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Carbon Cycle Main Parameters in Forests of European Russia Forest-Steppe Zone

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***Abstract* — Over the last 300-400 years, the forests of the forest-steppe zone in the Russian Federation have changed greatly as a result of human activity, which has led to a significant decrease in their biosphere functions, the main of which is carbon sequestration. The carbon balance in forest ecosystems of managed forests of the Russian Federation European part of the forest-steppe zone is positive and amounts to 0.747 million t C per year^{-1}. Herewith, in some areas it has a negative value mainly due to the large areas of forest fires. (Lipetsk region – 0.008 million t C*year^{-1}, Tambov region – 0.202 million t C * year^{-1}).**

Keywords — carbon sequestration, carbon cycle, carbon pickup by the forest, forest carbon stock, forests of forest-steppe zone.

I. INTRODUCTION

Solving the global problem of the progressive destabilization of the biosphere is impossible without restoring the ecological potential of forests which play a key role in shaping the gas composition of the atmosphere and preserving optimal climate parameters. However, the mutual influence of forest and climate, as well as the role of forests in the dynamics of the carbon cycle, was studied very insufficiently. In particular, this applies to various categories of protective forests of the forest-steppe region of the European part of the Russian Federation [2, 4].

Located in densely populated and sparsely forested areas, the forest-steppe zone has changed greatly in the last 300-400 years as a result of human economic activity [8, 11]. Practically there are no pristine areas here [2, 7, 10]. Forests of the forest-steppe region are very vulnerable due to the predicted climate changes and therefore they need a certain mode of forest management, which in turn requires their comprehensive study and development of special measures for their adaptation and preservation of biosphere functions.

Based on this, within the framework of the state program supervised by "Federal forestry agency" ("Assessment of the impact of forestry practice on the carbon cycle in the managed Russian Federation European part of the forest-steppe and steppe zone", state registration number AAA-A17-117041810011-7), the analytical studies were undertaken to assess the impact of forest biocenoses of the Russian Federation forest-steppe zone on the carbon cycle in the region (figure 1).

II. METHODS AND MATERIALS

The studies used statistical, reporting and other materials containing information on the state of the forest fund of 6 constituent members of the European part of Russia (Belgorod, Kursk, Lipetskaya, Tambov, Oryol, Voronezh regions) belonging to the forest-steppe zonal-regional polygon [5].

The research is based on the forest plans of the constituent members of the European Russia forest-steppe zone-regional test site, forestry regulations, the materials of the State forest register, legal documents regulating the order of different types of forest use and implementation of forestry activities, literature sources in the direction of research, as well as the data of the State forest register provided by the Federal forestry Agency for research objects on 01.01.2017.

III. RESULTS

One of the factors leading to the disruption of the carbon balance of the planet is an increase in the anthropogenic load on natural ecosystems. At the same time, the increase in yearly average temperature and precipitation enhancement affects the transfer of carbon and nitrogen stock in organic form: there is an increase in the stocks of these elements in the phytomass depot simultaneously with the impoverishment of the soil depot [12, 16].

In addition, forests of any region are subject to various external influences such as forest fires, windfalls, outbreaks of pest outbreaks, etc. Such disruption dispersions lead to the death or degradation of forest stands and, thus, to the loss of carbon stocks due to the carbon dioxide emissions into the atmosphere [12, 15].

Over the past 200 years, the forests area of the European Russia forest-steppe zone got smaller more than 2 times (from 21% to 8.6 %). In some regions, the forest area ranges from 7.8 % (in Kursk region) to 10.3% (in Tambov region). [1;9].

As a result of the unlimited cutting of the main (and often intermediate) use, there were negative structural changes: for coniferous (pine) plantations, the proportion of natural tree stands has decreased, and at present, reforestation is carried out mainly by creating forest crops. During the long-term forest exploitation, high-productive natural seed origin oak stands gave place to low productive coppice crops, whereby, at present, it is dominated by coppice forest not higher than III bonitet of 5-7th generation [7, 14].

Forests of the Voronezh and Tambov regions are characterized by the highest carbon-depositional ability, which account for 50% of the carbon stock contained in the total phytomass of the region's forests. The annual forest carbon dioxide stock varies very widely in the regions, in proportion to the growth of phytomass (in the same way annual carbon sequestration changes) (table 1).

Forest-steppe

Fig. 1. European Russia forest-steppe zone

Peculiarities of accumulation of timber stand (phytomass) and, as a result, of carbon in the conditions of the forest-steppe region and the steppe region, as well as the ER zone, essentially depend on forest origin, forest type, an ecotype and a condition of oak forests [1, 13].

TABLE I. TAXATION AND CARBON SEQUESTRATION CHARACTERISTICS FOR THE FORESTS OF THE TERRITORIAL MEMBERS OF THE EUROPEAN RUSSIA (ER) FOREST-STEPPE ZONE

Item №	Indicator description	Regions					Total
		Belgorod	***Voronezh***	***Kursk***	***Lipetsk***	***Tambov***	
1.	Total area, thous. ha	2780	5240	3010	2400	3280	16710
2.	Forest area, thous. ha	247	499	261	214	397	1618
3.	Forested area, thous. ha	231	436	235	192	355	1449
4.	Forest cover percent, %	8.3	8.4	7.8	8.0	10.3	8.6
5.	Stand of timber, millon cubic metres	37.5	63.8	27.9	29.8	56.6	215.6
6.	Phytomass, million t	27.2.	44.9	19.6	20.6	38.2	150.5
7.	Ecosystem production, million t/ year	0.75	1.35	0.69	0.57	1.25	4.61
8.	Phytomass carbon stock, million t	13.6	22.5	9.8	10.3	19.1	75.3
9.	Carbon sequestration, million t/ year	0.37	0.7	0.34	0.29	0.62	2.32
1.	CO_2 absorption, million t/ year	1.36	2.57	1.25	1.06	2.28	8.52
11	Carbone accumulator, million t	30.1	62.4	31.2	22.6	52.5	198.8

Karavanskaya N. V. [3] studied that the maximum carbon stock at the age of 85-90 is deposited in inundable oak forest (162.2 t C/ha), the minimum – in subor grass oak forest (95 t C/ha). The maximum carbon stock in live ground cover is the same as the period of the maximum forest stand carbon stock at the age of 80-100. In upland environments the most effective carbon sequestration is in sedge and glague oak-forest with late harvest varieties oak, the average of 2.0 t C/ha per year with early varieties oak on average 1.7 t C/ha per year. The annual carbon sequestration in sedge and third-class glague oak-forest is 1.27 t C/ha per year; in inundable oak forest – 2.3 t C/ha per year. The positive carbon balance was noted in oak ecosystems, i.e. carbon dioxide sink exceeds its atmospheric emission: in sedge and glague oak-forest – 1.6 - 3.9 t C/ha per year; in subor grass oak forest – 0.1-0.7 t C/ha per year; in glague and sedge oak-forest – 0.6-1.7 t/ha per year; in inundable oak forest - 4.4-4.6 t/ha per year [3].

When assessing the carbon-depositional function of forest plantations, it is necessary to take into account CO_2 emissions into the atmosphere due to soil respiration, which in the conditions of the forest-steppe zone can vary widely (especially in connection with various disturbances of forest ecosystems). Forest productivity depends significantly on carbon dioxide going from the soil [17]. Soil carbon dioxide meets the forest plants requirements in the photosynthesis process. The soil respiration average total is 4.5-5.0 t of CO_2 per 1 ha / year. The positive balance of net carbon sequestration will be maintained with an increase in soil respiration intensity of 1.5 times. Thus, forest-steppe woods have a higher (1.5-2.0 times) carbon sequestration capacity per unit area in comparison with the average data for Russian forests in a mass [6].

The carbon stock in stand biomass at Voronezh region Vorontsov forest district is greater than at Voronezh biosphere reserve according to Shishkin' data [13]. Carbon dioxide content at Vorontsov forest district in fresh oak forests is 134.28 t of CO_2 /ha, in a dry – 125.45 t of CO_2 / ha. Fresh sudubravacarbon stock at Voronezh forest districtis 113.67 t of CO_2 / ha, and fresh oak forests – 105.31 t of CO_2 / ha. The largest annual carbon sequestration in all kinds of explored forests takes place at the age of 60. The annual carbon sequestration at Vorontsov forest district is 1.39 t of CO_2 /ha/year, at dry-1.26 t of CO_2 / ha / year; in fresh oak at Voronezh biosphere reserve – 1.47 t of CO_2 / ha / year; in fresh sudubrava – 1.42 t of CO_2 / ha / year. The soil carbon stock rate against the ecotopes carbon total stock at Shipov forest is far more than at Usman coniferous forest. The soil carbon stock rate at Shipov dry oak forests is 47.1%, in fresh – 65.5%, at Usman fresh oak forests – 31%, and in fresh sudubrava – 12.4% [13].

The boreal belt forest landscapes have the natural mechanisms with relatively quick atmospheric carbon sequestration compared to steppe landscapes, which can be considered as a zone of carbon waste in the form of humus acting during the significant periods of time (centuries-millennia). The forest zone landscapes are undoubtedly of high priority in the global carbon cycle. Forest-steppe landscapes, due to the low forest cover (about 10 %) and a much smaller area in comparison with the forest zone, occupy a more modest place in the total carbon sequestration. Accordingly, for the forest-steppe zone it is more appropriate and long-term to implement measures aimed at creating energy plantations and increasing forest cover to the optimum (20-25%) in order to make a better use of the high carbon potential of forest ecosystems.

In this regard, the question of the species composition of existing forest stands and its prospects in the implementation of the strategy of forest reproduction in the region is relevant.

It is known that the main rate of carbon is contained in stem wood of the stand - 88 %, in coniferous and leaves - 5 %, in the dead tree stand and windfall - 6 %, in young trees, understorey, and live ground cover - 1 %. If we consider the ability to deposit bytree species groups (table 2), then hardwood species are in the lead per unit of volume, then coniferous and soft-leaved species are almost comparable with them [6;18].

Table 2 presents data on the volume of carbon sequestration by tree species groups and subjects that are part of the ER forest-steppe zone-regional test site, which indicate that the annual volume of carbon sequestration by tree species groups are distributed according to the representation of groups in the forest fund of the object of research.

TABLE II. ANNUAL CARBON SEQUESTRATION BY TREE SPECIES GROUPS

Region	Softwood		Hard leaved		Soft-wooded		Total	
	thous. t, C	*%*	*thous. t, C*	*%*	*thous. t, C*	*%*	*thous. t*	*%*
Voronezh	105	31.1	180	53.3	53	15.7	338	22.0
Belgorod	26	8.9	248	84.7	18	6.4	292	19.0
Kursk	37	13.5	173	62.9	65	23.6	275	17.9
Lipetsk	75	38.9	75	38.9	43	22.3	193	12.5
Tambov	229	52.0	66	15.0	145	33.0	440	28.6
Total	472	30.7	742	48.2	324	21.1	1538	100

Thus, the rate of conifers is 472 thousand tons of C (30.7%), hardwood - 742 thousand tons of C (48.2%), and soft-leaved - 324 thousand tons (21.1%). The calculations also showed that the largest carbon rages were deposited by the stationary at work stand in Tambov region forest fund (440 thousand tons – 28, 6%). The smallest carbon rages are in Lipetsk region (193.0 thousand tons – 12.5%).

However, the woody plant is an active carbon dioxide absorber; as a result, there is a mass gain at the life cycle first stage. This process is most intensive in young stands at the age of about 35. The rate of the gain and, therefore, CO_2 uptake rate decreases to mature forest stand. The organic material decomposes with CO_2 emission into the atmosphere under the plants falling leaves or die away. The plant growing and decomposition can take a long time, during which a certain CO_2 quantity will be absorbed from the atmosphere and be conserved for a time in the form of wood, roots, and soil carbon. 10% to 20% of the baseline carbon remains after 5-10 years of trivial biomass decay in soils. With aging, stand potential to absorb CO_2 from the atmosphere may be totally lost (up to about 1% of the required quantity). This is particularly true for the ER forest-steppe region ecosystems due to the quick salinity of the tree waste and fallen leaves.

The forest ecosystems exhaust a certain carbon quantity through the cleaning cutting and sanitation cutting, as well as through the fires (table 3).

As you can see, cleaning cutting is not more than 0.01% of the carbon stock in them and is not more than 1.5% of the annual sequestration volume against the background of the total carbon stocks and of its sequestration intensity in all pools of forest ecosystems of the studied zonal-regional test site regions.

TABLE III. CARBON STOCK LOSSES DURING CLEANING CUTTINGS, SANITATION CUTTINGS AND FIRES IN THE FOREST FUND OF THE TERRITORIAL SUBJECTS OF THE ER FOREST-STEPPE ZONAL-REGIONAL TEST SITE.

Region	**Biomass removal and carbon losses TCM/KTPAC**		
	Cleaning cutting	***Sanitation cutting***	***Fires (KTPA C)***
Voronezh	30.7/10.5	17.5/6.6	81.8
Belgorod	6.4/2.3	9.2/3.7	21.1
Kursk	29.7/10.7	1.9/08	6.0
Lipetsk	35.7/12.1	4.4/1.9	11.8
Tambov	91.5/28.0	5.1/2.1	403.1
Total	194.0/63.6	38.1/15.1	523.8

Carbon losses during sanitary cutting in the forest fund of the studied test site territorial subjects are on average 38,100 tons per year, representing about 0.05% of the carbon stock and, accordingly, 1.6% of its annual sequestration.

The largest forest ecosystems carbon losses are caused by fires; on average, they are more than 0.5 million tons per year, which is 0, 66% of its total stock and is 21, 55% of the annual sequestration.

The knowledge of the carbon cycle given parameters in the forest ecosystems of the studied region enables one to calculate the average annual carbon balance, both in individual pools and in the forest ecosystem as a whole (table 4).

TABLE IV. CARBON STOCK AND CARBON BALANCE IN ER FOREST-STEPPE ZONE ECOSYSTEMS

Region	**Carbon pool, million tonnes C per year**				
	Stand biomass	***Dead wood***	***Litter***	***Soil (0-30 cm)***	***Total***
Belgorod	17.275	3.618	3.204	13.234	37.331
	0.258	0.055	0.011	0.026	0.350
Kursk	14.963	3.459	2.633	15.808	36.863
	0.255	0.055	0.009	0.024	0.343
Lipetsk	10.147	2.606	1.618	14.203	28.574
	-0.008	0.002	0.000	-0.002	-0.008
Tambov	20.511	5.640	3.160	33.143	62.454
	-0.166	-0.023	0.000	-0.013	-0.202
Voronezh	19.809	4.796	4.571	31.661	60.837
	0.187	0.049	0.010	0.018	0.264
Total	82.705	20.119	15.186	108.049	226.059
	0.526	0.138	0.030	0.053	0.747

IV. Conclusion

Studies showed that the total carbon stock in the studied object was 226.059 million tons, including the stand biomass – 36.6 %; dead wood – 8.9%; forest litter – 6.7%, and the soil was 47.8%. The carbon balance in managed forest ecosystems of the ER forest-steppe zonal-regional research test site is positive and amounts to 0.747 million tons of C per year^{-1}.

Herewith, in some areas it has a negative value mostly due to significant forest fires area (Lipetsk – 0.008 million tons of C per year^{-1}, Tambov – 0.202 million tons of C per year^{-1}).

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