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Dynamics of Carbon Balance Components in Fallow Arable Lands on the Valdai Upland

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Abstract—The dynamics of carbon pools in the live phytomass, necromass, and soil reservoirs have been analyzed in fallow arable lands of Novgorod oblast. The results show that the amounts of above- and belowground necromass increase with the age of fallows, while the dynamics of live phytomass have no distinct trend. Comparisons with archival data show that the stocks of soil organic carbon in the studied ecosystems have decreased by 1.39 t C/ha since 1983, which is equivalent to an annual loss of 0.03 t C/ha. The main factors accounting for changes in the carbon stocks of fallow soils are the initial organic carbon contents in topsoil, the intensity of agromeliorative measures taken during the period of agricultural land use, and carbon contents in soils of meadow communities typical for a given region (zone).

Keywords: ecosystem carbon balance, fallow lands, greenhouse gases, Novgorod oblast

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The increase in concentrations of greenhouse gases in the atmosphere makes necessary a thorough assessment of their amounts and fluxes of both technogenic and natural origin. The latter are especially indeterminate, and numerous local studies are needed to reveal basic regional patterns of sinks and emissions of these gases, carbon dioxide in particular, by terrestrial ecosystems.

On global scale, the annual average net flow of CO_2 between terrestrial ecosystems and the atmosphere is equivalent to annual sequestration of $0.9 \pm 0.6 \times 10^9$ t C, excluding CO_2 emission from technogenic sources (IPCC..., 2007). However, estimates of this flow in Russia vary in a wide range, from annual CO_2 carbon emission of $0.16–0.39 \times 10^9$ t (Nilsson et al., 2000) to its annual sequestration in terrestrial ecosystems in amounts averaging approximately 0.49×10^9 t (Shvidenko et al., 2009) and reaching $0.8–1.0 \times 10^9$ t (Kudeyarov, 2000, 2005).

Anthropogenic impacts on ecosystems, including changes in the type of land use, have a considerable effect on the stock of soil organic carbon and the rate and direction of carbon flow between ecosystems and the atmosphere. Due to political and economic reforms of the past decades, up to 30% of arable lands in Russia have been excluded from agricultural use (Romanovskaya, 2006b), with the total area of fallows in 2009 reaching approximately 28×10^6 ha.

Due to gradual recovery of perennial meadow and forest vegetation in fallows and the absence of organic matter removal with harvest, their ecosystems can accumulate organic carbon. According to different authors, the rate of carbon accumulation may vary from 3.1 g/m^2 (Post and Kwon, 2000) to 302 g/m^2 per year (Kurganova et al., 2010). Our previous estimates show that the annual amount of soil organic carbon accumulated in fallow lands of Russia averages approximately 97–108 g/m^2 per year, or a total of about 29×10^6 t over the entire territory of the country (Romanovskaya, 2008). To determine these values more accurately, thorough studies are needed on regional trends of carbon stocks and flows in fallow arable lands located in different climatic and vegetation zones of Russia.

The purpose of this study was to assess the dynamics of main carbon pools in ecosystems of fallow arable lands on the Valdai Upland.

OBJECTS AND METHODS

The object of the study were fallow land areas in the Usadye test grounds of the Valdai Branch of the Russian State Hydrological Institute, the central Valdai Upland (Novgorod oblast). These areas were excluded from agricultural use in different years between 1984 and 1994. Some areas located closer to populated places were used for selective hay harvesting until the first decade of this century. In addition, a forest plantation established in a former arable field in 1954 was included in the study.

The study region is characterized by a hilly morainic landscape at elevations of up to 300–320 m a.s.l. (on average, about 200 m a.s.l.). Hills are 30–60 m high. The Usadye test grounds represent a typical

Average phytomass and necromass stocks in different ecosystems on the territory of Usadye test grounds, t/ha (dry matter)

Ecosystem	Aboveground		Belowground (estimative values)		Total
	Phytomass	Necromass	Phytomass	Necromass	
16- to 18-year fallow	6.3	2.5	10.9	8.1	27.8
22- to 24-year fallow	5.0	3.3	8.8	10.4	27.5
25- to 27-year fallow	5.1	4.0	8.9	12.8	30.8
Hay meadow unharvested over 10 years	10.1	4.1	15.6	13.3	43.1
Herbaceous layer in pine and spruce stand planted in 1954	0.5	10.1	–	–	–
Crop field plowed in 2009	3.7	0.1	2.6	1.1	7.5

present-day agricultural landscape of the Russian nonchernozem zone.

These ecosystems were studied with respect to carbon balance components, including the stocks of live and dead biomass (aboveground and belowground phytomass and necromass) and soil organic carbon. In July 2009, samples of aboveground herbaceous phytomass and undecomposed plant remains were taken from three fallow areas aged 16–18, 22–24, and 25–27 years and from a hay field left undisturbed since 1999. In addition, we studied an area of mixed Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) stand planted in 1954 on a former arable field in the Sinyaya Gnilka site adjoining the Usadye test grounds. Control samples were taken from a plowed field sown with oats near the village of Usadye. The amounts of belowground phytomass and necromass were estimated by calculations based on known ratios for typical meadow communities of the zone where our study was performed (Bazilevich, 1993).

To date, these fallow areas have developed into mixed herb–grass meadows dominated by grasses such as meadow fescue *Festuca pratensis* Huds., cocksfoot *Dactylis glomerata* L., bent grass *Agrostis tenuis* Sibth., timothy grass *Phleum pratense* L., and tufted hair grass *Deschampsia caespitosa* (L.) *Beauv*. Species dominating among herbs include tufted vetch (*Vicia cracca* L.), brown knapweed *Centaurea jacea* L., and yellow bedstraw *Galium verum* L. The grass stand is 120–140 cm tall and has 100% coverage. The establishment of self-sown tree seedlings is hindered due to strong sodding, but young willow (*Salix caprea* L. and *S. cinerea* L.), aspen (*Populus tremula* L.), birch (*Betula pendula* Roth.), and Norway spruce plants appear in some areas. The vegetation of the abandoned hay meadow has similar structure and composition (mixed herb–grass meadow dominated by *F. pratensis, D. glomerata, V. cracca*, and *C. jacea*.), but self-sown tree seedlings are completely absent.

The fallows have soddy weakly podzolic or cryptopodzolic soils of medium loam or, less frequently, sandy loam texture. The humus horizon is uneven, diluted by subsoil due to previous deep plowing. Its depth averages about 25 cm. The arable horizon in places is enriched with gravel, unstructured, and has a coarse blocky surface structure when moist. The underlying horizon consists of reddish brown moraine loam with a nutlike crumb structure.

In the pine and spruce plantation in the Sinyaya Gnilka site, natural self-thinning processes have resulted in the accumulation of dead-standing and fallen trees. The understory is poorly developed, and the sparse undergrowth of rowan (*Sorbus aucuparia* L.), aspen, oak (*Quercus robur* L.), spruce, maple (*Acer platanoides* L.), and some other species hardly rises above the herbaceous layer. This layer is also sparse (coverage about 30%) and consists mainly of wood sorrel (*Oxalis acetosella* L.). Proportions of other species are insignificant. Most of them are meadow or forest-edge plants, while typical forest herbs occur rarely. The humus horizon is shallow (4 cm at most) and has a light loam texture.

In all these areas, test plots were established to collect soil samples from the upper soil horizon (0–20 cm), ten samples per plot. Samples from each plot were pooled to obtain an average sample for chemical analysis. In fallow areas, soils were sampled by layers, from the litter (0–0.5 to 0–6cm, depending on its depth) and from the underlying layer (0.5–6 to 20 cm). In areas sown with crops, the whole arable horizon (A_{ar}) and, when necessary, the underlying horizon were sampled. The samples were sorted manually, dried, and analyzed for total carbon content by Tyurin's method modified by Nikitin. The analysis was performed at the Institute of Physicochemical and Biological Problems in Soil Science, Russian Academy of Sciences, making all measurements in triplicate. In addition, samples from the soil profile at a depth of 5–10 cm were taken from all test areas to determine the specific soil density. Carbon measurements were used to calculate the average contents of organic carbon in 0–20-cm soil layer, which were recalculated to be expressed as soil carbon stock per hectare.

RESULTS AND DISCUSSION

According to our estimates, the total stocks of phytomass and necromass in fallow areas were slightly lower than in the abandoned mixed herb–grass hay meadow but exceeded fourfold these stocks in the crop field (table). The amounts of aboveground and belowground necromass were found to increase with the age

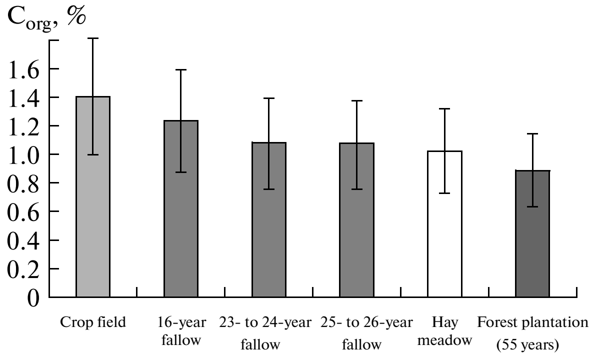

Fig. 1. Soil organic carbon contents in crop field, fallows, and abandoned hay meadow in the Usadye test grounds and in forest plantations in the Sinyaya Gnilka site.

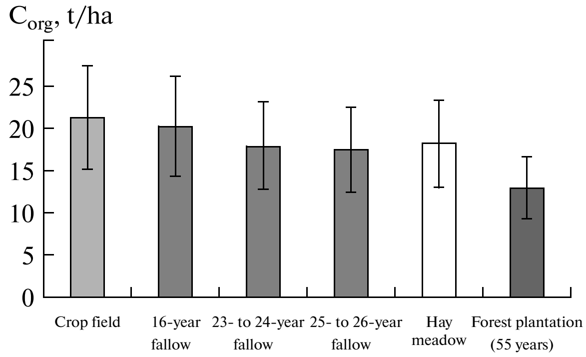

Fig. 2. Soil organic carbon stocks in crop field, fallows, and abandoned hay meadow in the Usadye test grounds and in forest plantations in the Sinyaya Gnilka site.

of fallows, but no distinct age-related trend was revealed for the phytomass. On average, the stocks of aboveground phytomass in the fallows were almost half lower than in the abandoned hay meadow.

In the course of studies performed in 2010, we obtained quantitative estimates of humus content and analyzed its long-term dynamics in the test areas.

The results of analysis for soil organic carbon in the 0–20 cm layer in samples from the crop field, fallows, abandoned hayfield (the Usadye test grounds), and forest plantation (the Sinyaya Gnilka site) are shown in Fig. 1, and these results expressed as carbon stock per hectare are shown in Fig. 2. These diagrams indicate that the content of soil organic carbon decreases during the period (years) elapsed since land exclusion from agricultural use. After approximately 25 fallow years, carbon contents in the upper soil horizon of former plowed areas have stabilized at approximately the same level that appears to be characteristic of natural meadow ecosystems in the study region. A slight decrease in the soil carbon content recorded in the abandoned hay meadow is within the limits of observation error; however, it can also be explained by periodic hay harvesting and consequent partial removal of plant biomass, which is the main source of humus (Fig. 1). On the other hand, the carbon stock calculated for the abandoned hay meadow could be slightly overestimated because of relatively high specific soil density (1.52 g/cm^3, compared to 1.39–1.42 g/cm^3 in the fallows), which could also be due to periodic hay harvesting and, therefore, soil trampling in this area (Fig. 2).

In the forest plantation in Sinyaya Gnilka, the content and stock of soil organic carbon proved to be the lowest. Apparently, it is the almost complete absence of the herbaceous layer and the small amount of necromass in this area that are responsible for a low input of organic carbon into the soil and, therefore, for its reduced content in the upper soil horizon, compared to those in the crop field and meadow biocenoses.

It should be noted that the apparent reduction in the contents and stocks of soil organic carbon observed during the fallow period in test areas on the Usadye territory does not conform to general trends characteristic of fallow lands in other regions of Russia (Romanovskaya, 2006a, 2008). Thus, our studies in Murmansk, Moscow, Sverdlovsk, and Stavropol regions provided evidence for a gradual increase in the stocks of soil organic carbon in abandoned arable lands in the course of their conversion to meadow biocenoses. Similar results were also obtained by other authors (Kurganova, 2010; Sazonov, 2005). Therefore, to confirm our preliminary conclusions, it was necessary to consider previous data on carbon contents in the soils studied.

According to archives of the Novgorodskaya station of the Federal Agrochemical Service, soils of the Usadye test grounds were surveyed in 1983 and 1995. Figure 3 shows the results of comparing the archival land use map with the scheme of 2009 sampling sites.

As follows from the archival data, the carbon content in arable soils of the Usadye test grounds during the period of their agricultural use varied between 0.76 to 1.43%, averaging 1.12%. This result is close to the value we obtained for the crop field (1.41%). In should be noted that the average carbon content in these soils increased from 1.06% in 1983 to 1.18% in 1995, which was apparently due to effective measures for stabilization and improvement of humus content taken during this period. When these measures (including annual application of fertilizers) were terminated, the organic carbon content in sandy soils of the majority of test areas began to decrease and then gradually stabilized at the level characteristic of natural biocenoses (Fig. 4).

An exception was the test area in the former arable field abandoned approximately 25–26 years ago, where soil carbon was found to accumulate during the fallow period. This fact is apparently explained by the relatively low initial content of soil organic carbon, which was increasing to the typical regional level as the perennial meadow vegetation was formed in this area.

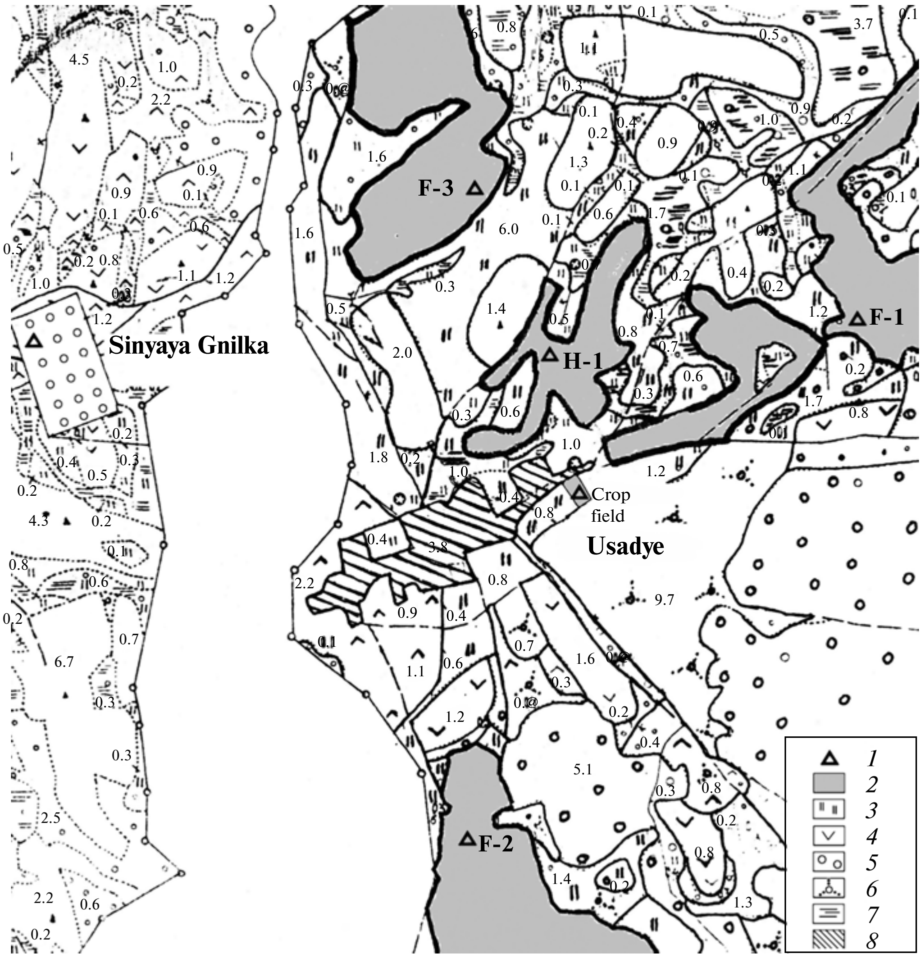

Fig. 3. Schematic map of land use in the Usadye test grounds and locations of sampling areas (F-1, 16-year fallow; F-2, 25- to 26-year fallow; F-3, 23- to 24-year fallow; H-1, abandoned hay meadow): (*1*) sampling areas, (*2*) former crop fields for which information is available on humus contents in arable horizon as of 1983 and 1995, (*3*) hay meadows, (*4*) fallows, (*5*) forest, (*6*) open woodland, (*7*) waterlogged land, (*8*) territory of Usadye village.

As follows from Fig. 4, the soil carbon content in all test areas tends toward a level of 1.1–1.2%.

Taking the specific bulk density of arable soils to be standard (1.3 g/cm^3), the average total loss of soil carbon in the test areas was estimated at 1.39 t/ha since 1983 and 0.45 t/ha since 1995, which is equivalent to annual losses of 0.03 t/ha.

Thus, the results of this study show that the majority of fallow ecosystems on the territory of Usadye test grounds, the Valdai Upland, have been losing soil organic carbon since the termination of plowing. Simultaneously, carbon has been accumulated in "short-term" necromass and phytomass reservoirs.

It is obvious that the main factors determining the degree of change in soil carbon stock during the overgrowing of abandoned arable lands are the initial level of organic carbon in topsoil, the intensity of agromeliorative measures taken to stabilize humus content during agricultural land use, and the level of carbon stocks in the soils of meadow communities typical for a given region (zone). Soils with initially low humus contents show a tendency to accumulate carbon after the termination of tillage, and the same is true of insufficiently ameliorated soils. Conversely, humus-rich arable soils annually supplied with additional amounts of carbon in the form of plant remains or organic fertilizers may lose organic carbon after abandonment. In both cases, soil carbon stocks tend to be stabilized at the level typical for natural meadow biogeocenoses in a given zone.

Therefore, an assessment of the potential of Russian fallow arable lands for atmospheric CO_2 sequestration based on empirical results obtained in a limited number of regions may be highly inaccurate. In particular, it may result in overestimates if not taking into account the possible loss of soil organic carbon in fallow arable lands of the Russian nonchernozem zone.

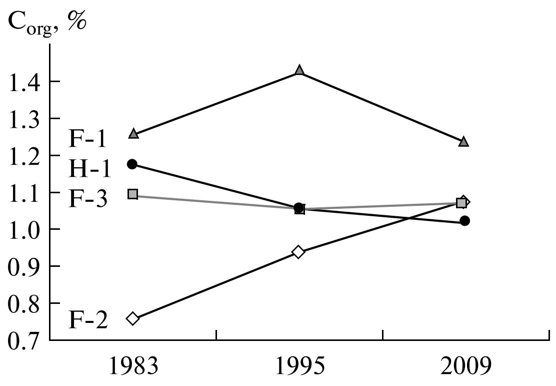

Fig. 4. Dynamics of soil organic carbon in soils of Usadye test grounds: (F-1) 16-year fallow, (F-2) 25- to 26-year fallow, (F-3) 23- to 24-year fallow, (H-1) abandoned hay meadow.

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