Carbon Dynamics Projection for the *Quercus petraea* and *Robinia pseudoacacia* Species - Case Study

Bara Norbert, Rotaru Anda, Laslo Lucian, Matei Monica, Boboc Madalina, Coman Valentina, Voicu Madalina, Enache Natalia, Deak György

National Institute for Research and Development in Environmental Protection, Bucharest, Romania

E-mail: gyorgy.deak@incdpm.ro

**Abstract.** Atmospheric CO₂ is rising rapidly. As forests cover some 43% of the Earth’s surface, they are considered to be the largest terrestrial carbon sink on Planet Earth. Within this study, calculations of the most abundant tree species were conducted in the study area, which is situated in the Eastern region of Romania. Thus, the forest carbon balance for the Oak (*Quercus petraea*) and Black Locust (*Robinia pseudoacacia*) species were projected for the period of 2015 - 2040. Data from management plans were used and analyzed using a forest model that is projecting forest resource development on regional up to European scale, known as The European Forest Information SCENario Model - EFISCEN. This study is aiming to point out the potential of the Oak and Black Locust forests to store carbon within the aforementioned period considering that the same management practices will be applied. The results of the simulation show that the forests accumulate CO₂ over time and also their magnitude can be observed. Conclusions can be drawn from the comparative analysis of the input data and the simulation results, considering the limitation of the used data in terms of their precision.

1. Introduction

The UN Framework Convention on Climate Change (1992) and the Kyoto Protocol (1997) aimed to stabilize greenhouse gas levels in the atmosphere. New commitments were agreed by Parties of Paris Agreement (2015) as National Determined Contributions with the target “to keep the temperature rise this century below 2 degrees Celsius” [1]. Forests play an important role in the sequestration of carbon dioxide and the storage of carbon, the protection and enhancement of existing and the establishment of new carbon reservoirs and sinks being important for the targets to reduce Greenhouse Gases emissions [2], [3]. As stated by the IPCC expert report, the current atmospheric concentration of CO₂ is only 57% of what it would have been if the forests had not stored carbon [4]. Despite the actions that are considering mitigation strategies, the effects of climate change are evident.

The atmosphere–biosphere carbon cycle has been intensively studied in order to quantify the different processes affecting atmospheric CO₂ concentrations, with the mission to mitigate climate change [5]. Within the carbon cycle, vegetation plays an important role by absorbing CO₂ from the atmosphere through photosynthesis and storing the carbon in organic material [1]. The forests in Romania, like all the forests in the temperate zone, have been exploited for a long time as a source of firewood and construction...
or as a place for pastures. In the middle of the last century, most European forests were affected by
increased pressure of the growing demand of wood, thus the increase of the harvested volume of timber,
which reduced the stock of aerial and underground biomass [2].

The report of the National Forest Inventory of Romania (NFI) from 2009 [6], indicates that there was a
net increase in both the forest area and the average volume of standing wood compared to the data of the
National Forest Inventory published in 1984. Also, as stated by the latest Greenhouse Gas Inventory, the
total GHG emissions in 2018, excluding removals by sinks, amounted to 116115.12 kt CO₂ equivalents.
According to the provisions of the Kyoto Protocol, Romania has committed itself to reduce GHG
emissions by 8% in 2008-2012 considering the reference year (1989) levels. The total GHGs emissions
(without considering sinks) decreased by 62.10% in 2018 compared to 1989 while the net GHG emissions
/ removals (taking into account the CO₂ removals) decreased by 68.32% [6].

Area of forest land reported at the end of NFI second cycle (2018) is 6929.05 kha, which represents
about 29% of the country area. The most abundant 10 species in Romania are Beech (31%), Spruce
(20%), Sessile Oak (8%), Common Hornbeam (7%), Fir (4%), Black Locust (4%), Turkey Oak (4%),
Pedunculate Oak (2%), Hungarian Oak (2%) and Birch (1%). The vast majority of Romania’s forests are
between 40 and 80 years old, meaning that they are in the most productive age now. Even so, the harvest
did not exceed the increment and indeed the actual felling was lower than the planned felling [7].

Soil organic carbon (C) dynamics have been used to assess sustainable land management in forest
ecosystems. Impact, defined as intensive forms of land use that affect the soil function, can change C
quantity and quality in soils, leading to a progressive degradation of the ecosystems [8,9]. Estimates of the
effect of forest practices on soil C storage are critical to predictions of both local ecosystem sustainability
and global C exchange with the atmosphere. Forest practices may have a significant effect on forest floor
structure and function through mechanical disturbance, inputs of logging slash, alterations in litter
production, and leaching of dissolved organic matter, as well as the alteration of temperature and moisture
regimes [10]. It is critical to study how different forest management practices affect forest carbon
sequestration under the global climate change regime. Many previous researches focused on the stand-
level forest carbon sequestration with rare investigation of forest carbon stocks influenced by forest
management practices and climate change at regional scale.

In this paper calculations of the most abundant tree species were conducted in the study area, which is
situated in the Eastern region of Romania. Thus, the forest carbon balance for the Oak (Quercus petraea)
and Black Locust (Robinia pseudoacacia) species were projected for the period of 2015 - 2040. Data from
management plans were used and analyzed using a forest model that is projecting forest resource
development on regional up to European scale, known as The European Forest Information SCENario
Model - EFISCEN. This study is aiming to highlight the potential of the Oak and Black Locust forests to
store carbon within the aforementioned time period considering that the same management practices will
be applied.

2. Materials and Methods

2.1. Material

Geographically, the studied Forest District is located in the Moldavian Plateau, the district of the Pliocene
hilly peaks of Fălciului and Corvului in the eastern part of the country (figure 1).
Figure 1. Representation of the administrative boundaries of the studied Forest District.

The administrative boundaries of the forest district are represented in the national Stereo 70 coordinate system, the official cartographic projection of Romania being the Stereographic Projection 1970. Figure above represents the administrative boundaries of the studied district and not the boundaries of the forest fund. In this territory, the state-owned forest fund represents only a part, in the form of relatively grouped forest bodies. Based on this limit, taking into account the geographical coordinates, as well as a series of databases, maps were processed in QGIS, highlighting the types of land cover (figure 2), as well as the types of soil (figure 3) within the studied Forest District.

Figure 2. Types of land cover in the studied Forest District.
The present study focused on two species of trees: Black Locust (*Robinia pseudoacacia*) and Sessile Oak (*Quercus petraea*). These represent the largest weights of trees in the arrangement, namely 37% and 28% respectively (figure 4). Thus, the area represented by Black Locust is 1863.3 ha, and the Sessile Oak is present in a total area of 1419.73 ha.

Forest biomass is one of the sinks recognized by the Intergovernmental Panel on Climate Change (IPCC) as having the potential to reduce concentrations of atmospheric carbon dioxide (CO₂) [11]. This has led to increased interest in forests and forest management as potential mitigators of climate change [12].

Species choice is potentially an important management decision for increasing carbon stocks in forest ecosystems. Black Locust (*Robinia pseudoacacia L.*) is a drought resistant tree, a fast growing tree species with ability to fix atmospheric N [13]. The Sessile Oak (*Quercus petraea*) is indigenous to Europe and...
widely distributed throughout the continent. Management of Oak forests is one of the biggest problems that forestry research is facing in recent years [14]. According to Sabaté et al. [15], the Oak species and their hybrids may be included in the list of species that will be transformed from C sinks to C sources as a result of global warming. If we know the size of the C sink formed by these forests, we will then be able to estimate the potential C source.

2.2 Methods
Typical methods for estimating soil carbon dynamics include repeated field surveys, paired sites and modeling. The European Forest Information Scenario Model (EFISCEN) was developed in the early 1980s by Saltnäs (1989) and was later used for the IIASA forest study for European forests [16]. The model has been further developed and used to provide baseline projections for European countries [17]. This model generates scenarios using information regarding forests in Europe and is used to analyze the consequences of the effects of climate change and the consequences of forest management practices at European level [18]. The software runs on the basis of manually generated matrices and includes forest data that are taken and added from national forest inventories [19,20]. The program determines the state of a forest in the form of distribution by age classes and volume classes in the form of matrices. Tree growth is described as changes in volume classes, which move to a larger volume class, and forest growth in terms of age [17].

In the matrix, growth is expressed as transition probabilities between its cells. The growth simulation is based on five-year volume increment as a percentage of standing volume. The percentage is predicted as a function of age. The growth functions are estimated from the data based on standing volume, volume increment and age. Each growth function is related to a particular series of standing volumes over age. To prevent high stocked cells from growing exponentially fast and to take into account the increase in growth after thinning, explicit corrections are made [17].

In order to run the software, data from the management plans of the researched area were used. The basis of this simulation consists of one region, 4 sub-units of production, one site class, two tree species and the age classes. Furthermore, the basic input data used in this study is composed from the structure of the age class, area, average standing volume and net annual increment. The stratification was made by dividing the study area in sub-units of production (SOP) as follows: SOP A, SOP Q, SOP M, SOP E, SOPK and SOP O. As an example of data used in this study, input data for the Oak species from SOP A and for Black Locust from 3 cumulated SOP’s is depicted in the following table (table 1).
**Table 1.** Example of the basic information used in order to run the main software.

| Age class | Area (ha) | Average standing volume (m$^3$ha$^{-1}$) | Net annual increment (m$^3$ha$^{-1}$an$^{-1}$) |
|-----------|-----------|----------------------------------------|-----------------------------------------------|
|           | Oak       | Black Locust                          | Oak                                           |
| 1 - 20    | 25.9      | 272.6                                 | 5.3                                           |
| 21 - 40   | 91.5      | 57.58                                 | 137                                           |
| 41 - 60   | 169.5     | 6.6                                    | 165.7                                         |
| 61 - 80   | 704.1     | 2.62                                   | 203.8                                         |
| 81 - 100  | 89.3      | 0                                      | 131                                           |
| 101 - 120 | 73        | 0                                      | 134.1                                         |
| 121 - 140 | 0         | 0                                      | 0                                             |

The growth function for the researched species was defined on the basis of the a0, a1 and a2 parameters [21] in the following table the growth functions used for a strata are defined for the researched species (table 2).

**Table 2.** The growth functions used within the simulation for strata of the two species.

| a0    | a1       | a2       |
|-------|----------|----------|
| -5.08 | 1129.7   | -6136.6  |
| 53.479| -2282.6  | 17511    |

Other relevant parameters are $c_v$ that is the coefficient of variation of the volume per hectare, $r$ is the correlation between volume per hectare and ln(age), $VCW$ is the volume class width and $Beta$ is considered to be the parameter that is describing the relation between the relative standing volume and the relative volume increment (table 3) [21,22]. For both species, the young forest coefficient was set to 0.4, so it was the Gamma parameter that is expressing the regrow capacity after thinning. The bio-parameters are established in order to define the carbon content, dry wood density, biomass allocation and litter production [23]. Therefore, the following parameters were defined as the proportion of carbon in total biomass of dry matter, the basic wood density, the age classes for the biomass distribution functions, the proportion of total biomass and living biomass in stem, branches, coarse roots, fine roots and foliage by age class were used [23]. The data used for the bio-parameters is represented in table 4.
Table 3. Depiction of cv, r, VCW and Beta parameters used for running the study.

| Forest identification number | 1111 | 1211 | 1311 | 1411 | 1112 | 1212 | 1312 | 1412 |
|-----------------------------|------|------|------|------|------|------|------|------|
| cv                          |      |      |      |      |      |      | 0.65 |      |
| r                           | 0.45 |      |      | 0.5  |      |      |      |      |
| VCW                         | 57   | 1.3  | 61   | 1.3  | 24   | 21   | 20   |      |
| Beta                        |      |      |      |      |      |      |      | 1    |

Table 4. The data used for the bio-parameters.

| Physical property          | stem share  | branches share | coarse roots share | fine roots share | foliage share |
|----------------------------|--------------|-----------------|--------------------|------------------|---------------|
|                            | 0.5996       | 0.0999          | 0.2358             | 0.0206           | 0.0441        |
|                            | 0.6655       | 0.1096          | 0.1895             | 0.0116           | 0.0238        |
|                            | 0.6901       | 0.1183          | 0.1673             | 0.0080           | 0.0163        |
|                            | 0.6985       | 0.1208          | 0.1601             | 0.0066           | 0.0140        |
|                            | 0.7115       | 0.1085          | 0.1608             | 0.0059           | 0.0133        |
|                            | 0.7196       | 0.0959          | 0.1655             | 0.0056           | 0.0134        |
|                            | 0.7212       | 0.0888          | 0.1709             | 0.0053           | 0.0138        |

Since the software is allowing its user to define scenarios, within this study were defined different scenarios files, comprising the management practices. However, the same data was used in the scenario files for both tree species as well the same soil and management parameters were used during the simulation. Further researches are needed for the quality control and quantification of uncertainties of the input data.

3. Results and Discussions

Under the used input data, it has been found that the total carbon content in the Oak tree species increases over time (figure 5). Furthermore, the carbon from different compartments of the soil are represented and it can be noticed that the carbon from soil is fluctuating over time in the soluble and non-woody litter compartments. However, within the holocellulose and fine-woody and coarse-woody litter compartments, the sequestered carbon is increasing. Therefore, the more detailed information of the carbon content in different compartments of soil, such as in holocellulose, in the soluble compounds, within the non-woody, fine-woody and coarse-woody litter can be observed in figure 6. Although the total carbon stock in soil is increasing over time, within the first humus, second humus and lignin-like compounds compartments slight differences can be noticed (figure 7).
**Figure 5.** Total carbon content in Oak trees (Gg C).

**Figure 6.** Carbon in different compartments of soil: holocellulose, soluble compounds, non-woody litter, fine-woody litter and coarse-woody litter.
The results for the second researched tree species showed that the total carbon content from Black Locust trees is increasing until the year 2020, afterward it can be observed as a decreasing trend. However, for the last 5 years, a slight increase in total carbon in trees can be noticed (figure 8). Regarding the carbon from soil, it can be observed that in the holocellulose, in the soluble compounds and non-woody litter the carbon content is decreasing over time, while the carbon content in fine woody and coarse woody litter is increasing (figure 9). Additionally, the carbon content from the first and second humus compartments and within the lignin like compounds is slowly decreasing. Therefore, the total carbon stock in soil is decreasing over the projected period of time (figure 10).
Figure 9. Carbon in different compartments of soil within Black Locust trees: in holocellulose, in the soluble compounds, non-woody litter, fine woody litter and coarse woody litter.

Figure 10. Carbon in different compartments of soil: 1st humus compartment, 2nd humus compartment, lignin-like compounds, total carbon stock in soil.
4. Conclusions

This study focused on the capacity of two tree species from the study area to store carbon. Therefore, data for the Oak (*Quercus petraea*) and Black Locust (*Robinia pseudoacacia*) species were collected and used within The European Forest Information SCENario Model - EFISCEN. The input data characterizing the tree species, such as age classes, area, average standing volume and net annual increment were selected from local management plans. Then, the growth functions were calculated for each tree species. However, the same bio-parameters were used for both tree species, so it was in the case of management scenario files, in order to highlight the difference between the two species by the rest of their characteristics.

On a first analysis over the study, it can be observed that the forests accumulate carbon over time. The most important quantities are represented by the Oak species, since it can accumulate higher amounts of carbon over time both in trees and its soil compartments. In contrast, the simulations showed that the other species is also accumulating carbon, however after a period the capacity of the Black Locust forest to sequester carbon decreases. Regarding the carbon present in the analyzed soil compartments: in the humus compartments any changes are barely noticeable; apart from these, the carbon content in the lignin like compounds is slowly increasing for the Oak tree while for the later species is dropping; the same situation is happening within the total carbon stock in soil.

Comparing the tree species analyzed within this study, it can be verified that the Oak species have higher capacity to store carbon overtime, than the Black Locust species. The Oak trees are storing carbon by increasing their amount over the studied period, while the projections were showing that the carbon content within the Black Locust species is decreasing overtime.

Due to lack of accurate information some of the input parameters (e.g. bio-parameters) were used for both researched species. Further research is needed for quality control and uncertainty quantification of other input parameters (e.g. input data for growing stock, soil parameters) by aggregation with other data sources as forest inventories or validation by other methods (e.g. field measurements, remote sensing). Regarding the forest management practices, different situations can be simulated for each species with the aim to increase the carbon reservoirs without affecting the state of the forest and other ecosystem services and also the results must be verified.

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