



FORECASTING SOIL CARBON STOCK OF DECIDUOUS BROADLEAF FOREST IN DAK LAK PROVINCE USING THE ROTH C MODEL

Duong Dang Khoi

Hanoi University of Natural Resources and Environment, Vietnam

Received 04 October 2022; Accepted 28 November 2022

Abstract

This study aims to apply the RothC model for predicting the carbon storage potential of Deciduous Broadleaf Forest (DBF) in Dak Lak province. The prediction results reveal that soil organic carbon of the DBF shows an increasing trend during the period of 2020 - 2050. The results of the prediction of organic components indicate that Humified Organic Mater (HUM) and Resistant Plant Material (RPM) are the main components of total soil organic matter in the DBF region. Decomposable Plant Material (DPM), Microbial Biomass (BIO), and Inert Organic Matter (IOM) account for smaller percentages. The different states of the DBF are projected to have approximately the same soil carbon storage levels. Specifically, the moderate DBF is predicted to store a soil organic amount of 70.42 tons per hectare. The poor DBF is forecasted to have an average organic amount of 70.37 tons per hectare. The very poor DBF is projected to store an amount of 72.15 tons per hectare. Forecasting of the DBF soil carbon storage potential is for the assessment of the total organic carbon stock of the DBF ecosystem, as a basis for payment of local forest carbon storage service.

Keywords: RothC; Total Organic Carbon (TOC); Soil Organic Carbon (SOC); Deciduous Broadleaf Forest (DBF); Dak Lak.

Corresponding author. Email: ddkhai@hunre.edu.vn

1. Introduction

Soil organic carbon is an important carbon pool of forest ecosystems, playing an important role in storing CO₂ in the soil, and contributing to climate change mitigation (FAO, 2018; Yao Huang et al., 2008). However, the prediction studies of the ability to store organic carbon in forest soils have not received much attention in Vietnam. The main reason is limited funding for forest soil carbon surveys.

Moreover, forest soil carbon prediction using the modeling method has not been paid attention.

In the literature, various methods can be applied to estimate the carbon storage capacity of forest soil, but the most common methods are soil survey and modeling. The soil survey is a standardized method, widely applied, with the highest accuracy. However, soil survey often requires a long time and a large amount of money and manpower

involved in taking soil samples as well as analyzing soil samples. The modeling method is often applied to forecast soil organic matter using existing soil datasets. The most commonly used models for quantitative assessment of soil organic carbon are CENTURY (Parton et al., 1987), RothC (Coleman and Jenkinson, 1999), Agro-C (Yao Huang et al., 1999). 2008) and InVEST-C (Tallis et al., 2013).

The RothC, developed from experimental data at the Rothamsted Agricultural Research Station of the United Kingdom, often applies to assess soil organic matter in non - flooded areas. Currently, the model has been extended to include agricultural, grass and forest soil worldwide (Coleman and Jenkinson, 1999; Falloon et al., 1998; Weihermüller et al., 2013). Datasets required for running the model include monthly rainfall, monthly evaporation, monthly average temperature, clay content and organic matter decomposition coefficients. In this study, the RothC is applied to predict the organic matter storage potential in the soil of the DBF in Dak Lak province. The RothC was chosen because the dataset used to run the model can be collected locally and is suitable for the limited soil data conditions of Vietnam and Dak Lak province.

2. Methods

2.1. Data collection

The secondary datasets of monthly rainfall, monthly evaporation, monthly mean temperature, clay content and soil organic carbon were collected to run the RothC. Meteorological data was collected in the period 1981 - 2018. The clay and soil organic content dataset were collected from the soil degradation survey dataset of Dak Lak province in 2019 released

by the Dak Lak Department of Natural Resources and Environment (Dak Lak Department of Natural Resources and Environment, 2019). In addition, 60 soil samples were taken at the study area in the year 2022 to supply the prediction.

2.2. Predicting soil carbon stock by RothC model

The study predicts soil carbon storage potential by the RothC for each soil type within the boundary of the DBF, then synthesizes the carbon storage potential according to each forest state type. Soil carbon stock predicted by RothC software can be summarized in the following steps:

Step 1. Calculate initial organic components: initial organic components starting in the year 2020 (DPM, RPM, BIO, HUM, IOM) were calculated using pedotransfer functions (Falloon et al., 1998; Weihermüller et al., 2013) as follows:

+ Resistant Plant Material (RPM) is estimated as:

$$RPM = (0.1847 * SOC + 0.1555) * (clay + 1.2750)^{-0.1158}$$

In which, clay is the percentage of soil mass, SOC is soil organic carbon (tons per hectare)

+ Decomposable Plant Material (DPM) is given as:

DPM is estimated by the ratio of RPM and DPM.

+ Microbial Biomass (BIO) is estimated as:

$$BIO = (0.0140 * SOC + 0.0075) * (clay + 8.8473)^{0.0567}$$

+ Humified Organic Matter (HUM) is calculated as:

$$HUM = (0.7148 * SOC + 0.5069) * (clay + 10.3421)^{0.0184}$$

+ Inert Organic Matter (IOM) is calculated as:

$$\text{IOM} = 0.0049 * \text{TOC}^{1.139}$$

In which, TOC is total soil organic carbon.

Step 2. Create a soil data file: Enter monthly organic material input data, along with monthly land cover in file format in RothC software.

Step 3. Create a climate dataset file: Enter monthly rainfall data, monthly evaporation amount, monthly average temperature, and simulated clay content and soil thickness data into the format table of RothC software.

Step 4. Create a scenario.set file for running the RothC model. The software allows to create a script file for running the model, the scenario file will integrate all input data including input organic matter and climate data. The file is saved in the format “*scenario.set*”.

Step 5. Run RothC according to the file “*scenario.net*” of each soil type. Run the “*scenario.set*” created in *step 4* using the run command. The RothC calculates the amount of each organic component. Let say Y (ton C per hectare) is the amount of organic carbon (Y is the component of DPM, RPM, BIO, HUM, except for the IOM component because IOM is very stable, lasts 50,000 years, so it does not calculate fluctuations in time) at a certain time (month), then after one month the carbon stock of each component according to the state of the forest is calculated (Coleman and Jenkinson, 1999) by the expression as:

$$C_t = Y * e^{-abckt}$$

In which, C_t is the amount of the residual carbon component in the soil at the time after one month from the starting time.

The amount of organic carbon decomposed in one month is estimated as:

$$Y(1 - e^{-abckt})$$

a is the constant of adjustment for the effect of temperature, b is the constant of adjustment for the effect of moisture, c is the decomposition constant of the organic component; $t = 1/12$ because it is month by month.

$$a = 47.9/1 + e^{(106/T + 18.3)}$$

where T is the monthly average temperature.

$$b = - (20.0 + 1.3 (\% \text{ clay}) - 0.01 (\% \text{ clay})^2)$$

The value of b is calculated for the soil layer of 23 cm if the soil thickness is greater than 23 cm, then b is adjusted as divided by 23 and multiplied by the soil thickness (cm).

c = 0.6 for soil with land covered by vegetation and c = 1.0 for bare land.

k is assigned a constant of 10 for DPM; 0.3 for RPM, 0.66 for BIO; 0.02 for HUM.

Step 6. Interpret simulation results: Display the results in the form of graphs or access the resulting data files for each soil type to perform analysis and present the resulting data in appropriate graphs or charts.

3. Results

3.1. Predicting soil carbon stock by soil type

By the use of the input datasets of organic materials, climate and soils in the region, RothC predict change in DPM, RPM, BIO, and HUM components

for each month in the entire simulation period. The climate dataset used in the study is from 1981 to 2018 (37 years). Therefore, the study makes a forecast for 30 years from 2020 to 2050. The starting point is defined at the year 2020.

a. Fluvisols

Fluvisols consist of 2 soil types distributed in the DBF area; therefore, the study predicts these soil types. The red - yellow patchy alluvial soil (Pf) soil shows an uptrend carbon in the simulation period.

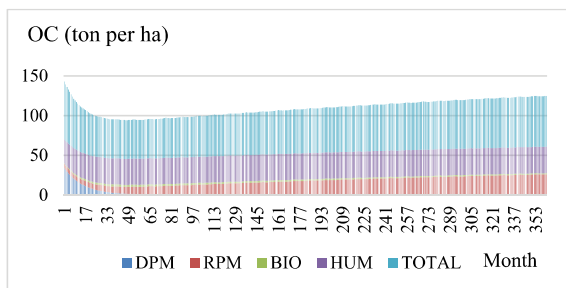


Figure 1: Change in predicted soil carbon of Pf

The stream and alluvial soil (Py) is formed mainly along narrow, steep streams with strong currents on relatively lower terrain compared to other areas of the region. The forecasting results showed that there is a decrease in the amount of organic matter for several years from the starting year 2020, followed by a cycle of increasing soil organic matter accumulation until 2050. This is explained by an increase in HUM as well as RPM in the soil.

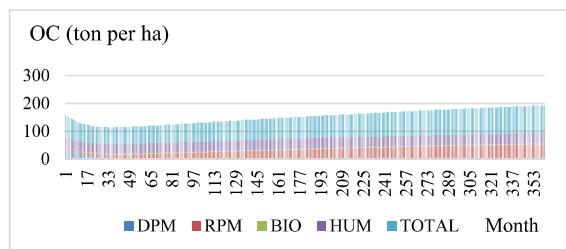


Figure 2: Change in predicted soil carbon of Py

b. Acrisols

The clay soil based on acid magma and sand rock (Xa) covers an area of 137,473 hectares, accounting for 10.51 % of the province’s total natural area. Xa is distributed in most of the Ea Sup, Ea Kar and Ea HLeo districts. The forecast results showed that the amount of organic matter accumulated in the soil has increased steadily, with a large contribution from the increase in the amount of RPM, followed by HUM.

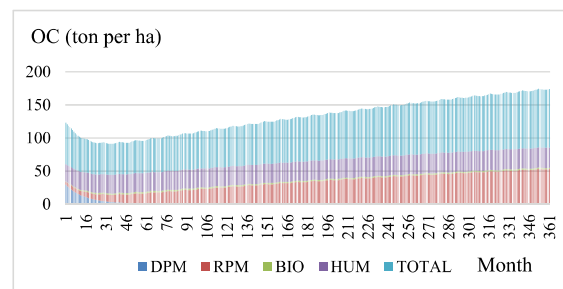


Figure 3: Change in predicted soil carbon of Xa

c. Luvisols

The black soil based on basalt rock (Rk and Ru soils) has an area of 8,286 hectares, accounting for 0.55 % of the province’s natural area. Luvisols are distributed in lowland terrain, narrow valleys where there are conditions to accumulate accretion products of basalt rock. The simulation results showed that the total organic matter increased as a result of an increase in HUM and RPM.

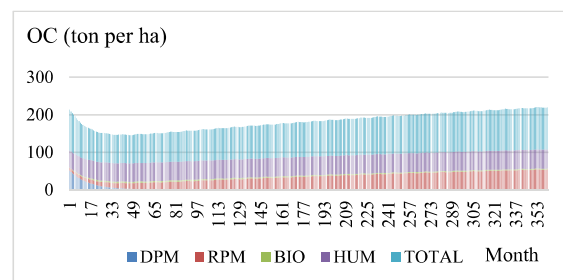


Figure 4: Change in predicted soil carbon of Rk

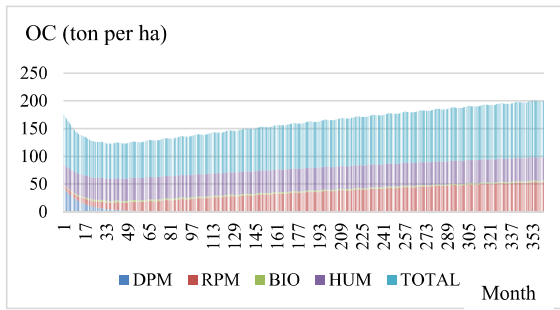


Figure 5: Change in predicted soil carbon of Ru

d. Ferrasols

The red - yellow soil based on acid magmatic rock (Fa), the amount of HUM dominates in the calculation period, the HUM is much larger than the RPM, almost twice. At the end of 2050, the amount of new RPM increased by oversold compared to the amount of HUM.

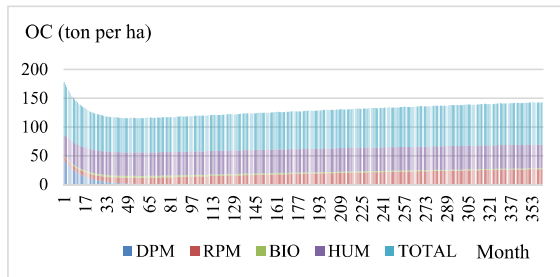


Figure 6: Change in predicted soil carbon of Fa

With the red - brown soil based on basalt rock (Fk), the two components HUM and RPM are adjusted in the simulation stages. In the first 20 years (2020 - 2040), the amount of humus (HUM) dominates. But in the period of 2040 - 2050, the amount of HUM and RPM are approximately the same.

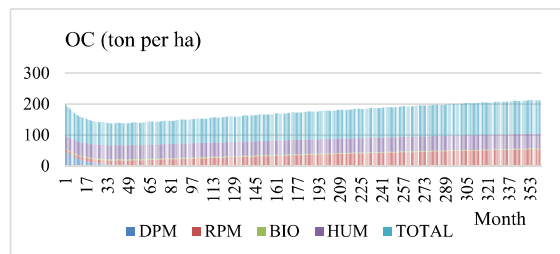


Figure 7: Change in predicted soil carbon of Fk

The yellow - brown soil based on ancient alluvium rock (Fq), organic matter in the first period is that the amount of HUM dominates, then RPM prevails in the later stage.

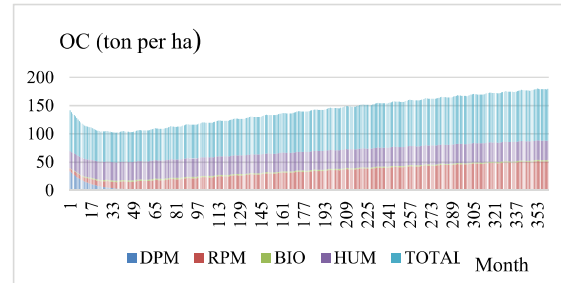


Figure 8: Variation in predicted soil carbon of Fq

The yellow - red soil based on clay and metamorphic rocks (Fs) and the yellow - brown soil based on basalt rock (Fu), HUM always dominates in the whole forecast period. The amount of RPM accounted for less than half (Fs and Fu) in the late period. Thus, HUM is the decisive factor in the total organic content in Fs, Fu soil in the study area.

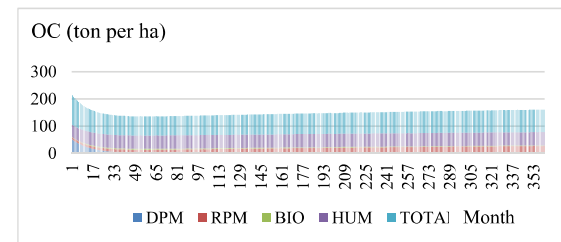


Figure 9: Change in predicted soil carbon of Fs

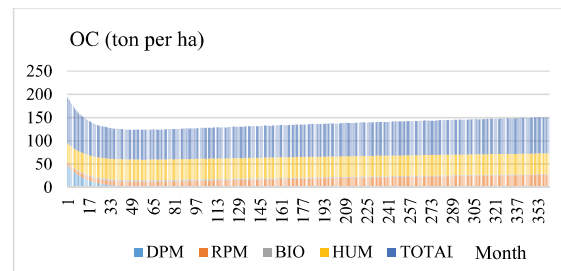


Figure 10: Change in predicted soil carbon of Fu

e. Humic Ferrasols

The analysis of the organic carbon predicted by RothC showed that the

amount of HUM is dominant over the entire forecast period. The amount of RPM is cumulative and is about half of the HUM at the end of the forecast period.

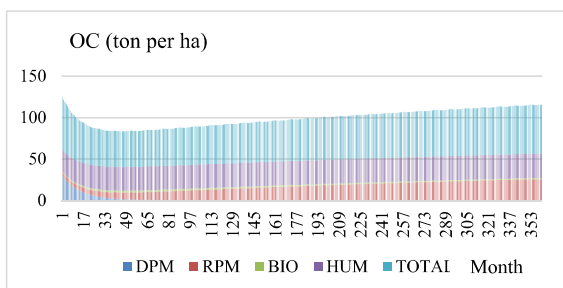


Figure 11: Change in predicted soil carbon of Ho

f. Dystric Gleysols

The valley soil (D) has an area of 11,548 hectares, accounting for 0.83 % of the total natural area of the province. It is scatteredly distributed in the valleys of the hilly areas, present in most districts, except Ea Sup district. The results showed that the accumulated organic amount in the 30 - year period (2020 - 2050) ranges from 60 to nearly 80 tons per hectare. In the valley soil, HUM and RPM components are dominant in the forecasting period, the remaining organic components account for a small proportion.

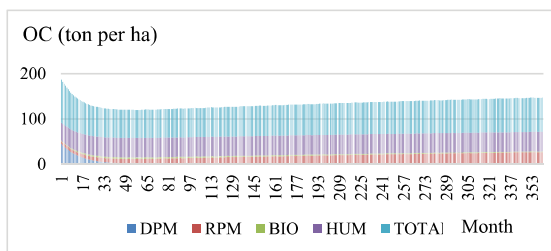


Figure 12: Change in predicted soil carbon of D

g. Lithic Laptosols

The erosive soil (E) covers an area of 27,538 hectares, accounting for 2.10 % of the total natural area, mainly concentrated in Ea Hleo, Ea Sup and Buon Don districts. If afforestation and forest restoration are carried out, the total organic carbon will increase significantly, ranging from 45 to 85 tons per hectare during the forecast period. The predominant organic component is HUM in the first 10 years of the forecast, and then in the next 20 years, the RPM dominates.

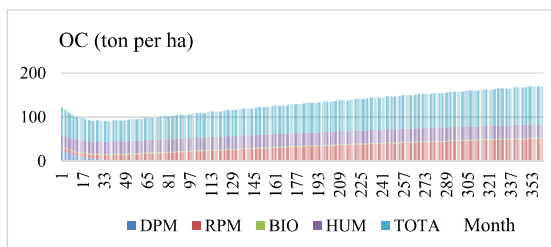


Figure 13: Change in predicted soil carbon of E

3.2. Predicting soil carbon stock by forest states

a. Moderate deciduous broadleaf forest

Table 1. Predicted TOC of soil types in moderate deciduous broadleaf forest

Soil description and scientific name	Symbol	TOC (tons per ha)		
		Max	Min	Mean
Eroded soil (Lithic Laptosols)	E	86.65	46.59	65.99
Gray soil based on acid magma and sandy rock (Haplic Acrisols)	Xa	88.48	46.86	66.98
Red and yellow soil based on clay and metamorphic rocks (Plinthic Ferrasols)	Fs	109.05	70.19	76.96

Yellow red soil based on acid magma rock (Rhodic Ferrasols)	Fa	91.18	59.65	66.73
Dark terracotta soil based on pumice and basalt rock (Chromic Luvisols)	Ru	102.28	63.27	82.08
Yellow soil based on sandstone (Xanthic Ferrosols)	Fq	91.62	52.56	71.46
Alluvial and stream soil (Eutric Fluvisols)	Py	98.19	58.43	77.62
Reddish brown soil based on Basalt rock (Rhodic Nitisols)	Fk	108.84	71.06	89.26
Red yellow humus soil in the high mountain (Humic Ferrasols))	Ho	63.59	42.96	50.85
Alluvial soil with red and yellow patchy layers (Cambic Fluvisols)	Pf	72.96	48.68	56.28
Moderate DBF mean				70,42

In the state of the moderate DBF, it is expected to have a carbon stock mean of 70.42 tons per hectare. However, the carbon stock of the moderate DBF state depends on the carbon content of the soils occupying the predominant area. The yellow soil is based on sandy rocks (Fq), accounting for 63.4 % of the total moderate DBF area and the yellow red soil is based on clay and metamorphic rocks (Fs), occupying 11.95 % of the total moderate DBF. Thus, these soils dominate the soil carbon of the moderate DBF.

b. Poor deciduous broadleaf forest

The state of the poor DBF is forecasted to store an amount of carbon in the period 2020 - 2050 at an average of 70.37 tons per hectare. Just like the poor DBF state, two types of soil are yellow soil based on sandy rocks (Fq) accounting for 61.2 % of the total area of the poor DBF and red yellow soil based on clay and metamorphic rocks (Fs) accounting for 13.83 % of the total area. Therefore, these two soils govern the carbon stock of the poor DBF.

Table 2. Predicted TOC of soil types in poor deciduous broadleaf forest

Soil description and scientific name	Symbol	TOC (tons per ha)		
		Max	Min	Mean
Eroded soil (Lithic Laptosols)	E	86.65	46.59	65.99
Gray soil based on acid magma and sandy rock (Haplic Acrisols)	Xa	88.48	46.86	66.98
Red and yellow soil based on clay and metamorphic rocks (Plinthic Ferrasols)	Fs	109.05	70.19	76.96
Yellow red soil based on acid magma rock (Rhodic Ferrasols)	Fa	91.18	59.65	66.73
Dark terracotta soil based on pumice and basalt rock (Chromic Luvisols)	Ru	102.28	63.27	82.08
Yellow soil based on sandstone (Xanthic Ferrosols)	Fq	91.62	52.56	71.46
Alluvial and stream soil (Eutric Fluvisols)	Py	98.19	58.43	77.62
Reddish brown soil on basalt rock (Rhodic Nitisols)	Fk	108.84	71.06	89.26

Dark terracotta soil based on pumice and basalt products (Haplic Nitisols)	Fu	98.87	64.13	71.09
Red yellow humus soil in the high mountain (Humic Ferrasols)	Ho	63.59	42.96	50.85
Valley soil (Distric Gleysols)	D	95.58	62.12	69.17
Alluvial soil with red and yellow patchy layers (Cambic Fluvisols)	Pf	72.96	48.68	56.28
Poor DBF mean				70.37

c. Very poor deciduous broadleaf forest on acidic igneous rock and sandstone (20.36 % of the DBF area), red - yellow soil is based on clay and metamorphic rock (14.18 % of very poor DBF area), the red - yellow soil based on acidic igneous rock (10.55 % of very poor DBF area) are soil types that dominate the total organic storage stock of the very poor DBF.

The very poor DBF is forecasted to store an amount of carbon in the period 2020 - 2050 at an average of 72.15 tons per hectare. The yellow soil is based on sandy rocks (accounting for 49.90 % of the very poor DBF area), the gray soil is based

on acidic igneous rock and sandstone (20.36 % of the DBF area), red - yellow soil is based on clay and metamorphic rock (14.18 % of very poor DBF area), the red - yellow soil based on acidic igneous rock (10.55 % of very poor DBF area) are soil types that dominate the total organic storage stock of the very poor DBF.

Table 3. Predicted TOC of soil types in very poor deciduous broadleaf forest

Soil description and scientific name	Symbol	TOC (tons per ha)		
		Max	Min	Mean
Eroded soil (Lithic Lptosols)	E	86.65	46.59	65.99
Gray soil based on acid magma and sandy rock (Haplic Acrisols)	Xa	88.48	46.86	66.98
Red and yellow soil based on clay and metamorphic rocks (Plinthic Ferrasols)	Fs	109.05	70.19	76.96
Yellow red soil based on acid magma rock (Rhodic Ferrasols)	Fa	91.18	59.65	66.73
Dark terracotta soil based on pumice and basalt rock (Chromic Luvisols)	Ru	102.28	63.27	82.08
Yellow soil based on sandstone (Xanthic Ferrosols)	Fq	91.62	52.56	71.46
Alluvial and stream soil (Eutric Fluvisols)	Py	98.19	58.43	77.62
Reddish brown soil on Basalt rock (Rhodic Nitisols)	Fk	108.84	71.06	89.26
Dark terracotta soil based on pumice and basalt products (Haplic Nitisols)	Fu	98.87	64.13	71.09
Red yellow humus soil in the high mountain (Humic Ferrasols)	Ho	63.59	42.96	50.85
Black soil based on alluvial products of Basalt rock (Ferric Luvisols)	Rk	112.65	75.46	93.42
Valley soil (Dystric Gleysols)	D	95.58	62.12	69.17
Alluvial soil with red and yellow patchy layers (Cambic Fluvisols)	Pf	72.96	48.68	56.28
Very poor DBF mean				72.15

4. Conclusion

By the use of the RothC model for predicting soil carbon of DBF soils in Dak Lak province, the result revealed that the RothC model is quite suitable in the condition of Dak Lak province. The model is a simple, effective and cost-effective calculation tool for the prediction of organic carbon change over time in forest soils. The results of predicting organic components of soils distributed in the DBF area demonstrated that the total organic carbon of all soil types shows an increasing trend in the period 2020 - 2050. The results of the prediction of changes in organic components also indicated that HUM and RPM are the main components constituting the total organic matter of the soil. DPM, BIO and IOM account for smaller percentages. The DBF states are projected to have approximately the same soil organic carbon storage levels. The moderate DBF state has a soil organic stock mean of 70.42 tons per hectare. The poor DBF is forecasted to have an organic stock mean of 70.37 tons per hectare. The very poor DBF is forecasted to have a storage capacity mean of 72.15 tons per hectare. The prediction results can be used as useful reference data for estimating the economic value of soil carbon in the local DBF, as a basis for payment of DBF carbon storage service.

Acknowledgements: This study was funded by the Dak Lak Department of Science and Technology through the research project: “*Quantification of CO₂ storage capability of forest states and rubber plantation in Dak Lak province using Landsat data*” with grant number 97/HD-SKHCN. The author would like to thank the anonymous reviewer for constructive comments that help to improve the manuscript.

REFERENCES

- [1]. Department of Natural Resources and Environment of Dak Lak province (2019). *Report on land degradation in Dak Lak province in 2019*. Department of Natural Resources and Environment of Dak Lak province (In Vietnamese).
- [2]. FAO (2018). *Global soil organic carbon map: Technical report*. FAO, Rome.
- [3]. Falloon, P., Smith, P., Coleman, K. & Marshall, S., (1998). *Estimating the size of the inert organic matter pool from total soil organic carbon content for use in the Rothamsted carbon model*. Soil Biology and Biochemistry 30, 1207 - 1211.
- [4]. Parton, W.J., Schimel, D.S., Cole, C.V. & Ojima, D. S. (1987). *Analysis of factors controlling soil organic levels of grasslands in the Great Plains*. Soil Sci. Soc. Am. J. 51:1173 - 1179.
- [5]. Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C. K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J and Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. (2013). *InVEST 2.5.6 User's Guide*. The Natural Capital Project, Stanford University, USA.
- [6]. Huang, Y; Yu, Y; Zhang, W; Sun, W; Liu, S; Jiang, J; Wu, J; Yu, W; Wang, Y; Yang, Z. (2006). *Agro-C: A biogeophysical model for simulating the carbon budget of agroecosystems*. Agricultural and Forest Meteorology 149: 106 - 129.
- [7]. Weihermüller, L., Graf, A., Herbst, M., Vereecken, H. (2013). *Simple pedotransfer functions to initialize reactive carbon pools of the RothC model*. European Journal of Soil Science 64: 567 - 575.