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COMPUTER SIMULATION OF CARBON SEQUESTRATION POTENTIAL IN FOREST ECOSYSTEM

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ABSTRACT

Computer simulation has been widely used in various fields of ecology with the cross-integration between the various disciplines. As the largest organic carbon (C) pool in terrestrial ecosystems, forest plays an important role in regulating the global C balance and mitigating the increase of atmospheric CO_2 concentration. Combined with forest inventory data and literature, this study analyzed the potential of C sequestration in existing forests in Jilin Province, China using CO_2FIX model. The results showed that in the end of 120 years simulated, the highest and the least amount of C stock was accumulated in the bioenergy and soil, respectively. In contrast, C storage of the biomass was more than that of forest products. The application of computer model not only can effectively estimate the C sequestration potential of the forest ecosystem, but can show the dynamic of C sequestration in simulated period. Therefore, the computer simulation is a relatively convenient, economical and effective method to estimate C stock of forest ecosystem of large-scale area.

Keywords: *Computer simulation, CO_2FIX model, Carbon sequestration potential, Forest ecosystem*

1. INTRODUCTION

Global warming has become one of the major environmental problems threatening human survival, which is the result of the large number of fossil fuel combustion and the reduction of forest resources. Government and scientists attach great attention to reducing emission of CO_2 from energy activities to the atmosphere. Forests, as the largest organic carbon (C) reservoir of the terrestrial ecosystem, play a significant role in regulating the global C balance and mitigating the increase of atmospheric CO_2 concentration [1].

It has been reported that forests store about 45% of terrestrial C, more than double the amount of C in the atmosphere [2]. In addition, making use of the C sequestration of the forest ecosystem to reduce emission has many advantages, such as low-cost, easy to operate, bear fruit quickly and so on [3]. Therefore, it has become an important research on C sequestration capacity and potential of forest ecosystems in the global C cycle. Researchers in many countries have done a lot of work for enhancing C storage in forest ecosystems in order to offset the CO_2 emissions [4].

Forest C is not only fixed in the biomass and soil, but in the variety of forest products. On the one hand, large amounts of C can be stored in timber forest products for decades, on the other hand, wood products replacing steel and cement as building materials can reduce emissions indirectly. Traditional methods only utilize the forest resource inventory data for statistical analysis, and researches on forest C storage mainly focus on biomass and soil [5]. However, it is some lack of knowledge about the forest products C storage as yet.

With the cross-integration between the various disciplines, computer simulation has been widely used in various fields of ecology. Computer model can integrate all aspects and the limiting factors to estimate the C sequestration potential combined with the inventory data, providing a novel and feasible way for forest ecosystem C sequestration potential analysis [6]. Therefore, this study calculated the potential of C sequestration in existing forests in Jilin Province, China based on the forest inventory data and literature, using CO_2FIX model in order to provide a reference for more comprehensive and accurate estimate.

2. METHODS

CO_2FIX model was developed by the University of Wageningen, based on the C balance of the ecosystem-level model [7]. The model can be used to simulate C storage and C flux of live tree, soil and wood products in the forest ecosystem, and the unit was 1 year. CO_2FIX V3.1 version [8] included biomass module, soil module, products module, bioenergy module, financial module and C accounting module.

The total C physically stored in the system at any time (CT_t) was considered to be:

$$CT_t = Cb_t + Cs_t + Cp_t \tag{1}$$

Where Cb_t is the total C stored in living biomass at any time 't' (MgC ha^{-1}), Cs_t is the C stored in soil organic matter (MgC ha^{-1}), and Cp_t is the C stored in wood products (MgC ha^{-1}).

2.1 Biomass Module

Biomass module considered C stock per unit area on the biomass was effected by the growth of stem (including bark), foliage, branches, roots, and the mortality of the vegetations and logging, among which the effect of the growth of stem was dominant. The increase of the branches, foliage and root biomass were determined by the coefficient of the relative proportion compared with the increase of the stem biomass. The carbon stored in living biomass (Cb_t) of the whole forest stand, can be expressed as the sum of the biomasses of each cohort:

$$Cb_t = \sum Cb_{it} \tag{2}$$

Where Cb_{it} is the carbon stored in the living biomass of cohort 'i' at time 't' (MgC/ha).

$$Cb_{it+1} = Cb_{it} + Kc\left[Gb_{it} - Ms_{it} - T_{it} - H_{it} - Ml_{it}\right] \tag{3}$$

Where Cb_{it} is calculated as the balance between the original biomass, Gb_{it} is biomass growth, T_{it} is the turnover of branches, foliage and roots, Ms_{it} is tree mortality due to senescence, H_{it} is harvest and Ml_{it} is mortality due to logging. Kc is a constant to convert biomass to carbon content (MgC per Mg biomass dry weight).

2.2 Soil Module

Soil C stock and C flux were estimated by the dynamic soil module of YASSO in model. The input factor of soil C could be directly imported from biomass module. The module comprised three residual portions and five decomposing parts. This model regarded the soil layer as a whole rather than considered C sinks in different soil layers in the current version of the model.

2.3 Products Module

The trend of C after forest products harvesting was tracked in the product module. The stems and harvested branches were the material source of the product modules. The module only considered the C formed in biomass initially without vegetable glue. It was assumed that C emissions were average in the useful life of the forest products.

The products module distinguished three categories of end products: long term, medium term and short term products. Each of the commodities was distributed over these end product categories. For each end product category, for the mill site dump and for the landfill, an a half live was defined. In CO_2FIX V3.1 exponential discard or decay functions were used:

$$P_{t+1,k} = P_{tk} \times \left[1 - \ln(2)/L_k\right] \tag{4}$$

Where P_{tk} is the amount of carbon in product category 'k' at time 't' and L_k is the half live for category 'k'.

2.4 Bioenergy Module

Burning fossil fuels made the C sequestered in long term released into the atmosphere, while the utilization of biomass only released a short-term fixed C, without additional increasing of the atmospheric C. In the model, bioenergy was derived from the residues of industrial production (waste products, the loss of processing, et al.) and cutting remainders. There were two ways to reduce the consumption of the biomass: (1) Replace fossil energy with biomass; (2) Improve the existing technology of employing biomass.

$$GHG_{mitj} = E_{sj} - E_{aj} \tag{5}$$

Where GHG_{mitj} is greenhouse gas mitigation of greenhouse gas 'j', E_{sj} is emissions of greenhouse gas 'j' of the fuel/technology to be substituted and E_{aj} is emissions of greenhouse gas 'j' of the alternative technology.

In this study, we assumed that the tree will be harvested when it has been matured and plant the same species subsequently. In addition, we assumed that non-timber forest reached C cycle dynamic equilibrium when it matured, using this scenario to simulate the net amount of C sequestration of the forest ecosystem. The simulation time of this study was 120 years.

3. MODEL PARAMETERS

3.1 The Area Of Immature Forest

The area of the dominant timber species containing the young forest, middle-aged forest and near mature forest in Jilin was showed in Table I.

*Table I: Area Of Premature Forest In Jilin Province (×102 Ha2)**

Dominate species	Young forest	Half-mature forest	Near-mature forest
Phellodendron amurense	793	685	365
Needle-leaved mixed species	42	279	257
Abies	22	214	85
Larix olgensis	3531	2077	1411
Betula	706	1007	749
Picea	343	214	171
Populus davidiana	728	512	576
Others	855	385	172
Quercus	2224	5162	1926
Tilia	321	493	321
Hardwood species	107	556	214
Pinus koraiensis	642	86	21
Broadleaved mixed species	4324	7453	3833
Pinus sylvestries var.mongolica	491	514	235
Needle broad-leaved mixed species	278	877	750
Total	15407	20514	11086

*: Data from the sixth forest resources inventory

3.2 Biomass Module

The module inputted the growing proportion of branches, foliages and the roots relative to stem. CAI is used to represent the annual net productivity of stem. In this study, CAI per unit area was 1000 ha^{-1} [9]. The C of each species was consistent with the value of 0.5 (MgC Mg^{-1} DM) recommended in IPCC and the time for species from seedling to mature stage was defined as the rotation period in the study. We did not consider about the individual mortality resulting from interspecific competition and harvesting. Due to the limited research on turnover rate of branches, foliages and roots in our country, this research referenced previous CO_2FIX model applied in the research and related literature to estimate the parameters [10] and calculated the density of the wood according to Xu [11].

3.3 Soil Module

The module inputted the monthly average temperature throughout the year and month of the growing season in Jilin Province (Table II). The monthly average temperature in Jilin Province referenced to that in the past 30 years. The rainfall of the growing season in Jilin Province was 650 mm. In this study, we assumed the initial C stock of soil C pool was zero.

Table II: The Monthly Average Temperature Of Jilin Province In 30 Years

Month	Temperature(℃)	Growing season
Jan	-16.8	N
Feb	-13.1	N
Mar	-3.7	N
Apr	6.1	N
May	13.6	Y
Jun	18.4	Y
Jul	21.4	Y
Aug	20.3	Y
Sep	13.5	Y
Oct	5.6	N
Nov	-4.4	N
Dec	-13.3	N

3.4 Products Module

The module entry distribution of forest products, the amount of losses in the allocating process, the proportion of distribution and recycling of the final products in the long, medium and short time as well as the period of the long, medium and short-term, waste or landfill. The study used the parameters of the high performance level alternative sets of the forest products and the recovering efficiency provided by the model. The periods of the long, medium and short-term, waste or landfill were in accordance with that in the reference of "Good Practice Guidance for Land Use, Land-Use Change and Forestry" (Table III, Table IV, Table V and Table VI) [12].

Table III: Raw Material Allocation

Raw material	Sawnwood	Boards	Paper	Firewood
logwood	0.50	0.30	0.10	0.10
pulpwood	-	0.00	0.80	0.20

Table IV: Allocate Of End Products

Production line	Long term products	Medium term products	Short term products
Sawnwood	0.60	0.30	0.10
Boards	0.20	0.60	0.20
Paper	0.00	0.10	0.90

Table V: Process Losses

Production line	Fraction lost in process reallocation			
	Boards	Paper	Firewood	Mill site dump
Sawnwood	0.10	0.12	0.15	0.00
Boards	-	0.05	0.10	0.00
Paper	-	-	0.10	0.00
Firewood	-	-	-	0.00

Table VI: Usage Of End Products

Product type	Fraction disposed		
	Recycling	Energy	Landfill
Long term products	0.10	0.60	0.30
Medium term products	0.20	0.70	0.10
Short term products	0.40	0.60	0.00

3.5 Bioenergy Module

Logging residues falling objects as well as industrial waste woody debris were considered the alternative to the use of coal, which were used for fuel wood with the use of improved stoves technology in the bioenergy module.

4. RESULTS AND DISCUSSION

In 120 years simulated, total C stock had a tendency of increase, but there were differences between the modules (Figure 1). Biomass C stocks had a significant increasing trend in the previous 35 years and showed regular fluctuations subsequently. The biomass C storage in 0-80 years were higher than other modules and increased to 330.11 TgC accounting for 34.06% of total C storage in the end of simulation (Figure 2). There was no apparent increase in C stock of the forest products without regular forest logging before 24 years, later it increased with regular fluctuations. Forest products C storage was 208.49 TgC with 21.47% of the total C storage. In contrast, soil C storage were relatively stable with only 2.18% of the total C sequestration. Bioenergy C storage presented a sustaining increase and reached 402.87 TgC in the end of simulated period.

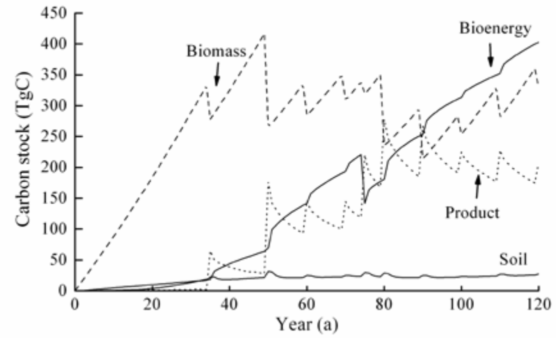

Figure 1: Carbon Sequestration Dynamic Of Forest Ecosystem In 120 Years

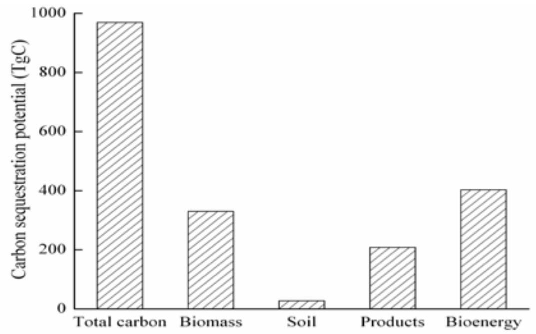

Figure 2: Carbon Sequestration Potential Of Forest Ecosystem At The End Of 120 Years Simulated

In this study, biomass C stocks had a significant increasing trend in the previous 35 years, followed by regular fluctuations. This phenomenon may be due to the reason as follows. With the increase of simulation time the near mature forests first reached rotation periods, which were considered different for the dominant tree species in this paper. So the biomass C storage showed the increase trend in initial period and then regular fluctuations because of the logging. C stocks of bioenergy and forest products also exhibited a corresponding change with the middle-aged forest and young forests harvested.

CO_2FIX model is a reliable model to simulate C cycle in long-term, what has been well verified in this study. But there were some uncertainties about simulated results using this model. In the biomass module, it was too dependent on growth rate of stem (obtained from the harvest table) to reflect the impact of changes in soil fertility, climate and other factors on stem growth timely. Therefore, the model failed to simulate the impact of climate on the entire forest ecosystem C cycle. Meanwhile, it could not reflect the changes of C allocation in the different harvesting periods in forest products module.

5. CONCLUSION

This study model analyzed the potential of C sequestration in forest ecosystem using CO_2FIX. The results showed that existing forests in Jilin Province had a huge potential for C sequestration. In the end of 120 years simulated, the total amount of C sequestration reached 968.75 TgC, among which, bioenergy had highest C stock, forest products followed by biomass, and soil had the least amounts. Therefore, computer simulation is a relatively convenient, economical and effective method to estimate C stock in forest ecosystem of large-scale area.

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