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Resource characteristics of post-agrogenic chernozems in multiple-aged fallow lands of the Belgorod Region

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Abstract. As a result of anthropogenic degradation, chernozems often lose their ability to provide an economically acceptable crop and, therefore, are removed from use, passing into a state of fallow. In this state, a certain restoration of the resource characteristics of chernozems is possible, but this process should be investigated using an extensive empirical base. The purpose of this work was the accumulation and primary analysis of data on the natural reproduction of forest-steppe chernozems. The authors have studied the structure and properties of regenerative (post-agrogenic) soils of abandoned arable land in the Belgorod Region which were taken out of use due to severe erosion degradation. For comparison, we have examined the arable soils located in the same agricultural landscapes. Depending on the abandoning age, the soils are characterized by different degrees of recovery in terms of humus horizon's morphological structure and agrochemical properties. The most obvious regenerative feature of bedding rocks is the thickness of a newly formed humus horizon. For 30 years of recovery, it is 12–14 cm and can reach 18 cm in the 80-year-old fallow soils. Post-agrogenic soils demonstrate an accumulation of carbon and nitrogen as well as restoration of soil absorbing complex. The soil organic matter in the recent fallow lands is characterized by a narrower C/N ratio as compared to the middle-aged fallow soils. As compared to arable soils, post-agrogenic soils have less acidic solutions reaction. An intensity degree of progressive changes in post-agrogenic soils tends to decrease with age, which is an indicator of a slowdown in their recovery.

1. Introduction

The erosion processes, which ran intensively in the agricultural landscapes of the Belgorod Region in the 20th century, resulted in significant soil losses and widespread situations when any soils degraded due to washout were consistently withdrawn from the use accompanied by the formation of multi-aged fallow lands. The most typical landscape conditions for these objects are 5 to 7° inclined slopes which are directly adjacent to the ravine, gully and valley network. In the 60s and 70s of the 20th century, the Belgorod Region carried out large-scale forest reclamation works to create anti-erosion forest belts which mostly ensured decommissioning of medium- and highly eroded arable land plots with natural forage sites being formed. These plots were subsequently used for haymaking and grazing, i.e. they were characterized by regular alienation of phytomass and removal of biogenic elements. At present, the use of these fallow soils as forage land has significantly decreased due to the fact that the number of cattle owned by the population has considerably reduced and the animal husbandry has mainly switched to stall barn housing. The reduction of anthropogenic load on natural forage lands has led to some changes in the structure of plant communities of the fallow lands: an increased share of tree and shrub vegetation and a certain prairification with rootstock grasses being dominated. These changes in fallow lands and former pastures of the forest-steppe zone are well known [1, 2].



Studies of the formation of postagrogenic soils in the forest-steppe zone [3, 4] indicate the restoration of the structure, an increase in humus reserves, the content of total nitrogen, and other progressive changes, but these changes are less pronounced than, for example, in the boreal zone. This is probably due to the inherited residual signs of eroded chernozems. Yet these changes are more noticeable if the preceding soil was destroyed by erosion more heavily. According to the available estimates [5, 6], the stock of organic carbon and nitrogen has reached the wild land level in the humus accumulative horizon of post-agrogenic forest-steppe chernozems over 40 to 60-year period of regeneration, at least, in the 0 to 5 cm layer. However, in our opinion, these estimates need to be verified. Thus, by some estimates [7], the post-agrogenic soils (a layer of 0–50 cm) can reach the stable level of organic matter reserve in steppe conditions only at the age-old stage of reproduction.

A progressive formation of post-agrogenic soil properties proves that it is possible to use natural renewal of soil resources on agrogenically degraded lands [8]. However, it is essential to have an idea of the limitations imposed by such ecological rehabilitation method — both in relation to individual soil properties and their total resource potential as well as with regard to acceptable terms of land withdrawal from use. There are no hard and fast answers to these questions yet, which requires an accumulation of empirical material. The purpose of this work was to expand the empirical base necessary to substantiate trends in the change in the properties of fallow soils over time.

2. Objects and Methods

To understand the general trend of development of post-agrogenic soils with their morphological structure being disturbed during the period of agrogenesis due to mechanical energy input (plowing, mechanical compaction) and erosion processes, it is important to consider their renaturation process [9] over time. One of the possible approaches is to make chrono-series of post-agrogenic soils [5]. A suitable spatial-temporal full-scale model should look like this: an extended slope (preferably, with warm exposure as the most erosion-dangerous) where the arable land contours gradually receded to the watershed due to the abandonment of degraded soils. The Belgorod Region has quite a lot of such situations as evidenced by the presence of several plowing ridges on the slopes of many gullies which are currently not plowed. But, as a rule, there are 1 to 3 such stages of abandonment. Therefore, it is more appropriate to make chrono-series of post-agrogenic soils which are spatially separated but have similar landscape conditions.

As part of our studies conducted on the territory of the Belgorod Region (Rakitnoye, Prokhorovka and Rovenky districts), we have described morphologically and analyzed the genetic profiles of the post-agrogenic soils formed on multiple-aged fallows (12 to 77 years old). The most recent fallows (12 to 20 years old) are represented by plots of arable land abandoned as a result of field contours adjustment during the transition to the use of wide-grabbing equipment (it was the main reason) and because of withdrawal of unproductive areas from cultivation. The fallows with an age of about 30 (up to 40 years) were formed when some plots of degraded arable land were removed during anti-erosion forest plantations. The oldest areas (classified by us as middle-aged fallows, in ontogenetic terms) were formed during the Great Patriotic War in 1943 when the Soviet troops constructed defensive fortifications during the preparation for the Battle of Kursk. Subsequently, these areas failed to be reclaimed and were used for hayfields and pastures. To date the fallow lands, we used multi-temporal maps and satellite images as an auxiliary method, i.e. the method of dendrochronology for synchronous forest planting and natural tree seeding.

To identify the physical and chemical recovery parameters, we took soil samples according to the following scheme: post-agrogenic horizon (AUpa), residual arable horizon (PU), control (arable land). Thus, for control purposes, we used samples of the arable horizon not covered by post-agrogenic management in fallow soil profile as well as samples of current arable land topsoil. The authors recognize the fact that this control should be considered as conditional since the residual plowing horizon also has the reproduction of indicators in the post-agrogenic period. In addition, firstly, the background arable soils are located upwards slope and they are generally less eroded as compared to fallow soils, secondly, they continued to experience agrogenesis, including farming agriculture development in

progressive way (by some properties). The background and preceding soils were migration-micellar (typical) and clay-illuvial (leached) agrochernozems. Background vegetation includes meadow (mottley grass-grasses) serial communities of the gully-ravine network and anti-erosion plantings (ash, locust, pine).

As indicators for recovery of soil resource characteristics, we used the following: post-agrogenic humus horizon thickness, total humus content and the content of total hydrolyzable nitrogen, the content of phosphorus and potassium mobile forms, cation exchange capacity, active and exchangeable acidity. All analyses have been performed by the Belgorodsky Center of Agrochemical Service with the use of standard methods.

3. Results and Discussion

One of the main morphological features of post-agrogenic soils is the newly formed humus-accumulative horizon which is formed in the disordered matrix of the plowing layer of the preceding agricultural soil. It is primarily formed due to soil material structuring and accumulation of organic matter (detritus, newly formed humus) with an active involvement of herb root systems and earthworms. As a result, the post-agrogenic humus-accumulative horizon is visibly separated from the underlying residual plowing layer and can be easily diagnosed by the following parameters: color (darker, with a brownish tinge, more uniform than the underlying one, especially when the transitional horizon of highly-eroded agro-soils is plowed); structure (lumpy, coprogenic, well-splitting — unlike the clumpy underlying layer); consistence (fluffy, with well-developed interstices — unlike the compact structure of the plowing and especially subsurface layers); boundary — as a rule, it is undulating line which is adjusted to the structure of the underground layer of plant associations and the distribution of roots, in contrast to the almost flat lower boundary of the plowing layer.

For the studied objects, the thickness of the newly formed (more correctly, reorganized) humus-accumulative horizon varies from 8 to 18 cm, depending on post-agrogenic development duration (please see the table 1). At the same time, the average rate of formation exceeds 6 mm per year in the first decade, more than 4 mm per year over 30 years and then falls down to 1 mm/year and lower. Such recovery rates are significantly (approximately, by at least 20%) higher than during soil formation on a newly exposed parent rock or on disordered soil [10].

With rare exceptions, the agrochemical indicators of post-agrogenic humus horizons are also characterized by progressive development — in comparison with residual plowing horizons, and they often overrun the fertility performance of the background arable land. At least, it is obvious for total carbon and nitrogen as well as easily hydrolyzable nitrogen. The newly formed humus of post-agrogenic soils is probably more nitrogen-rich than the residual humus of plowing horizon, as evidenced by the narrower C/N ratio for AU_{pa} horizons. Recent fallows have a lower C/N ratio as compared to the middle-aged ones, which also indicates a rapid recovery of nitrogen reserves in the fallow lands. It can be argued that the content of easily hydrolyzed nitrogen in post-agrogenic soils is their second most important recovery indicator (after humus content).

As for other parameters — mobile phosphorus and potassium forms, cation exchange capacity — the differences among the studied objects are also more often estimated in favor of post-agrogenic horizons in comparison with plowing horizons — both buried and background ones. In addition, fallow soils are characterized by neutral and alkaline reaction when compared to agro-soils. But this feature is probably inherited from the soil material of the plowing horizons of highly-eroded soils which was additionally plowed from the underlying transitional horizons.

Despite the fact that the studied objects form no genetic chrono-series, their comparative analysis shows that you will not necessarily observe upward trends in soil properties as long as the fallows become older. This is also facilitated by the disposal of ecosystem phytomass when using the fallow lands as hayfields and pastures. Therefore, one can make conclusions on the orientation of post-agrogenic soil fertility indicators only when analyzing mass empirical material.

Table 1 . Properties of post-agrogenic and background arable soils.

Object number (age)	Horizon	Depth / thickness, sm	Humu s	Total nitroge n %	C/N	N _{hydr.}	P ₂ O ₅ ppm	K ₂ O	pH (H ₂ O)	pH (KCl)	CEC*, mmol/ 100 g
20Dob1 (12 years)	AUpa	0-8/8	4.0	0.22	10.55	140	7	268	8.2	7.2	28.4
	PU	8-25/17	2.8	0.12	13.53	126	6	197	8.2	7.2	29.8
20Dob2 (28 years)	AUpa	0-14/14	3.4	0.20	9.86	140	11	119	6.8	5.8	37.2
	PU	14-24/10	2.9	0.17	9.89	126	5	249	7.7	6.8	41.0
20Dob1 and 20Dob2 (arable)	PU	0-25/25	3.4	0.20	9.86	140	68	88	6.5	5.5	32.4
20Mel1 (about 30 years)	AUpa	0-13/13	4.8	0.28	9.94	161	10	224	6.1	5.0	24.0
	PU	13-26/13	3.8	0.22	10.02	140	10	84	5.6	4.6	22.0
20Mel2 (about 20 years)	AUpa	0-9.5/ 9.5	6.2	0.38	9.46	203	14	135	6.3	5.4	33.6
	PU	9.5-28/ 18.5	4.9	0.27	10.53	161	10	91	6.2	5.0	29.6
20Mel1 and 20Mel2 (arable)	PU	0-25/25	4.4	0.28	9.11	154	44	128	6.0	5.0	30.0
20Ryn3-1 (30-40 years)	AUpa	0-11/11	5.9	0.34	10.06	196	15	263	8.2	7.3	33.6
	PU	11-25/14	3.7	0.31	6.92	140	8	188	8.2	7.2	28.8
20Ryn3-1 (arable)	PU	0-25/25	5.5	0.25	12.76	168	21	124	6.3	5.4	39.2
20Sviat1 (more than 30 years)	AUpa	0-13/13	5.6	0.34	9.55	182	119	378	6.4	5.5	32.4
	PU	13-24/11	3.5	0.19	10.68	140	43	256	6.5	5.6	29.6
20Sviat1 and 20Sviat2 (arable)	PU	0-25/25	5.5	0.35	9.11	175	65	367	7.7	6.8	36.4
20Aid1 (about 30 years)	AUpa	0-13/13	4.7	0.24	11.36	165	6	279	7.8	6.9	45.4
	PU	13-25/12	3.8	0.15	14.69	131	6	235	8.1	7.0	51.3
20Aid1 (arable)	PU	0-25/25	3.6	0.19	10.99	140	17	276	8	6.9	37.0
20PB1 (77 years)	AUpa	0-17/17	6.4	0.34	10.92	210	67	130	7.3	6.1	47.2
	PU	17-25/8	4.8	0.24	11.60	161	8	260	7.7	6.8	36.6
20PB1 (arable)	PU	0-25/25	6.9	0.36	11.12	245	175	174	5.9	5.0	41.2
20PB6 (77 years)	AUpa	0-17.5/ 17.5	6.0	0.33	10.55	196	24	107	6.6	5.6	42.0
	PU	17.5-25/ 7.5	4.4	0.24	10.63	161	26	92	7.1	5.9	40.8
20PB6 (arable)	PU	0-25/25	4.4	0.26	9.82	154	8	263	8.1	7.0	36.6
20Dr1 (77 years)	AUpa	0-18/ 18	6.2	0.38	9.46	203	33	318	7.1	6.0	38.9
	PU	18-24/ 6	3.6	0.21	9.94	148	27	191	7.4	6.3	48.7
20Dr1 (arable)	PU	0-25/ 25	5.3	0.32	9.61	168	79	97	7.2	6.2	55.2

*Cation Exchange Capacity

Post-agrogenic ecosystems are formed as a result of syngensis of soil and vegetation cover. Therefore, it seems to be promising to study the relationship between soil recovery processes and vegetation successions. The studied serial communities are characterized by the long-term existence of associa-

tions formed by rootstock grasses, in particular, *Elytrigia repens* (L.) Desv. ex Nevski, *Bromus inermis* Leyss., *Calamagrostis epigeios* (L.) Roth. This state of phytocenoses in the studied deposits can be considered as an anthropogenic subclimax with a reduction in the terminal stage [11]. Its existence was facilitated by regular anthropogenic disturbances of grass communities (haymaking, grazing, burning), the intensity and distribution of which have somewhat decreased in the last 10-20 years. The middle-aged fallows are characterized by increased involvement of loose-bunch and sod grasses, primarily, *Festuca valesiaca* Schleich. ex Gaudin. In the 77-year-old post-agrogenic soils the mineral content shows no significant increase and it may decrease, which can result in the change of associations to less demanding ones in terms of fertility factor.

4. Conclusion

The conducted studies confirm that it is essential to prove further empirically substantiation of the directions and reproduction rates of resource characteristics for post-agrogenic soils, with due account for zonal features of fallow ecosystems. The results obtained indicate a variety of ecological and landscape situations of soil reproduction on fallow lands, but, at the same time, about the presence of obvious regeneration trends. One of them (the most important in the resource and biosphere aspects) is the reorganization of the humus-accumulative horizon. The rate of its formation reaches values of 4-6 mm / year in the first 30 years of postagrogenic development of fallow ecosystems. Among agrochemical indicators, the total content of carbon (humus) and nitrogen, especially its easily hydrolyzed fraction, also has progressive dynamics. In the forest-steppe conditions of the Belgorod Region, the regenerative soil dynamics have the most pronounced ecological effect when the ecosystems reach the age of 30 years. In the course of postagrogenic development, the intensity of progressive changes decreases, which is an ontogenetic pattern of soil reproduction.

Soils are recovered synchronously with the formation of zonal herbaceous communities where the stages of primitive and complex plant aggregations are successively replaced, with a gradually increasing share of sod grasses. The studied regeneration processes (post-agrogenic soil recovery, species structure formation for vegetation cover) tend to slow down after 30 to 40 years of secondary successions.

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