ISSN 1064-2293, Eurasian Soil Science, 2007, Vol. 40, No. 1, pp. 51–58. © Pleiades Publishing, Ltd., 2007.
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SOIL BIOLOGY

Carbon Balance in the Soils of Abandoned Lands in Moscow Region

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Received July 8, 2005; in final form July 22, 2005

Abstract—A quantitative assessment of the carbon balance was performed in gray forest soils of the former agricultural lands abandoned in different time periods in the southern part of Moscow oblast. It was based on the field measurements of the total and heterotrophic soil respiration and the productivity of biocenoses. Geobotanical investigations demonstrated that the transformation of the species composition of herbs from weeds to predominantly meadow plants occurred in five–ten years after the soil was no more used for farming. The amount of carbon assimilated in the NPP changed from 97 g C/m^2 year in the recently abandoned field to 1103 g C/m^2 year in the 10-year-old fallow, and the total annual loss of carbon from the soil in the form of CO_2 varied from 347 to 845 g C/m^2 year. In five years, the former arable lands were transformed into meadow ecosystems that functioned as a stable sink of carbon in the phytomass and the soil organic matter.

DOI: 10.1134/S1064229307010085

INTRODUCTION

In the context of the global climate change connected largely with the increase of concentrations of greenhouse gases in the atmosphere, the problem of searching for sources of additional sequestration of carbon dioxide (CO_2), which determines 70–75% of the existence of the greenhouse effect, is becoming pressing [21]. Forests are the most important sink of carbon dioxide in the territory of Russia [9, 10], and afforestation and reforestation are considered to be traditional measures promoting accumulation of carbon in soils and plants [6]. For example, the amount of annual carbon sequestration in the forest vegetation in the territory of Russia is assessed as 240×10^{12} g C/year according to the data of the Center of Forest Ecology and Productivity of the Russian Academy of Sciences [7]. According to the calculations of the International Institute for Applied Systems Analysis (IIASA), the carbon budget in the forests of the Russian Federation comprised 95×10^{12} g C/year in the late 1980s to the early 1990s [33]. The meadow ecosystems of Russia were regarded as an unconditional sink of carbon (197×10^{12} g C/year; according the data of IIASA), whereas the losses of carbon in the form of CO_2 in agroecosystems exceeded its fixation in soil and vegetation. However, it is known that the directions of the main biogenic element fluxes in the atmosphere–plants–soil–atmosphere system change when former arable soils are abandoned. Carbon is accumulated in soils and plants that develop on these soils because the plant material is no longer removed in the form of the yield and the initial perennial vegetation is being restored [16, 20, 22, 23, 25, 26, 29, 37–39]. The rate of carbon accumulation in soils that were arable soils and became occupied by meadow and pastoral ecosystems varied from 3.1 to 113.5 g C/m^2 year (depending on the bioclimatic zone and the thickness of the soil layer for which the calculation was performed) and averaged 33.2 g C/m^2 year [36].

More than a quarter of the agricultural lands of the Russian Federation were abandoned owing to the economic crisis in the early 1990s. In 1990–1995, the area of arable land in Russia decreased by 34 million hectares [18]. However, our knowledge of those important changes in the carbon fluxes related to land use changes is insufficient [25, 34, 35, 40, 44]. The experimental data on the determination of the directions of carbon fluxes in ecosystems and the rates of changes that occurred due to the reverting of the former arable lands to meadow cenoses or abandoned lands are very poor for most regions of the Russian Federation [20, 31].

The goal of our work was to obtain quantitative estimates of carbon fluxes in former arable soils in the southern part of Moscow oblast, and it included the following tasks: (1) determining the changes in the botanical composition of meadow cenoses depending on the duration of the time period of the lay land status of the soil, (2) determining the net primary productivity of lands abandoned at different moments, and (3) quantification of the annual emission loss of carbon in the form of CO_2 and the carbon budget in former arable lands.

Table 1. General characteristics of soils (0–10 cm layer) and vegetation of former arable soils in the southern part of Moscow oblast

Characteristics	Age of abandoned land				
	current year	1 year	5 years	10 years	25 years, old-sown meadow
Association	Forb	Tansy–forb	Wheat grass–forb	Willow weed–tansy–wheat grass	Reed grass–forb
C_{tot}, %	1.1–1.2	1.1–1.2	1.0–1.1	1.1–1.2	1.0–2.2
N_{tot}, %	0.07–0.09	0.07–0.08	0.06–0.07	0.07–0.08	0.07–0.15
C/N	13–15	15–17	16–17	15–18	12–15
Bulk density, g/m^3	1.31–1.36	1.32–1.37	1.39–1.48	1.38–1.49	1.24–1.48

Note: The concentrations of total carbon and nitrogen in the soil were determined using a CN analyzer (LECO, Germany) in average soil samples taken from the layers of 0–5 and 5–10 cm.

OBJECTS AND METHODS

The study was carried out in 2004 on the former arable lands of the Experimental Field Station of the Institute of Physicochemical and Biological Problems of Soil Science of the Russian Academy of Sciences. These lands were excluded from agricultural use during the last decade of the 20th century. According to the data of long-term weather observations (Integrated Background Monitoring Station, Danki village, Serpukhov district, Moscow oblast), the mean annual air temperature (Ta) in the studied region is approximately +5.5°C and the mean annual precipitation (P) is 670 mm. These climatic parameters in the year of our research were close to the average annual values: Ta = 5.6°C, P = 662 mm. The five key sites were the following: an abandoned field of the current year (fallow field sown in August 2004 with winter wheat; it was regarded as the control); 1-, 5-, and 10-year-old abandoned fields; and the unfertilized variant of a 25-year-old sown meadow hayfield. The soil in the studied plots was qualified as a gray forest one (on mantle loams) subject to erosion of different intensity. The main soil characteristics and the names of the plant associations are presented in Table 1.

The aboveground phytomass of the old-sown meadow and the fallow field of the current year was estimated within the seasonal dynamics (from May to October) according to cuts made every month from 0.25 m^2 plots in four replicates. The phytomass reserves in the 1-, 5-, and 10-year-old abandoned fields were determined once in the period of the maximal development of the grass stands according the same scheme. The plants were cut near the soil surface, sorted into the main botanical-ecological groups (cereals, forbs, legumes, and mosses), and these groups were sorted in turn into the fractions of living phytomass (biomass) and dead plants (current falloff). The reserves of litter, which are an important destructive link in the cycle of biogenic elements, were sampled and estimated in the same plots. Then, the sorted samples of the plants and litter were dried to their absolutely dry weight and weighed with an accuracy of 0.01 g.

The intensity of the accumulation of the annual aboveground net production (ANP) and the dying and destruction of the aboveground phytomass in the old-sown meadow were calculated with the help of budget equations [14, 15, 19] in which the minimal estimate of the above listed processes was based on the seasonal dynamics of different fractions of the plant matter. The phytomass of the herbaceous cenoses in the period of their maximal development (G max) was taken for the measure of the aboveground annual production in the other plots. The average annual ratio of G max/ANP was 0.9–1.24 [4] for different variants of the old-sown meadow, and 0.7–1.0 for the mesophytic meadows of the steppe zone [1]. The annual belowground net production (BNP) of the phytomass was estimated according to the mean annual ratio between its aboveground and belowground parts, which equals 2.1 in this meadow cenosis [4]. The net primary production (NPP) represented the sum of the annual aboveground and belowground net production and characterized the ingress of carbon from the atmosphere. The part of the carbon in the dry mass of the roots and plants was taken to be equal to 40% [8, 19].

The total loss of carbon from the soil represented the summary annual emission of CO_2, which was determined for the soil under the sown meadow and the fallow of the current year on the basis of year-round weekly field measurements. For the soils of the other cenoses, the emission losses were assessed by single measurements of the CO_2 emission from the soil surface during the growing period and by the comparison of these losses with the multi-annual data using the relationship [28] between the value of the summer CO_2 fluxes from the soil and the total annual emission. The flux of CO_2 from soil surface (or total soil respiration) was determined using the chamber method. Gas samples were analyzed in a laboratory using a Chrom-5 gas chromatograph with columns filled with Porapack Q. An extended description of this method and the principles of the calculation were given in our earlier works [13, 27]. The value of the microbial respiration (MR) or respiration of the microorganisms decomposing the soil organic matter and litter from the soils of the studied cenoses were calculated taking into account the contributions of the root respiration and the respiration of the rhizosphere microorganisms to the total emission of CO_2 from the soil. The contribution of the roots (root respiration (RR)) to the total soil respiration in the current fallow and in the old-sown meadow was determined every month from May to October using the method of substrate-induced respiration [17]. Then, the MR was calculated according to the following formula:

$$MR = TSR(1 - RR), \quad (1)$$

where MR is the annual microbial respiration (g C/m^2 year), TSR is the total soil respiration (g C/m^2 year), and RR is the part of the respiration of the roots and rhizosphere microorganisms in the total CO_2 emission from the soil.

The budget of CO_2 in the ecosystem (net ecosystem production (NEP), g C/m^2 year) was measured by the difference between the respiration of the microorganisms decomposing the organic matter and litter, and the net primary production:

$$NEP = MR - NPP. \quad (2)$$

Negative NEP values indicate a carbon sink in the ecosystem components, and positive values suggest the domination of CO_2 emission over the carbon sink in the ecosystem.

RESULTS AND DISCUSSION

The botanical composition of the vegetation overgrowing the abandoned lands of different ages. We cannot consider with full confidence the studied time series of former arable soils of the Experimental Field Station as a succession series, because the natural replacement of plant communities in some experimental plots was periodically disturbed by uncontrolled burning of the litter and remnants of dry grass in the spring. However, similar burning is typical for the abandoned lands. A part of the arable field (fallow of the current year) that was considered as a starting point (control) for the series was under fallow until mid-June 2004, and weeds (*Taraxacum officinale* Wigg. s.l., *Cirsium arvense* (L.) Scop. s.l.) grew on it. Then, this plot was plowed and sown with winter wheat in August. The herbaceous community on the abandoned field of the first year was composed mostly of forbs. It was dominated by *Artemisia vulgaris* L., *Cirsium arvense* (L.) Scop. s.l., and some weeds associated with fields of cultured plants. The plant cover of the five-year-old abandoned field was formed mostly by cereals (*Agropyron repens* L. and *Poa compressa* L.) and a few forbs (*Equisetum arvense* L., *Tanacetum vulgare* L., *Stachys palustre* L., *Taraxacum officinale* Wigg. s.l., and *Convolvulus arvense* L.) were found.

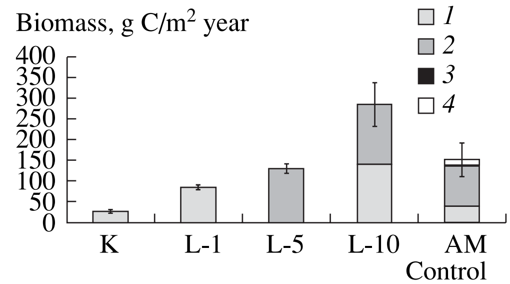

Fig. 1. Reserves and botanical composition of the aboveground phytomass in abandoned lands of different ages in the period of maximal development of grasses. Here and in Fig. 3: *1*, forbs; *2*, grasses; *3*, legumes; *4*, moss; Control, fallow of current year; L-1, lea, 1 year; L-5, lea, 5 years; L-10, lea, 10 years; AM, artificial meadow, 25 years.

The vegetation of the 10-year-old abandoned field was much more diverse in species composition than that of the previous sites. It was dominated by *Chamenerion angustifolium* L., *Tanacetum vulgare* L., *Achillea millefolium* L., *Artemisia vulgaris* L., *Taraxacum officinale* Wigg. s.l., *Fragaria vesca* L., *Elytrigia repens* L., and *Poa compressa* L. and young birch and pine trees were found rather often.

The 25-year-old abandoned field is now an old-sown meadow (unfertilized hayland) formed by sowing an herb mixture: *Festuca pratensis* Huds., *Phleum pratense* L., and *Trifolium pratense* L. It was dominated at the moment of the research by grasses (*Agrostis tenuis* Sibth., *Bromopsis inermis* (Leyss.) Holub, *Calamagrostis epigeios* (L.) Roth, *Dactylis glomerata* L., and *Poa compressa* L.), forbs (*Taraxacum officinale* Wigg. s.l., *Melampyrum nemorosum* L., *Fragaria vesca* L., *Veronica chamaedrys* L., and *Galium mollugo* L. s.l.), and legumes (*Lathyrus pratensis* L., *Trifolium hybridum* L., and *Vicia hirsuta* (L.) S.F. Gray).

Productivity of abandoned lands of different ages. The aboveground phytomass estimated in the period of its maximal development (Fig. 1) varied depending on the fallow age from 85 ± 4 g C/m^2 (one-year-old abandoned field) to 285 ± 52 g C/m^2 (10-year-old abandoned field). The phytomass was minimal in the fallow field and comprised 25 ± 1 g C/m^2. The maximal aboveground biomass of grasses was usually formed in the phase of the blossoming–beginning of fruiting of the dominant species. The composition of the maximal reserves of living phytomass slightly differed in the studied phytocenoses (Fig. 1). For example, the abandoned field of the first year was dominated by forbs (up to 100%), the 5-year-old abandoned field and sown meadow were dominated by grasses (63 to 98.0%), and the 10-year-old abandoned field was dominated equally by forbs (up to 49.3%) and grasses (up to 50.6%). It was found that the living phytomass exceeded the dead phytomass in the period of the maximal development of the grasses by 2.0–3.8 times in all the communities.

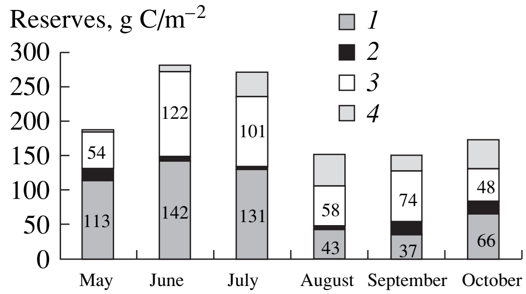

Fig. 2. Dynamics of reserves of different groups of plant matter in artificial meadows during the growing period of 2004: *1*, litter; *2*, moss; 3, biomass; 4, dead grass.

As the seeds ripened, the aboveground organs of all the plants died off: first, only the lower leaves (midsummer), then, by autumn, the leaves and generative and vegetative shoots passed to the dead phytomass. Dead plants comprised 4.5% in May and 49% by autumn of the total biomass of the grass communities. The average rate of the dead grass formation was low at the beginning of the growing period (0.6 g C/m^2 day) and increased by more than 2–3 times by the end of growing period. The amount of dead grass in the sown meadow averaged 52 g C/m^2 over the growing period. The process of dead grass transformation to litter was simultaneous with its formation. The intensity of this process increased by the end of the growing period. The seasonal dynamics of the litter reserves in the old-sown meadow were characterized by a decrease of the litter amount from the spring to summer and its increase in September to October (Fig. 2). The maximum litter reserves exceeded the minimal ones in that particular season by 3.4 times. The average carbon content in the litter over the growing period was about 88 g C/m^{2}day. The decomposition of litter was most active in June and July (in the wettest period) and reached 0.8 g C/m^2 per day.

The productivity of the phytocenoses is an integrated parameter of the biological features of the species and components of these phytocenoses along with the effects of the environmental factors. The knowledge of the primary production amounts and the rhythms of their formation is necessary for understanding and analyzing the functioning of biogeocenosis as an integral system, because it determines the matter and energy fluxes. Our previous study of the dynamics of the phytomass reserves in a sown meadow demonstrated [2–5] that they agreed well with the increment of the living phytomass, the temperature variations, and the amount of rainfall not only in the current year but also in the previous year (especially in the spring and early summer). An intense increase of the aboveground biomass was observed in June. Up to 28–30% of the annual production was formed in this period, and the intensity of this process reached 2.4 g C/m^{2}day. The average reserves of the biomass over the growing season comprised 122 g C/m^2 and were smaller than their maximal values by 1.2 times. The net production (sum of increments) of the aboveground biomass (ANP) over the growing period (taking into account its production in May) comprised 191 g C/m^2 in the old-sown meadow. The aboveground productivity of the plants was calculated in the other plots on the basis of the phytomass stock in the period of the maximal plant development (Table 2), which was 1.25 times lower than the ANP as demonstrated by the long-term observations of the yield of hay on the unfertilized variant of the old-sown meadow [4].

The proportion between the above- and belowground productivity of the phytocenoses depends on the age of the grass communities as well as on the weather conditions [3, 4]. The rainfall in the growing period of 2004 comprised 363 mm; this was about half of the annual rainfall and was close to the mean annual value. The mean annual air temperature and the average one of the growing period were also close. Therefore, we consider it correct to use the increment of the aboveground phytomass measured in the current year and the mean annual ratio between the annual above- and belowground production of the meadow cenoses ANP : BNP = 1 : 2.5 [4] for calculating the productivity of the belowground phytomass (Table 2). We summarized the production of the aboveground and belowground parts of the plants and obtained the net primary production (NPP) of the phytocenoses. It varied from 97 g C/m^{2}year in the fallow field to 1100 g C/m^2 year in the 10-year-old abandoned field (Table 2). The annual production of the grass stand on the long-term fallow was equal to 592 g C/m^2 year, and this was 18% lower than the mean annual value (725 g C/m^2 year) and 26–28% lower than the annual production on the other steppe-like and mesophytic meadows (800–832 g C/m^2 year) [1]. These differences can be explained, in our opinion, by the older age of the meadow cenosis studied, in which some plant species that were cenosis-forming species at the earlier stages of the development disappeared at the stage the maximal biological age.

Emission of CO_2 from idle soils. The flux of CO_2 from the soil surface (or total soil respiration (TSR)) comprises the respiration of the soil microorganisms destroying soil organic matter, the root exudates, the emission from the litter, and the root respiration without accounting for the respiration of the aboveground phytomass. The rate of the CO_2 emission (ER_{CO_2},) from the soils of the 1-, 5-, and 10-year-old abandoned fields and the old fallow was relatively high in July (214–273 mg C/m^2 h), and it did not differ significantly among these study objects (Fig. 3). The emission of CO_2 from the arable soil (fallow of the current year) was 4–5 times lower and comprised 57 ± 24 mg C/m^2 h. In September, the $ERCO_2$ from the soils of the abandoned fields decreased significantly (to 37–90 mg C/m^2 h), but, in the arable field sown with wheat in August, it remained at the same level (53 mg C/m^2 h). This was apparently explained by the increase of the contribution

Table 2. Productivity, emission loss, and budget of carbon (g C/m^2 year) in ecosystems of abandoned fields of different ages

Characteristics	Age of abandoned field				
	current year	1 year	5 years	10 years	25 years, old sown meadow
Maximal stock of aboveground phytomass (G_{max})	25	85	129	285	151
Productivity					
Total (NPP) including	97	330	499	1103	592
aboveground (ANP)	31	106	161	356	191
belowground (BNP)	66	223	338	747	401
Emission loss of C					
Total over a year (TSR), including	347	613	580	671	845
during the growing period	156	460	435	503	632
beyond vegetation	190	153	145	168	213
Microbial over a year (MR), including	272	297	281	325	411
during the growing season	103	161	152	176	221
beyond the growing season	169	136	129	149	190
Net ecosystem production					
NEP = HR – NPP	+175	–32	–217	–778	–181

of the respiration of the wheat roots and rhizosphere microorganisms to the total CO_2 emission from the soil.

The annual dynamics of the intensity of the CO_2 emission from the soil surface in the old-sown meadow (Fig. 4) had the form of a typical one-cone curve with maximum values of $ERCO_2$ = 200–350 mg C/m^2 h in June to August. This period was characterized by a favorable combination of temperature and moistening conditions and by maximal development of the plant roots, whose respiration comprised a significant part of the total CO_2 emission from the soil. The maximal intensity of the CO_2 emission from the surface of the abandoned field of the current year was observed in late May–early June (before plowing, 107–123 mg C/m^2 h), when the production of the belowground phytomass was maximal and its part in the total emission of CO_2 from the soil was significant. The total soil respiration sharply decreased after plowing (in mid-June) and actually represented pure microbial respiration, which was relatively low (13–52 mg C/m^2 h) because of the low amount of plant residues and the absence of plants. The intensity of the CO_2 emission remained practically at the same level in the autumn, because the winter wheat began to develop intensely at that time. The rates of the CO_2 emission from the meadow and arable soils did not differ significantly from each other in the late autumn, winter, and early spring periods (Fig. 4).

The total annual losses of carbon from the soils in the form of CO_2 (TSR) varied from 347 g C/m^2 year in the arable field to 845 g C/m^2 year in the 25-year-old

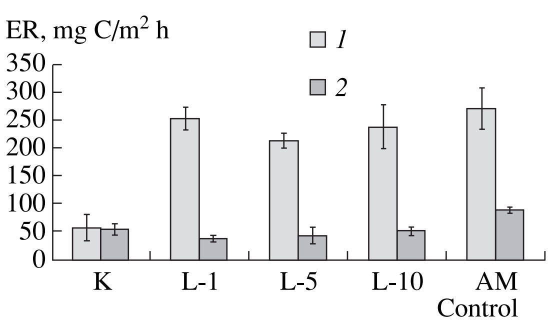

Fig. 3. Rate of CO_2 emission (ER) from soil in (*1*) June and (*2*) September.

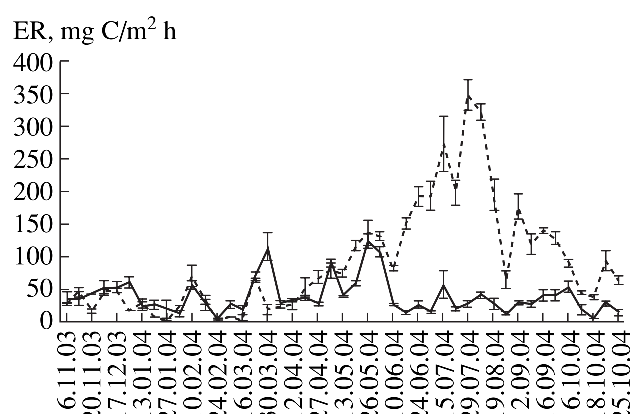

Fig. 4. Annual dynamics of the rate of CO_2 emission (ER) from the surface of arable soil (fallow of current year, firm line) and artificial meadow (dotted line).

fallow (Table 2). It should be noted that these values were close to the average annual values of the summary of the annual emission of CO_2 from the soil determined on the basis of long-term observations for 6 years: 361 ± 55 g C/m^2 year in the agrocenosis and 806 ± 86 g C/m^2 year under the meadow vegetation [28]. The annual losses of carbon from organic soils of Finland under conditions of a colder climate (mean annual air temperature of 2.2°C) and similar annual precipitation (612 mm) were similar among the objects: 400 g C/m^2 year in a fallow field and 750 g C/m^2 year under meadow vegetation [32]. In the northern prairies of the United States (Great Plains) with a drier climate (404 mm) and a similar mean annual air temperature (5.0°C), the summary of the annual emission of CO_2 from the soil averaged 814 g C/m^2 year over 1996–2000 and was also close to the values obtained in out study [24].

The average contribution of the roots and the rhizosphere microorganisms to the total CO_2 emission from the soil determined in the course of the continuous observations during the growing period (May–September) comprised 65% and 35% in the long-term fallow and the recent fallow, respectively. We determined earlier [12] that the part of the root respiration in the total CO_2 emission from the soils of meadow cenoses did not exceed 11% during the cold period of the year. Since the contribution of the root systems to the total soil respiration depends significantly on the period of the observation, we consider that it is necessary to use a differentiated approach; thus, in order to calculate the MR value more correctly, it is advisable to divide the total annual flux of CO_2 into two parts: (i) over the period of active plant vegetation from May to September and (ii) over the period of their relative rest from October to April. It was found that the carbon losses in the arable field in May to September comprised only 45% of the total annual emission, but this value was significantly higher (75%) in the 25-year-old meadow cenosis and coincided with that for the average part of the growing period in the annual emission of CO_2 from the other soils of the taiga zone [11]. We consider it correct to use this value to calculate the total emission of CO_2 over the growing period in the soils of the 1-, 5-, and 10-year-old abandoned fields, in which only single measurements of the CO_2 emission were performed during the growing period of 2004. The results of our calculations are presented in Table 2. The values of the annual microbial respiration were relatively close (272 to 297 g C/m^2 year) in the arable soil and in the soils of the young abandoned fields (1- and 5-year-old) and reached a maximum value of 411 g C/m^2 year in the soil under the 25-year-old lea land (Table 2).

Budget of carbon in ecosystems of abandoned fields depending on the time of their excluding from agricultural use. The value of the carbon budget in the ecosystems of the abandoned fields (NEP) corresponded to the difference between the microbial respiration of the soil and the productivity of the ecosystem and varied from +175 to –778 g C/m^2 year; it depends on the type of land use and the age of the abandoned ecosystem (Table 2). Taking into consideration the ambiguity of the obtained estimates (25–30%), we can postulate that lea ecosystems formed in the place of agroecosystems 5 to 25 years ago serve as stable sinks of carbon with an NEP value of ≈ –217 to –778 g C/m^2 year. In these ecosystems, the losses of carbon for respiration are covered completely at the expense of its assimilation by plants in the process of photosynthesis. Fallowing arable soils represent a source of CO_2 emission to the atmosphere (NEP ≈ +175 g C/m^2 year), but the 1-year-old abandoned field had a carbon budget close to zero (NEP ≈ –32 g C/m^2 year) and can be a source or a sink of CO_2 depending on the weather conditions of the particular year. The carbon budget in an old lea (25-year-old grassland) comprised –181 g C/m^2 year and was two times lower than that of a 12-years-old grassland in 1992 : –387 g C/m^2 year [30]. Our conclusions also agree well with the first results obtained within the framework of the European project for research of the budget of greenhouse gases in meadow ecosystems of Europe (Green Grass Project) performed using Eddy covariance. These results demonstrated that the investigated meadows situated in 10 different European countries also served as a sink of carbon with the NEE[1] being from –50 to –550 g C/m^2 year depending on the geographical position, regime of use, and age of the meadow cenoses [41]. At the same time, the fallow plot is a source of CO_2 (NEE = +500 g C/m^2 year), and passing from growing barley to grasses was characterized by almost negative (close to zero) NEE values. Somewhat different results were obtained in organic soils of eastern Finland, where meadow cenoses were sources of carbon during the growing period but barley fields represented a pure sink of CO_2 [32]. These results were explained by the authors as being due to the weather conditions: a hot summer with high emission of CO_2 from peat soils and a deficiency of moisture for biomass formation in meadow cenoses were observed. Year-round research carried out using micrometeorological methods on typical prairies of the United States (in the state of Kansas) demonstrated that the annual budget of the prairies was zero over three years of study (1997–1999); the water stress in the dry season was a dominating factor, which controlled the NEE [42]. For comparison purposes, we present the values of the carbon sink in young forest ecosystems of Europe; they ranged from 7 to 30 years. According to the estimates obtained within the framework of the European forest project EUROFLUX, the carbon sink comprises 100–670 g C/m^2 year [43] and is relatively close to our data concerning the carbon sink in 5- to 25-year-old leas.

[1] The NEE is the net ecosystem exchange representing the difference between the amount of carbon emitted to the atmosphere due to the ecosystem (soil + plants) respiration and the amount of carbon assimilated by the system in the process of photosynthesis. We can assume that the NEP and NEE are equivalent values.

Our calculations demonstrated that the average value of the carbon sink in abandoned lands equals 302 g C/m^2 year. As calculated for the whole territory of the Russian Federation, the reverting of former arable lands (during the period of perestroika) to abandoned lands resulted in an additional sink of carbon, which comprised (according to our rough estimates) 105×10^{12} g C/year. This additional accumulation of carbon in the ecosystems of abandoned lands neutralizes practically two thirds of the sources of CO_2 that are represented (according to the estimates of IIASA [33]) by soils of agroecosystems. It should be emphasized that our estimates are very approximate and that long-term observations of the CO_2 fluxes and budget calculations for abandoned lands in different climatic zones are required to determine these parameters more exactly. However, we can already conclude today that grasslands on low-fertile arable lands can be a good alternative to forest planting for the purposes of additional sequestration of carbon and will help to solve the problems facing Russia in the context of fulfillment of the requirements of the Kyoto Protocol.

CONCLUSIONS

(1) Exclusion of soils from agricultural use initiates a succession of plant species starting with weeds during the first 2–3 years and progressing to predominately meadow vegetation in the next 5–10 years.

(2) The net primary production of the vegetation overgrowing the abandoned lands in the south of Moscow oblast (C-NPP) ranged from 97 g C/m^2 year in the fallow plot (the abandoned field of the current year) to 1103 g C/m^2 year in the 10-year-old abandoned fields. These values point to the accumulation of carbon in the vegetation overgrowing the abandoned lands.

(3) The total loss of carbon in the form of CO_2 from the abandoned lands comprised 347–845 g C/m^2 year, and the microbial component in the total soil respiration varied from 272 to 411 g C/m^2 year depending on the time elapsed since the fields were abandoned.

(4) Former arable soils after five years of their fallowing and overgrowing with natural vegetation were characterized by negative NEP values and functioned as a stable sink of carbon. Young one-year-old abandoned lands had a carbon budget close to zero and could be a source or a sink of CO_2 depending on the weather conditions of the particular year.

(5) The reversion of low-fertile arable lands to grasslands can be a good alternative to artificial afforestation for the purposes of additional sequestration of atmospheric carbon dioxide.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (projects nos. 04-04-48653 and 05-04-48441); by program no. 16 of the Presidium of the Russian Academy of Sciences; and by the International Bureau of the German Federal Ministry of Education and Research (RUS 03/A30). We are grateful to researchers from the Institute of Physicochemical and Biological Problems of Soil Science of the Russian Academy of Sciences (D. Sapronov, T. Miakshina, V. Lichko, and L. Rozanova) for their valuable help in field and laboratory studies.

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