ha^{-1}$) is:

$$trunk\ carbon(t) =< plant\ density >* (a * t^{b}) *< carbon\ in\ wood > \tag{2}$$

where <plant density> is the plant density (#plants/ha) and <carbon in wood> is taken to be 0.45.

Having in mind, the calculation for biomass above ground, we proceed in formulating the biomass in roots. The C in root can be estimated as a function of the S:R (shoot to root ratio), the yield Y (Mg ha^{-1}) and the harvest index (HI) and is given by:

$$carbon\ in\ roots = \left(\left(\frac{Y}{HI}\right) * S\!:\!R\right) *< carbon\ in\ wood > \tag{3}$$

The shoot to root ratio is based on C1 measurements and the values used are given in Table 2.

	S:R
Olive	0.3178
Orange	0.3350
Apple	0.3237
Almond	0.3419
Peach	0.3714

Table 2. S:R values used in the model.

As it has been described above, the root is connected directly to the soil pool, losing a part of it, defined as root exudates, which is translated into soil input. This amount is described by:

$$root\ exudates = 0.09 * \left(\frac{Y}{HI}\right) *< carbon\ in\ wood > \tag{4}$$

The formulas (3-4) are adopted by Farina et al. (2017; 2013) and are based on the work of Kong et al. (2005), Kuzyakov & Domanski (2000) and Skjemstad et al. (2004).

Debris pool

The 2nd pool, the debris pool, has as an input the plant residues (Mg C ha^{-1}) including pruning and fruit products left on the field. These are comprising a flow to the soil pool. The monthly input of plant residuals values is provided by the questionnaires collected and processed in C1.

So, if the residuals are left in the field, the amount of carbon due to pruning is:

$$carbon\ from\ pruning = pruning * < carbon\ in\ wood > \qquad (5)$$

where pruning is in $tn\ ha^{-1}\ year^{-1}$ and the values used are shown in Table 3. This is divided in the months that the pruning takes place (Table 4).

	pruning ($tn\ ha^{-1}\ year^{-1}$)	**% crop losses**	**fresh to dry**
Olive	1.35	10%	0.486
Orange	1.27	20%	0.235
Apple	0.91	20%	0.16
Almond	0.85	10%	0.941
Peach	1.45	20%	0.154

Table 3. Pruning values ($tn\ ha^{-1}\ year^{-1}$).

Similarly, the amount of carbon present due to crop losses is given by:

$$carbon\ in\ crop\ losses = Y * < \%\ crop\ losses > * < fresh\ to\ dry > * \\ < carbon\ in\ wood > \qquad (6)$$

where Y is the yield ($tn\ ha^{-1}\ year^{-1}$) and the other two constants are displayed in Table 3. This amount is divided to the months that the crops are collected and differs from tree to tree (months are shown in Table 4)

	Pruning period	**Crop collection period**
Olive	Feb-March	Oct-Dec
Orange	Feb-March	Jan-July & Nov-Dec
Apple	Feb-March	Sept-Oct
Almond	Feb-March	Aug-Oct
Peach	Feb-March	May-Sept

Table 4. Period of pruning and crop collection.

Soil

In our model, the dynamics of carbon in soil, are assessed spatially and temporally at regional scale based on RothC model, version 26.3 (Coleman and Jenkinson, 1996). The original model is extended in order to run spatially and is combined with (a) the administrative boundaries defined by NUTS 1, 2 and 3, for the countries under study, and (b) a spatial database including soil and climate characteristics.

RothC uses monthly time steps to calculate soil organic carbon (t C ha^{-1}). In RothC, the Soil organic carbon (SOC) is modelled by four active connected pools and an inner organic matter pool (IOM). The four pools are the Decomposable Plant Material (DPM), the Resistant Plant Material (RPM), the Microbial Biomass (BIO) and the Humified Organic Matter (HUM). The structure of the model is shown in Figure 2. The amount in each pool decomposes according to first order kinetics with its own rate.

So, the incoming carbon (in our case through debris pool and roots), is split between DPM and RPM based on the DPM/RPM ratio (default value is 1.44 i.e. 59% goes to the DPM pool and the rest to the RPM pool). All the incoming carbon passes through these polls, only once. Then DPM and RPM decomposes to CO_2, BIO and HUM. The proportion of DPM and RPM that goes to CO_2 and to BIO+HUM depends on the soil characteristics (for example clay content). Finally, BIO, HUM is further decomposing to CO_2, BIO and HUM and so on. The overall decomposition rate on the active pools is a function of temperature, moisture and a decomposition rate constant (k in $years^{-1}$) specific for each pool.

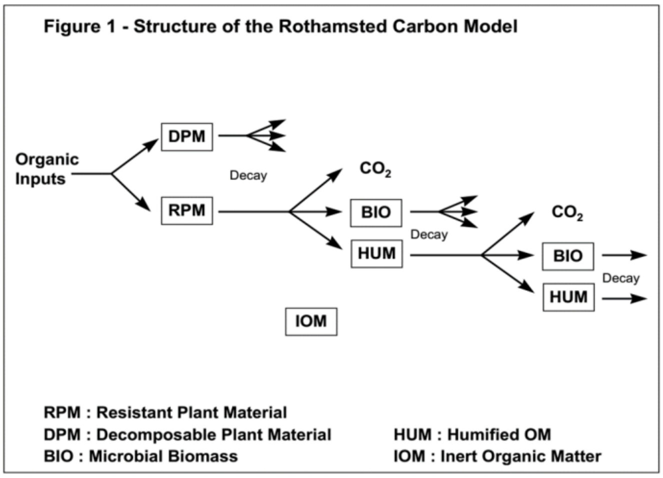


Figure 2. Structure of the RothC model.

In order to run the model, we need to define the input carbon (organic input in Figure 2), initial values for the four pools (RPM, DPM[1], BIO and HUM) and datasets used to setup the parameters of the model (e.g. soil characteristics).

The monthly input carbon (t C ha^{-1}) that flows into that pool, as it has been described, is a combination of the carbon in debris pool, the carbon in roots exudates and the carbon weeds given by:

$$carbon\ weeds = 0.07 * \left(\frac{Y}{HI}\right) * < carbon\ in\ wood > \tag{7}$$

So, these three components compose the organic input.

Further, we must evaluate initial values for the pools in the model. In our case, these carbon values have been based on pedotransfer functions described in Weihermuller et al. (2013). The initial values of carbon for RPM, HUM and BIO are:

$$RPM = (0.1847\, TOC\ + 0.1555)(\, clay + 1.2750\,)^{\,-0.1158} \tag{8}$$

$$HUM = (0.7148\, TOC\ + 0.5069)(\, clay + 0.3421\,)^{\,0.0184} \tag{9}$$

$$BIO = (0.0140\, TOC\ + 0.0075)(\, clay + 8.8473\,)^{\,0.0567} \tag{10}$$

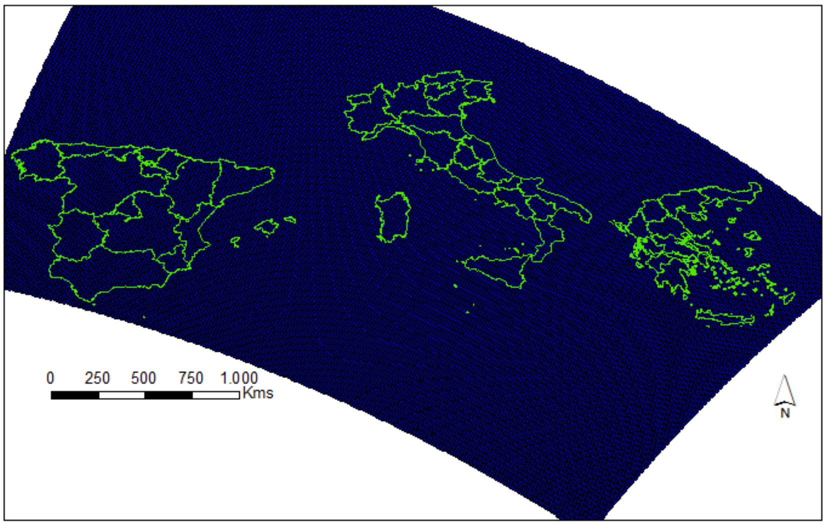
where clay in % mass and TOC is the total organic carbon content at equilibrium (t C ha^{-1}). TOC was evaluated based on bulk density. Bulk density and % clay is obtained from LUCAS 2009 TOPSOIL dataset (Orgiazzi et al., 2018; Tóth et al., 2013).

The data required to setup the parameters of the model are:

- Climatological data. These include monthly rainfall (mm), open pan evaporation (mm) and average air temperature (^{o}C).
- Soil characteristics. The clay content on topsoil (%).
- An estimate of the decomposability of the incoming plant material (DPM/RPM ratio) and
- Monthly input of monthly farmyard manure (FYM, in t C ha^{-1}), if any.

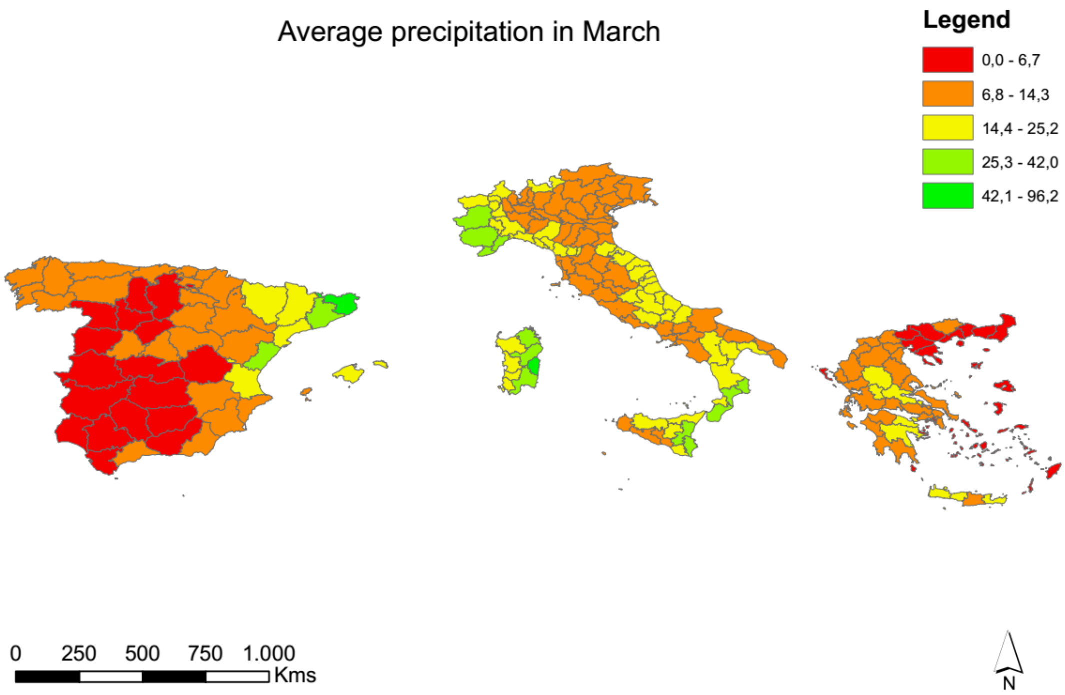
The climatological data are provided by the simulations in C2 for the whole Mediterranean region at a scale of 0.10 degrees in longitude and 0.05 in latitude, for every month of the year (mean value), as can be seen in Map 1. These climatic data are given for two periods. The first is an monthly average for the period 2008-2012 and the second for the period 2048-2052.

[1] DPM is assumed to have an initial value of zero.



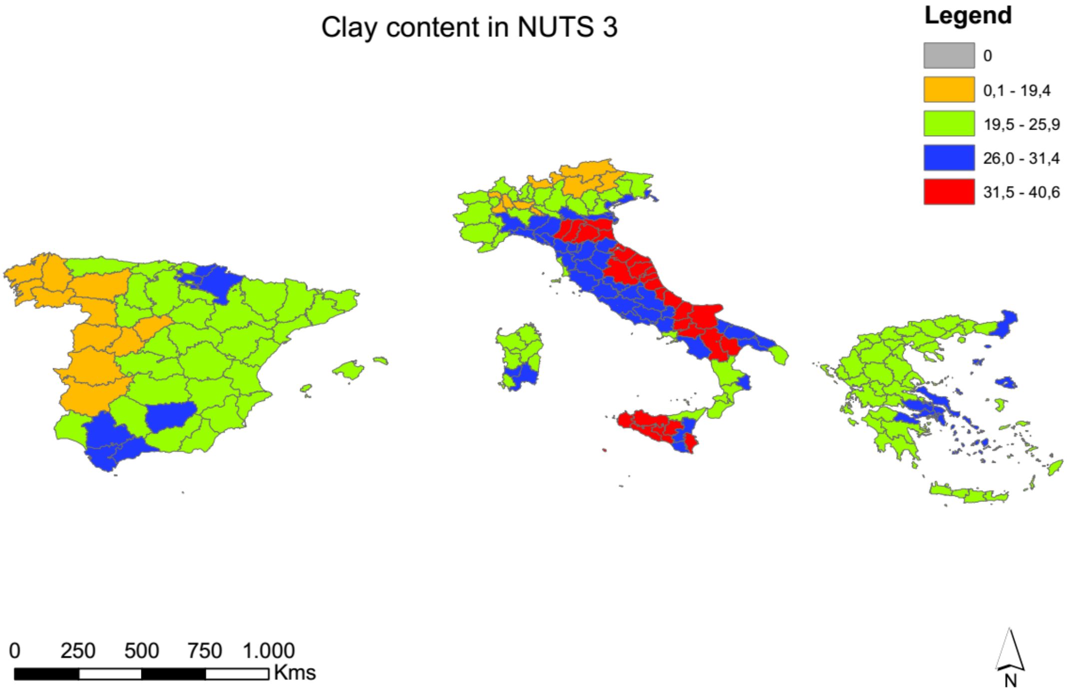
Map 1. NUTS 2 regions and points where the climatic dataset is defined.

The point data set for temperature, rainfall and open pan evaporation cannot be used without further processing. The analysis is done in regions in NUTS 1, 2 or 3, so the point data are averaged accordingly in the regions of the three countries under study. So, for example a thematic map of rainfall for March, in NUTS 3 spatial level of detail, for the current period is shown in Map 2.



Map 2. Variation in precipitation in the Mediterranean region (NUTS 3).

Similarly, we have procced with the soil properties (clay in our case). For that purpose, the LUCAS 2009 TOPSOIL dataset is used (Orgiazzi et al., 2018; Tóth et al., 2013). The density of LUCAS topsoil sample points is around 1 per 199 km^2, which would, in principle, allow a grid cell size of around 14 km (Ballabio et al., 2016). So, in order to have a value for clay for each of the regions in NUTS 1, 2, and 3, aggregate values from the initial raster dataset have been obtained. A thematic map for NUTS 3 can be seen in Map 3.



Map 3. Variation of clay content in Mediterranean region.

The DPM/RPM will be given the default value proposed by Coleman and Jenkinson, 1996.

The particulars of the model and its full description and application can be found in Coleman & Jenkinson (1996) and Coleman et al. (1997).

4. Implementation

The methodology and the datasets needed, have been described in the previous sections. In this paragraph the two outputs of this actions are illustrated. The first is the software code (with the full dataset) and the second is a web application.

Before going into the details of the code and the web application, I will recap the main characteristics of the model presented. The model is dynamic, runs on a monthly timestep and starts at the present time until 50 years ahead. Spatially, an instance of the model can run for all regions (or for specific regions) in NUTS 1, 2 and 3 level. The model consists of the biomass (trunk and roots), the debris pool and the soil. The biomass grows with time and accordingly the roots. The pruning (if left on the field) and the crop losses are feeding the debris and then together with the root's exudates are feeding the soil. The soil processes are modeled by RothC which are affected by climatic data and soil characteristics.

So firstly, the model is implemented in programming language R and is distributed as an open source software in github[2]. The repository includes all the data produced in various steps of the project (e.g. C1) and the secondary data collected and needed to make the carbon calculations.

Secondly, a dashboard is developed in Shiny (shiny.rstudio.com) and a web deployment is available for use by avoiding all the technicalities of the model[3].

Open source package

The repository consists by two R script files and an RData datafile (Table 5).

filename	**scope**
model_code.R	functions of the model
climatree_model.R	GUI in shinny
shp_nuts_v4.RData	dataset

Table 5. Filename on the github repository.

The datafile includes 3 dataframes for current climatic conditions (one for each NUTS), 3 dataframes for future climatic conditions (one for each NUTS), 3 dataframes for Soil (one for each NUTS) and 3 SpatialPolygonsDataFrame containing the polygonal geometry for the NUTS 1,2 and 3[4]. A full list can be seen in Table 6.

[2] The code and the data are available in https://github.com/amimis/climatree with GPL-3.0 license.
[3] The web application is in https://amimis.shinyapps.io/climatree/
[4] The NUTS 1,2 and 3 administrative boundaries are obtained from Eurostat NUTS 2013 at scale 1:3 Million

Name	Description	dimensions
nuts1_climatic	Climatic data in NUTS 1	16 obs. of 49 variables
nuts2_climatic	Climatic data in NUTS 2	53 obs. of 47 variables
nuts3_climatic	Climatic data in NUTS 3	221 obs. of 47 variables
nuts1_climatic_f	Future climatic data in NUTS 1	16 obs. of 49 variables
nuts2_climatic_f	Future Climatic data in NUTS 2	53 obs. of 47 variables
nuts3_climatic_f	Future Climatic data in NUTS 3	221 obs. of 47 variables
nuts1_soil	Soil data in NUTS 1	16 obs. of 21 variables
nuts2_soil	Soil data in NUTS 2	53 obs. of 20 variables
nuts3_soil	Soil data in NUTS 3	221 obs. of 22 variables
nuts1_shp	Geometry of NUTS 1 regions	16 polygons
nuts2_shp	Geometry of NUTS 2 regions	53 polygons
nuts3_shp	Geometry of NUTS 3 regions	221 polygons

Table 6. Dataframes present in RData file.

All the names start with the spatial level of detail i.e. nuts1, nuts2 or nuts3 and continue with a label denoting the purpose of the data i.e. climatic, soil or shp (from shapefile). The fields contained in the main type of dataframes, are described in Tables 7, 8 and 9.

name	Description	Type of data
NUTS_ID	3 letter region identifier	text
NAME_LATIN	Name of the region	text
*Count_*	# point data used	integer
Avg_TEx	Average temperature for x-th month	Real number
Avg_PEx	Average pan evaporation for x-th month	Real number
Avg_PRx	Average rainfall for x-th month	Real number

Table 7. Fields in nutsx_climatic dataframes[5].

[5] x stands for 1, 2 or 3.

name	**Description**	**Type of data**
NUTS_ID	3 letter region identifier	text
NAME_LATIN	Name of the region	text
clay	Aggregated % clay	Real number
bdensity	Aggregated bulk density	Real number
RPM	Initial carbon content	Real number
HUM	Initial carbon content	Real number
BIO	Initial carbon content	Real number

Table 8. Fields in nutsx_soil dataframes

The SpatialPolygonsDataFrame nutsx_shp contains, except form the geometry of the regions, several fields, the most useful of which is the NUTS_ID. This field is present in the dataframes described above (Tables 7, 8) and so can be used as a “key” to join datasets.

The two script files model_code.R and climatree_model.R contain the model and the shinny web application respectively. The first script is going to be described briefly and the second will be illustrated running, in the next section.

The code for the model is divided into three part. The first upper part contains all the parameters, already described in methodology. The second part contains the various functions of the model, functions for trunk, roots, debris and soil pools. The last, lower part, includes the main function (climatree_model) which by calling it, a modeler can make any calculation. The input parameters are listed in Table 9, and it returns a dataframe with the carbon contained in trunk, roots, debris and soil for each year of the calculation.

Name of the variable[6]	**description**	**type**
number_of_years	Years that the calculation will run	integer
surface	Total area	Real number
*tree_*	One of the five species	Text. One of "olive", "orange", "apple", "almond", "peach"
temperature	temperature	Vector with 12 values
*ftemperature**	future temperature	Vector with 12 values
*temp_future_change**	specific future temperature change	Real number
rainfall	rainfall	Vector with 12 values
*frainfall**	Future rainfall	Vector with 12 values
evaporation	Pan evaporation	Vector with 12 values
*fevaporation**	Future pan evaporation	Vector with 12 values
clay	% clay	Real number
Rothc_initial_pools	initial carbon in Soil	Vector with 5 values for DPM, RPM, BIO, HUM and CO_2
*soil_vegetated**	Is soil vegetated?	Boolean
*yield**	Yield	Real number
*pdensity**	Plant density	Real density
*keep_res**	Keep residuals on the field?	Boolean (default is True)
*farmyard_manure**	Manure	Real number
*perc_age**	% of the trees with a specific age	dataframe

Table 9. Parameters in main function of the model.

[6] * means that the parameter is optional.

Web application

The web application is based on the source code of the model described in the previous section. The application has been developed in shinny (source code in climatree_model.R) and is hosted in shinyapps.io[7].

The web application has 4 tabs. The *first tab* contains the "model description" (Figure 3) which is the main page of the application.

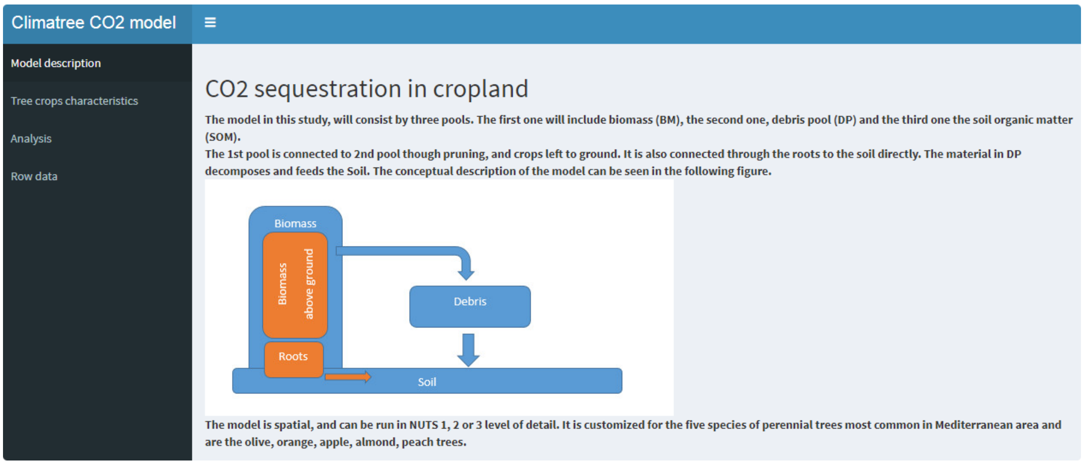


Figure 3. Model description tab.

The *second tab* is "tree crops characteristics" (Figure 4a, 4b). In this, the user chooses the spatial level he wants to work (NUTS 1,2 or 3) and then (a) picks a region, (b) adds the tree and land characteristics and (c) finally presses add to save the input. The user can add any number of cases.

The tree characteristics that are available, are the area, the plant density, the tree type and the yield. As far as the land characteristics are concerned, there are two check boxes, one for leaving the litter on the field and one for the existence of vegetation on the field.

After the user inserts a number of cases the inserted data are displayed at the lower part of the "tree crops characteristics" tab (Figure 4b).

[7] The web application is available in https://amimis.shinyapps.io/climatree/ . All the source code is available on the github repository.

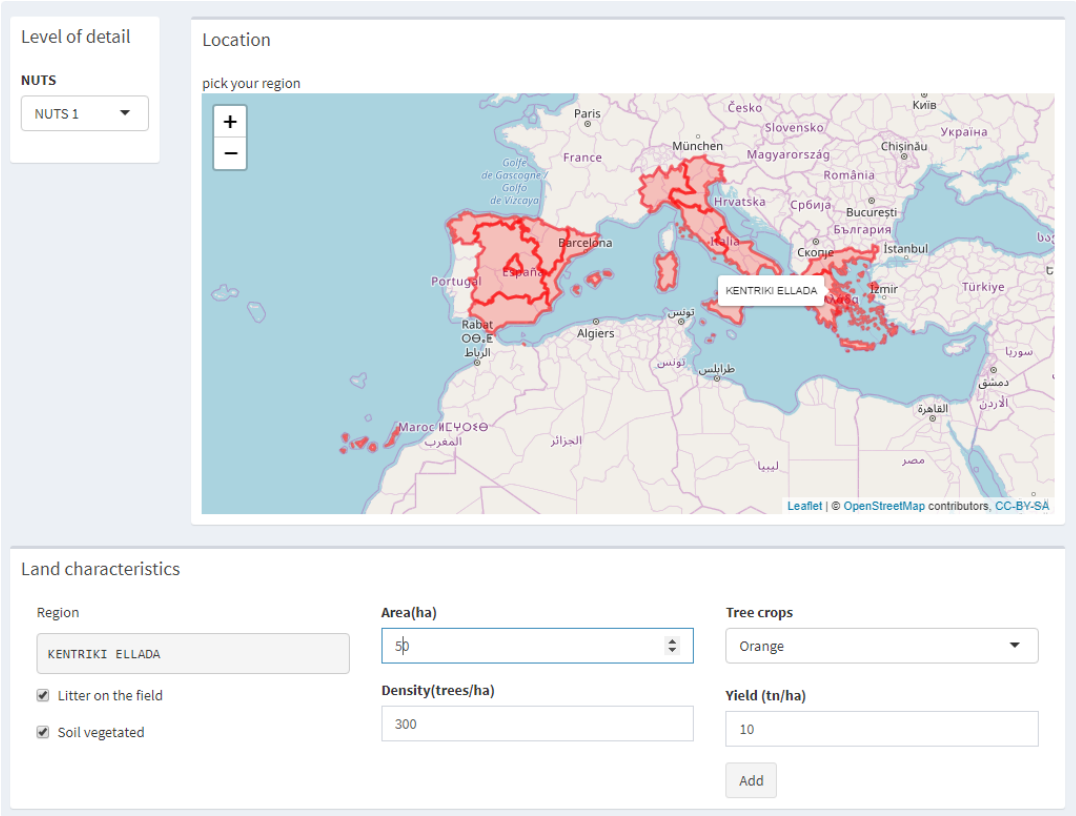
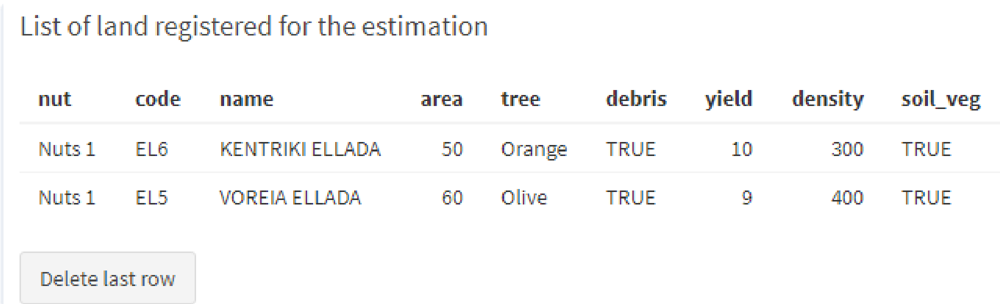


Figure 4a. Upper part of the tree crop characteristics tab.



nut	code	name	area	tree	debris	yield	density	soil_veg
Nuts 1	EL6	KENTRIKI ELLADA	50	Orange	TRUE	10	300	TRUE
Nuts 1	EL5	VOREIA ELLADA	60	Olive	TRUE	9	400	TRUE

Figure 4b. Lower part of the tree crop characteristics tab.

After the user has finished inserting all the areas of interest, moves into the *third tab* of “Analysis”. Here, in the uppers part (Figure 5a), the input data are illustrated and by pressing the “Run the model” button the graph results on the lower part of the page are produced (Figure 5b).

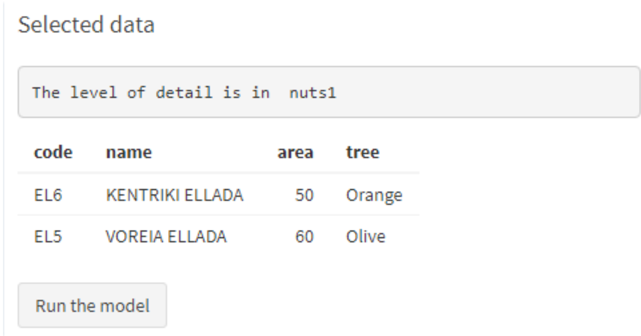


Figure 5a. Upper part of the analysis tab.

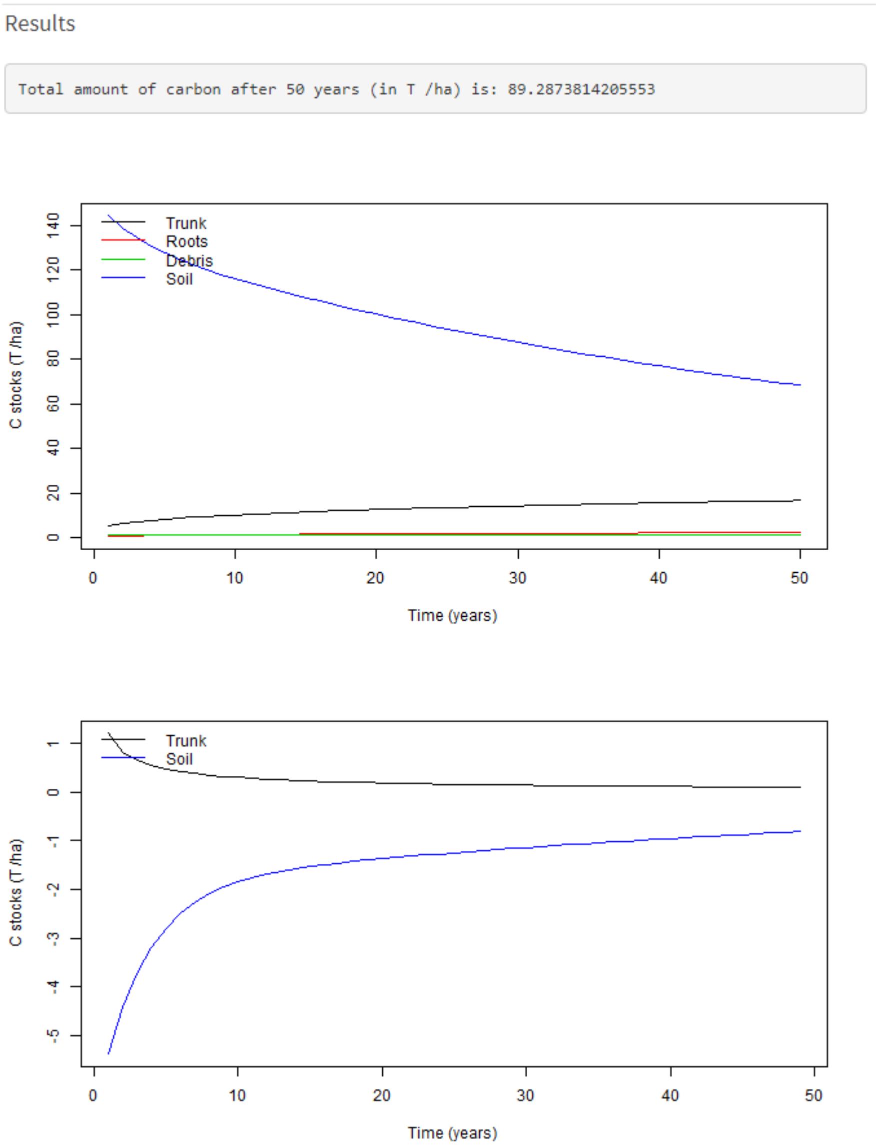
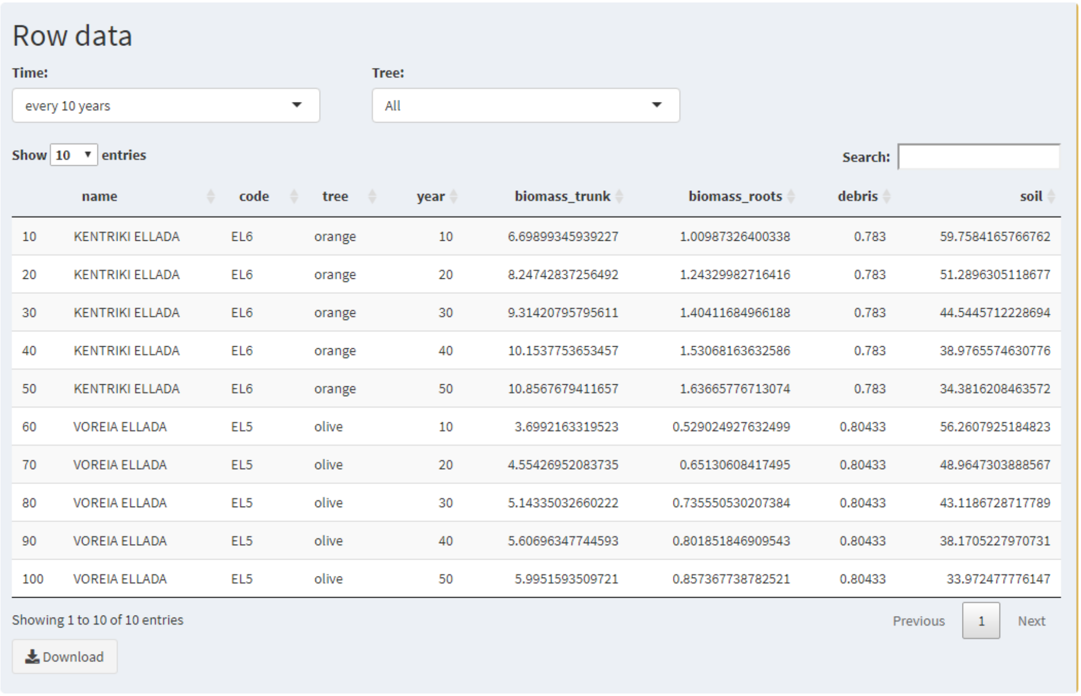


Figure 5b. Lower part of the analysis tab.

The *last tab* called “Row data”, a detailed result dataset is produced which can be downloaded in a csv format (Figure 6).


Row data

Time: every 10 years

Tree: All

Show 10 entries

Search:

	name	code	tree	year	biomass_trunk	biomass_roots	debris	soil
10	KENTRIKI ELLADA	EL6	orange	10	6.69899345939227	1.00987326400338	0.783	59.7584165766762
20	KENTRIKI ELLADA	EL6	orange	20	8.24742837256492	1.24329982716416	0.783	51.2896305118677
30	KENTRIKI ELLADA	EL6	orange	30	9.31420795795611	1.40411684966188	0.783	44.5445712228694
40	KENTRIKI ELLADA	EL6	orange	40	10.1537753653457	1.53068163632586	0.783	38.9765574630776
50	KENTRIKI ELLADA	EL6	orange	50	10.8567679411657	1.63665776713074	0.783	34.3816208463572
60	VOREIA ELLADA	EL5	olive	10	3.6992163319523	0.529024927632499	0.80433	56.2607925184823
70	VOREIA ELLADA	EL5	olive	20	4.55426952083735	0.65130608417495	0.80433	48.9647303888567
80	VOREIA ELLADA	EL5	olive	30	5.14335032660222	0.735550530207384	0.80433	43.1186728717789
90	VOREIA ELLADA	EL5	olive	40	5.60696347744593	0.801851846909543	0.80433	38.1705227970731
100	VOREIA ELLADA	EL5	olive	50	5.9951593509721	0.857367738782521	0.80433	33.972477776147

Showing 1 to 10 of 10 entries

Previous 1 Next

Download

Figure 6. Row data tab.

5. Typical Results

In this section, typical results, that can be produced by the model, will be illustrated. The results are displayed on an aggregate country level, although the runs were made on a larger scale.

The first table of results (Table 10) shows the total carbon sequestration for the countries in our study, in 50 years' time. For these calculations, the current statistical data for surface, yield, and plant density has been used.

	Greece	Spain	Italy
olive	27,67	220,71	36,49
orange	1,96	11,55	3,35
apple	1,35	2,95	12,71
almond	0,43	14,64	1,54
peach	1,34	1,68	2,82

Table 10. Total carbon (in Mt)

It should be noted here that approximately 80% of the carbon, in Table 10, is stored in soil.

The next table (Table 11) shows the effect of future temperature change on carbon sequestration.

	+ 0.0 C	**+1.0 C**	**+2.0 C**	**+5.0 C**
Greece	31,69	27,23	26,20	23,31
Spain	227,65	219,12	210,84	187,58
Italy	37,52	36,13	34,78	30,94

Table 11. Total carbon for olives (in Mt)

The last table (Table 12) displays the effect of (a) keeping the pruning material on the field and (b) keeping the field vegetated, have on the carbon sequestration.

	Greece	**Spain**	**Italy**
keep pruning & keep vegetation	27,67	220,71	36,49
no pruning & keep vegetation	25,05	196,50	32,80
no pruning & no vegetation	14,31	106,89	18,75
keep pruning & no vegetation	16,21	124,16	21,43

Table 12. Total carbon for olives (in Mt)

Similar results can be acquired for regions in NUTS1, 2 or 3 and for different tree species present in our study.

6. Conclusion

The model developed is dynamic, runs on a monthly timestep and starts at the present time until 50 years ahead. Spatially, the model can run for any region in NUTS 1, 2 and 3 spatial level of detail. The model consists of the biomass (trunk and roots), the debris pool and the soil. The biomass grows with time and accordingly the roots. The pruning (if left on the field) and the crop losses are feeding the debris and then together with the root's exudates are feeding the soil. The soil processes are modeled by RothC which are affected by climatic data and soil characteristics.

As it has been described the model can run on an aggregate level, for the entire country, or on specific regions. There are several other options useful to make comparisons and assess management practices. These are compiled on the following list:

- Five different tree types are available.
- Location characteristics affects the carbon sequestration.
- Soil vegetation affects the carbon capacity to hold carbon in soil.
- Pruning left on the field.
- Age of the trees. So new planting options can be assessed.
- Future climatological scenarios.
- Plant density.

Lastly, the model has been developed in such a way that permits its use by other researchers by providing the source code, the full dataset and an illustrative web application.

7. References

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