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Evaluation of Carbon Assimilation by Regenerating Soils of the Central Black Earth Region of Russia

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Abstract: The study presents the options for the estimation of soil assimilation rates with carbon regenerating after an anthropogenic influence in the Central Black Earth region of Russia. The evaluation methodology is based on the use of mathematical models of the trend component processes for the humus horizon and humus accumulation development in Forest-Steppe Black Earth areas. In postagrogenic soils of Central Black Earth region of Russia the rate of carbon assimilation with regenerating soils varies from 21.00-71.30 g C m^{-2} per year, depending on the degree of violation. The highest rate of carbon fixation in an organic matter is typical for postagrogenic soils with severely degraded humus horizon in which the relative content of humus is in the range of 1-3.5%.

Key words: Black earth areas of Forest Steppes, postagrogenic soils, reproduction of soils, the rate of soil formation, soil carbon, humus accumulation, formation of soils

INTRODUCTION

The generalization of the study results concerning the carbon emissions from the soils of the world (Bond-Lamberty and Thomson, 2010) showed that during the last decades there is a growth of this value which is related to global warming. In Russia, the significant losses of carbon by ecosystems are typical for agricultural regions in particular for the Central Black earth region where they have the following range of values: 60-600 kg ha^{-1} per year (Moiseev and Alyabina, 2007). However at the economic downturn of 1990-2005 the level of carbon losses by soils decreased due to the reduction of cultivation area (Romanovskaya, 2008; Lyuri *et al*., 2010). The emergence of large areas of wasteland contributed to the deposit of carbon into the soils, leading to the reduction of its negative balance. According to the estimations (Romanovskaya, 2008), the emission of carbon by arable soils in central Russia makes about 0.8±0.1 tons C ha^{-1} per year and the fixation of carbon on the 4-5 year deposits makes 1.24±0.56 tons C ha^{-1} per year (Stavropol black earth soils). The significant accumulation of carbon occurs in posttechnogenic landscapes where the reproduction of soils occurs on exposed man-made substrates. According to the estimates carried out by American scientists (Post and Kwon, 2000) during the early years of soil formation in recultivating ecosystems (at forest recultivation) are fixed by soils at the amount of 33.2-33.8 g C m^{-2} per year. The study summarizing the results of soil formation research in posttechnogenic ecosystems of the United States (Rhoades *et al*., 2001) the range of carbon assimilation by soil varies from 30-180 g C m^{-2} per year depending on the age, the type of an ecosystem and climatic conditions. The age (ontogenetic status) of regenerative ecosystems is one of the main factors that determine the intensity of carbon fixation in soils. As the studies showed (Goleusov and Lisetsky, 2008), the rate of humus horizon formation and humus accumulation in the regeneration soils of different ages may have ten-fold differences.

MATERIALS AND METHODS

The proposed method of carbon accumulation rate in the soils of postagrogenic or posttechnogenic ecosystems of forest steppe zone (under herbaceous vegetation) takes into account its current ontogenetic state within the trends of regenerative successions. The calculation is performed according to the model of humus stock growth in humus horizon by time and the growth of humus relative content in a previously described humus horizon (Goleusov and Lisetsky, 2009). At that we are guided by the hypothesis of analog development possibility concerning the various stages of soil degradation with their stages of development. The model of humus reserves formation by time (t, years) in the humus horizon (Z_t t ha^{-1}):

$$\begin{cases} Z_t = 50 \times \exp(-\exp(0.737 - 0.029t)) \\ Z_t = 500 \times \exp(-\exp(0.876 - 0.000335t)) \end{cases} \quad (1)$$

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In this model, 50 and 500 t ha^{-1} is the maximum reserve of humus in the soils of different ontogenetic development stages (n×10 and n×100 years, respectively) (Goleusov and Lisetsky, 2009). The remaining constants are the empirical coefficients in the equation of nonlinear regression. In order to calculate the rate of carbon fixation let's perform the following steps: Let's determine (in the field conditions) the residual capacity of the soil humus horizon (H, cm) which experienced the erosion (abrasion) of the profile upper part. Let's determine an average content of humus in a humus horizon (G, %). Let's calculate the stock of humus (Z, t ha^{-1}):

$$Z = H \times G \times \gamma \tag{2}$$

where, γ is the soil consistency density (t m^{-3}). Then let's conduct the calculation according to the equation of humus accumulation rate for forest steppe black earth areas. At that two situations are possible: if Z<50 t ha^{-1}, we use the calculation of soil ontogenetic status (t, years) according to the following formula:

$$t = \frac{0.737 - \ln\left(-\ln\left(\frac{z}{50}\right)\right)}{0.029} \tag{3}$$

if $Z \geq 50$ t ha^{-1}:

$$t = \left(\frac{\ln\left(\frac{1-\frac{z}{500}}{0.923}\right)}{0.000142}\right) \tag{4}$$

The t values are used to calculate the speed of humus fixation (ΔZ, t ha^{-1} year):

$$\Delta Z = \frac{d}{dt}\left(50 \times \exp\left(-\exp\left(0.737 - 0.029t\right)\right)\right) \times \left(t < 131\right) + \frac{d}{dt}\left(500 \times \exp\left(-\exp\left(0.876 - 0.000335t\right)\right)\right) \times \left(t \geq 131\right) \tag{5}$$

Let's calculate the rate of carbon fixation (ΔC, g/m^2 year), taking into account the carbon content in humus of about 58%:

$$\Delta C = 58 \times \Delta Z \tag{6}$$

The model of humus relative content growth (G_t, % $year^{-1}$) in the humus horizon during the regeneration of soil formation:

$$G_t = 6 \times \exp\left(-\exp\left(1.19 - 0.1t\right)\right) \tag{7}$$

Table 1: The calculated values of carbon fixation rate (ΔS) in the organic matter of newly formed soils, depending on the initial (current) stocks of humus (Z)

Z (t ha^{-1})	Ontogenic status (years)	ΔC (g m^{-2} year)
30	49	25.78
35	61	21.00
40	77	15.01
45	103	7.98
50	177	3.71
60	336	3.63
70	498	3.54
80	664	3.46
90	833	3.38
100	1007	3.30
150	1948	2.88
200	3033	2.47
250	4317	2.06
300	5888	1.65
350	7914	1.24
400	10770	0.82

In this Eq. 6 is the relative (%) humus content in the humus-accumulative horizon of soil in which its high humus content growth stabilization occurs at the stage of development n×10-3,000 years (Goleusov and Lisetsky, 2009). The remaining coefficients are substantiated empirically. The calculation by model is carried out as follows: Let's determine the humus content in soil (substrate) G (%). Let's find the ontogenetic status (t) of soil system, according to the formula:

$$t = \frac{1.19 - \ln\left(-\ln\left(\frac{G}{6}\right)\right)}{0.1} \tag{8}$$

Let's find the rate of humus fixation (ΔG, % year):

$$\Delta G = \frac{d}{dt}\left(6 \times \exp\left(-\exp\left(1.19 - 0.1t\right)\right)\right) \tag{9}$$

The rate of carbon fixation in a humus-accumulative horizon of postagrogenic soil (ΔS_A g/m^2 year) taking into account the formation density (γ, g/cm^3) is recalculated according to the following formula:

$$\Delta C_A = H_{t(mod)} \times \gamma \times \Delta G \times 5.8 \tag{10}$$

At that the "model" power of humus horizon ($H_{t(mod)}$, mm) is calculated for the age of newly formed soil (t, years) according to the following equation:

$$H_t = 200 \times \exp\left(-\exp\left(0.769 - 0.028t\right)\right) \tag{11}$$

RESULTS AND DISCUSSION

Main part: Table 1 shows the results of carbon fixation rate calculation for the discrete levels of humus stock in the humus horizon, conducted according to Eq. 1.

Table 2: Calculated speeds of humus accumulation (ΔG), carbon fixation (ΔS_A) in the newly formed humus horizon soil for a 10 year old deposit

Initial humus content (%)	ΔG (%/per year)	ΔC_A (g m^{-2} year)
1.0	0.18	49.65
1.5	0.21	57.62
2.0	0.22	60.88
2.5	0.22	60.65
3.0	0.21	57.62
3.5	0.19	52.27
4.0	0.16	44.94
4.5	0.13	35.87
5.0	0.09	25.26
5.5	0.05	13.26

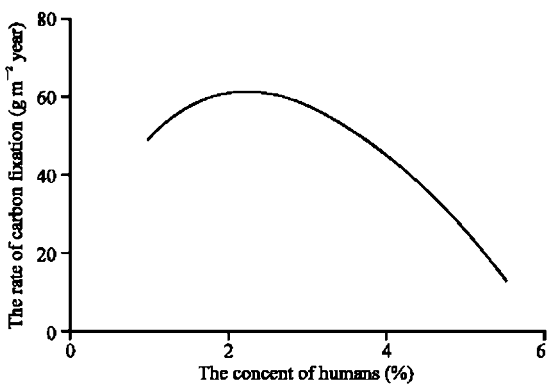

Fig. 1: The dependence of carbon fixation rate on the initial humus content in the soil

The calculations according to Eq. 1 are relevant for eroded agricultural soils with the preserved residual humus horizon at their transition into the mode of deposit (conservation). In such a degraded soil, the matrix of humus horizon is preserved with the stable organo-mineral complexes (the humus content makes 3-4%), so the humus accumulation occurs mainly due to the gradual (rather slow) assimilation of underlying poor humous layers by this process.

Obviously in anthropogenically disturbed ecosystems the soils with a disordered matrix are often involved in the regeneration of soils or the parent rocks on the surface. In such a situation, it is advisable to use the model of growth (Eq. 7) of the relative humus content in the humus-accumulative horizon of forest steppe black soils.

Table 2 shows the results of carbon fixation rate calculation in the soil for a 10 year deposit performed by the Eq. 7.

Figure 1 shows that the intensity of carbon fixation in the newly formed horizon of regeneration soil is at its maximum at its relatively low content in the substrate on which the reproduction of soils is performed.

The use of Eq. 7 is possible at initial humus content in an exposed soil and ground up to 6%. At that a deposit age for which the calculation by this model is possible is estimated in 50 years as during this period of soil reproduction in the zone of maximum humus accumulation (about 20 cm) the balanced humus reserves are reached, after which the growth of humus profile is slowed sharply and the calculations may be carried out according to Eq. 1.

CONCLUSION

The results of the carbon fixation rate calculation (conducted according to the mathematical models of humus horizon regeneration and humus accumulation processes) in postagrogenic soils showed that this value varies from 21.00-71.30 g C m^{-2} per year which is consistent with the available data (Kurganova and Lopes, 1990). Such an intensity of carbon fixation with regeneration soils may compensate to some extent for its specific losses due to the dehumification of agricultural soils. In absolute terms, the fixation of carbon by deposit soils (the area of which makes >1.2 mln ha) (Smelyansky, 2012) is quite high and may range from 250-856 thousand tons of carbon per year. However, a small share of deposits in the structure of agricultural landscapes does not allow to compensate fully for the loss of carbon in agricultural soils. The solution of this problem may be the expansion of arable lands, transferred into conservation and renaturation modes, the reduction of carbon losses by agricultural soils, the expansion of forest plantation area.

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